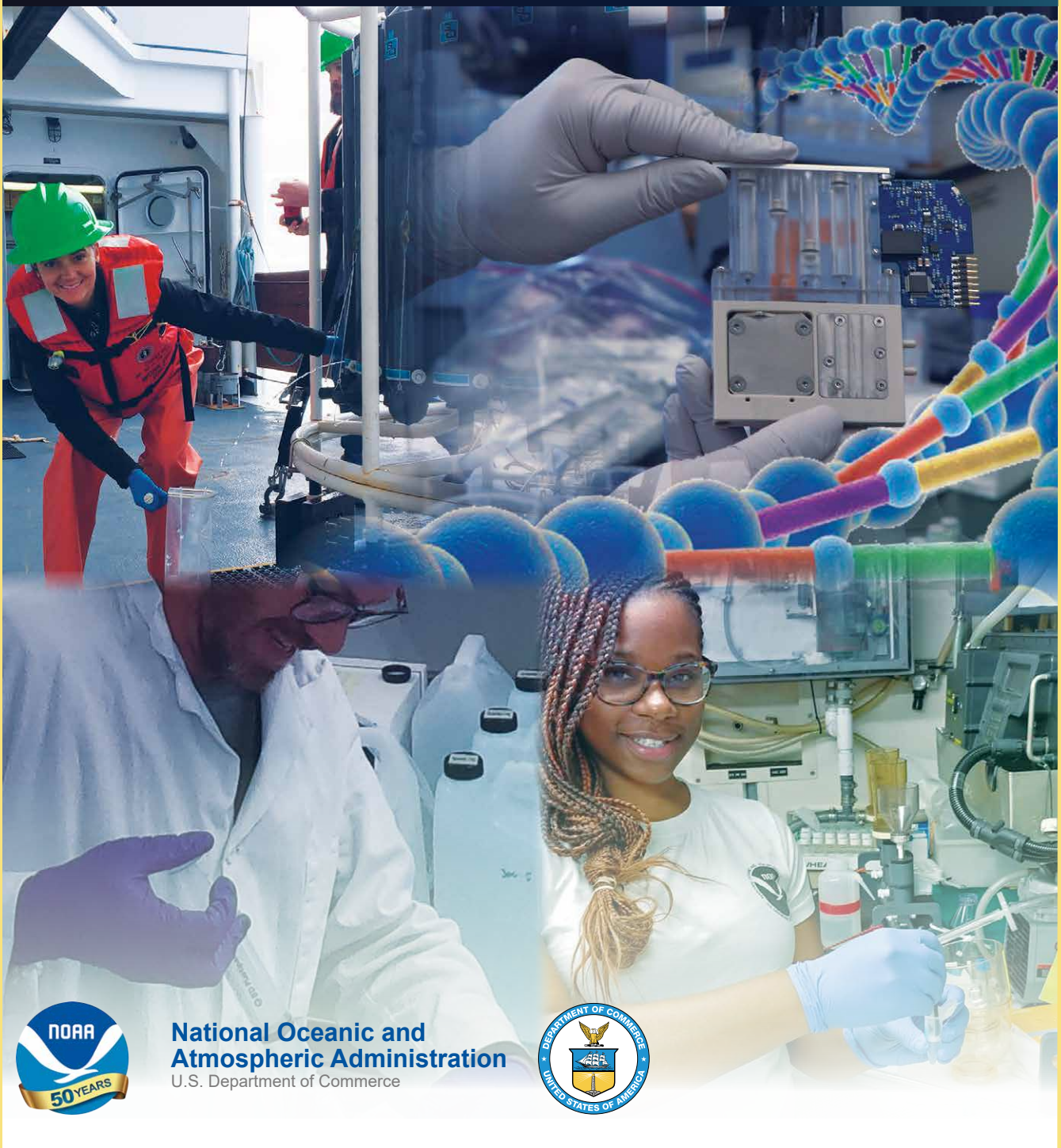
NOAA 'Omics

Strategic Application of Transformational Tools

Strategic Plan 2021-2025



National Oceanic and Atmospheric Administration
U.S. Department of Commerce

January 11, 2021

NOAA Science & Technology Focus Areas:

Uncrewed Systems ▪ Artificial Intelligence ▪ 'Omics ▪ Cloud ▪ Citizen Science ▪ Data

NOAA 'Omics Strategic Plan

Strategic Application of Transformational Tools

APPROVED:

Neil A. Jacobs, Ph.D.
Assistant Secretary of Commerce for Environmental Observation and Prediction
Performing the Duties of Under Secretary of Commerce for Oceans and Atmosphere

Tim Gallaudet, Ph.D., Rear Admiral, U.S. Navy (Ret.)
Assistant Secretary of Commerce for
Oceans and Atmosphere / Deputy NOAA Administrator
STRATEGY SPONSOR

Stephen Volz, Ph.D.
Assistant Administrator
National Environmental Satellite, Data, and Information Service

Louis W. Uccellini, Ph.D.
Assistant Administrator
National Weather Service

LE BOEUF.NICOLE.R.1365870841
Digitally signed by LE BOEUF.NICOLE.R.1365870841
Date: 2020.12.28 08:14:42 -05'00'

Nicole LeBoeuf
Acting Assistant Administrator
National Ocean Service

Chris Oliver
Assistant Administrator
for Fisheries

Craig McLean
Assistant Administrator
Oceanic and Atmospheric Research

Nancy Hann for
Rear Admiral Michael J. Silah
Director
Office of Marine and Aviation Operations and NOAA Corps

January 2021

NOAA 'Omics Strategic Plan

NOAA 'Omics Taskforce and Representatives:

Kelly Goodwin (co-chair), Mark Strom (co-chair), Felipe Arzayus, Margot Bohan, Shallin Busch, Gabrielle Canonico, Rebecca Certner, Jeanette Davis, Katharine Egan, Thomas Greig, Jason Philibotte, Jennifer Koss, Kirsten Larsen, David Layton, Krista Nichols, Jonathan O'Neil, Derek Parks, Leanne Poussard, Juli Trtanj, Cisco Werner

Introduction

'Omics describes a suite of cutting-edge tools used to analyze DNA, RNA, proteins, or metabolites. Many 'omics approaches are faster, less invasive, and more comprehensive than traditional methods. Advances in 'omics have revolutionized biological study, benefitting many fields including public health, medicine, agriculture, and conservation. For NOAA, techniques such as high-throughput DNA sequencing and subsequent bioinformatics analyses can be harnessed to benefit a myriad of national priorities including fisheries management, aquaculture development, food and water safety, species and habitat conservation, seafood consumer protection, biodiversity monitoring, and natural products discovery. Continued investment in 'omics within NOAA will aid operational efficiency, ecosystem assessments and forecasts, and the US Blue Economy (bioeconomy).

'Omics is one of the Science and Technology Focus Areas rolled out by NOAA in 2020. NOAA's 'omics vision aims to integrate modern 'omics technologies across the agency, transforming its approach to biological investigation and accelerating sustainable management of ecosystem resources for the benefit of people, communities, and economies. The NOAA 'Omics Strategy provides a framework to maximize the value of 'omics tools for agency research and operations and accelerate the application of 'omics to address mission priorities. It is a guide to dramatically expand NOAA's application of this science and technology area. The intent is to implement the 'Omics Strategy in conjunction with the strategies for Uncrewed Systems, Artificial Intelligence, Data, Cloud Computing, and Citizen Science to accelerate the advancement of these emerging areas in a coordinated fashion across the agency.

The purpose of the NOAA 'Omics Strategic Plan is to succinctly list actionable investments over the next five years to facilitate 'omics integration into areas of NOAA mission. As such, the text provided here is brief. Supplemental information is available in the NOAA 'Omics White Paper, the NOAA 'Omics Fact Sheet, and the NOAA 'Omics Strategy. This Strategic Plan details how the goals and objectives in the Strategy can be accomplished to promote efficiency, sustainable ecosystem management, and the ocean economy.

The NOAA 'Omics Strategy is organized into five overarching goals. Each goal has five objectives to specify deliberate and transparent approaches to 'omics integration. The NOAA 'Omics Strategy goals and objectives are provided in the table below, followed by a list of actions to implement them.

The actions were informed by a series of scoping exercises conducted in 2019 and 2020 by members of the NOAA 'Omics Taskforce (OTF) representing NMFS, OAR, NOS, TPO, and NESDIS. Scoping meetings included a mix of federal and cooperative institute scientists, science managers, laboratory leaders, and partners from Regional Associations and MBON. Participants were asked to identify a spectrum of actions that included on-going work, actions that could be executed through partnership and leveraging but with minimum new resources, and actions that would require new resources along with estimates of needed investment. There were 246 distinct actionable items received (130 responses from NMFS, 80 from OAR, 45 from NOS, 7 from TPO, and 3 from NESDIS). The OTF created a database to summarize the scoping input and condensed actions into those shown here, with research-focused goals requiring more aggregation than others. The leads and partners were identified from scoping and known capacity to undertake actions, with vetting from leadership of the identified programs and line offices. In general, actions have been initiated, with full implementation dependent on adequate funding to complete. Complete fulfillment of the 'Omics Strategic Plan can be achieved by a new funding initiative for the NOAA 'Omics Observatory and Bioinformatics Centers of Excellence (BCE) Program to promote the integration of 'omics into operations, transition of research to applications, establishment of virtual BCEs across the agency, and effective data management and dissemination throughout the enterprise.

It is recognized that NOAA's agency-wide implementation of 'omics depends on a diverse, collaborative, and well-trained workforce. Integrating 'omics technologies throughout NOAA's unique mission of science, service, and stewardship demands a diverse workforce to reflect, understand, and respond to the varied communities and stakeholders we serve. Equally important is an inclusive work environment that drives workforce performance and collaboration. The actions under Goal 5 - Promote Workforce Proficiency include deliberate steps to advance diversity and inclusion while promoting 'omics expertise. The fast pace of advancement within 'Omics and the other focus areas necessitates diversity, collaboration, and workforce proficiency. A composition of people with diverse backgrounds, experiences, and areas of expertise cultivates the creativity and innovation needed for all of the Science & Technology Strategies.

Goals and Objectives of the NOAA 'Omics Strategy

Goals	Objectives
Goal 1: Enhance infrastructure to meet the analytical demands of 'omics data	**LABS, SHIPS, AND VEHICLES** Objective 1.1. Provide adequate laboratory space in facilities and ships to collect, process, and store samples for 'omics analyses, and increasingly leverage UxS (uncrewed systems) for data collection (see NOAA Uncrewed Systems Strategy)
	COMPUTING POWER and STORAGE Objective 1.2. Procure the analytical and computational infrastructure needed to generate, analyze, and manage massive 'omics data sets, and increasingly leverage the commercial cloud for computation and data storage (see NOAA Cloud Strategy).
	BIOINFORMATICS and DATABASES for 'OMICS TIME SERIES Objective 1.3. Expand the databases that identify genetic sequences and develop bioinformatics tools needed to manage and interpret time series data, including impacts of large-scale environmental change through biodiversity monitoring.
	SHARED REPOSITORIES Objective 1.4. Create a central repository to share protocols, standards, and house bioinformatics pipelines to support a community of practice across laboratories and programs.
	MACHINE LEARNING AND AI Objective 1.5. Leverage computational approaches such as machine learning and artificial intelligence (see NOAA Artificial Intelligence Strategy) to help interpret genetic variation and recognize relationships within environmental data.
Goal 2: Execute 'omics research targeted to support and advance the Blue Economy	**BIO-SURVEILLANCE** Objective 2.1. Improve detecting and monitoring of harmful algal blooms, toxins, pathogens, and invasive species to protect health and coastal economies.
	SEAFOOD FORENSICS Objective 2.2. Support consumer protection and sustainable fishing practices by using genetic analysis to identify fraudulent and illegally sourced seafood products.
	SUSTAINABLE AQUACULTURE Objective 2.3. Foster the development of aquaculture by using 'omics to optimize animal health, yield, and product characteristics while supporting safe and sustainable farming practices.
	FOOD WEBS, FISHERIES, and PROTECTED RESOURCES Objective 2.4. Sustain fisheries resources and protect vulnerable species using 'omics to increase the breadth, depth, and throughput of information used to evaluate target populations' structure and distribution, generate indices of abundance, and characterize the food webs that support them.
	BIODIVERSITY AND BIOPROSPECTING Objective 2.5. Advance the exploration of biodiversity and bioprospecting to discover natural products that may have medical or other commercial value and provide international leadership in the use of marine genetic resources while protecting biodiversity.

Goal 3: Accelerate transition of 'omics research into operations	**UNDERSTAND AND FULFILL MISSION REQUIREMENTS** Objective 3.1 Conduct field trials to define operational requirements, calibrate 'omics approaches with traditional methodologies, and clarify design specifications to accelerate production of validated approaches.
	STANDARDIZED, INTEROPERABLE, AND AVAILABLE DATA Objective 3.2. Promote a unified approach to sample and metadata collection, sample processing, and data deposition in publicly searchable archives to promote interoperability and time series establishment.
	INDICATORS AND ACTIONABLE EVIDENCE Objective 3.3. Develop and integrate 'omics ecosystem indicators into reports, models, and forecasts to benefit seafood safety, public health, and economic protection.
	COMBINE TECHNOLOGIES TO ACCELERATE SUCCESS Objective 3.4. Combine 'omics with existing and emerging technologies to synergize the strengths of individual approaches and thus hasten the innovation of operations.
	UTILIZE R2X PROCESS Objective 3.5. Develop transition plans with NOAA Line Office Transition Managers (LOTMs) to outline steps for technology transfer and provide incentives and support for 'omics transitions (R2X).
Goal 4: Expand partnerships to advance 'omics research and applications across the agency	**INTERNAL COMMUNICATION AND CHAMPIONSHIP** Objective 4.1. Establish a NOAA Executive Committee, chaired by the Chief Scientist or designee, to guide the 'Omics Working Group (OWG) to share information, opportunities, and promote the priorities outlined in this strategy across the agency.
	ENGAGE USER COMMUNITIES Objective 4.2. Engage existing national and international groups working to enhance 'omics technology improvement, standardization, long-term observations, and data and sample archival.
	INTERAGENCY FUNDING OPPORTUNITIES Objective 4.3. Prioritize 'omics research in existing interagency funding opportunities to advance 'omics research and development.
	NATIONAL AND INTERNATIONAL ENGAGEMENT Objective 4.4. Foster coordinated and collaborative projects across agencies and internationally to advance 'omics applications.
	TECHNOLOGY TRANSFER PARTNERSHIPS Objective 4.5. Build and sustain partnerships with the private and academic sectors using existing vehicles to encourage engagement with federal 'omics research and development and to increase the potential for commercialization.
Goal 5: Promote workforce proficiency in 'omics	**NEEDS ASSESSMENT** Objective 5.1. Conduct a baseline needs assessment to inform goal implementation.
	TRAINING Objective 5.2. Provide training for 'omics data collection and bioinformatics analysis to increase expertise within the current workforce.
	RECRUIT AND RETAIN Objective 5.3. Recruit and retain information technology (IT) professionals and scientists with bioinformatics expertise to address current gaps in the ability to analyze and provide biological or environmental context to sequence data.
	DEVELOPMENT OPPORTUNITIES Objective 5.4. Develop opportunities for job details in laboratory facilities to provide career development for staff, interns, and fellows, and to promote 'omics projects and data integration.
	SHARE EXPERTISE Objective 5.5. Focus assignments in the NOAA Rotational Assignment Program (NRAP) to target offices where a cross-pollination of 'omics expertise would raise overall proficiency.

Goal 1. Enhance Infrastructure

Objective 1.1. Provide adequate laboratory space in facilities and ships to collect, process, and store samples for 'omics analyses and increasingly leverage UxS (unmanned systems) for data collection.

1.1.1. By 2022, establish cross-strategy communication regarding progress and challenges facing integration of 'omics into uncrewed systems. [**Cross-Strategy**, OWG]
1.1.2. By 2023, develop a strategy to utilize the Hollings Marine Laboratory Center for high-field NMR for metabolomics profiling of marine organisms. [**NOS/NCCOS**, NIST]
1.1.3. By 2024, add sampling capability for environmental DNA (eDNA) and other 'omics analyses to routine missions, including fisheries independent and exploration surveys. [**NMFS/Science Centers**, **OAR/OER**, OAR/'Omics, BCEs]
1.1.4. By 2025, modernize and maintain laboratory facilities to meet the demand for 'omics analysis. [**OAR/'Omics**, NMFS/Science Centers, NOS/NCCOS, BCEs]
1.1.5. By 2025, utilize unmanned systems capable of sample collection for 'omics analysis. [**OAR/'Omics**, **NMFS/Science Centers**, NOS/IOOS/MBON, MBARI, OAR/OER]

Objective 1.2. Procure the analytical and computational infrastructure needed to generate, analyze, and manage massive 'omics data sets and increasingly leverage the commercial cloud for computation and data storage.

1.2.1. By 2022, establish a cross-strategy working group to address 'omics computational demands and data management. [**Cross-Strategy**, OWG]
1.2.2. By 2024, work with cloud and high-performance computing cluster (HPCC) architects familiar with a range of bioinformatics practices to build and test architectures and evaluate feasibility and cost-effectiveness of moving bioinformatics workflows to the cloud. [**Cross-Strategy**, OWG, BCEs]
1.2.3. By 2025, procure and maintain cost-effective sequencing services or devices to generate 'omics data in the field and laboratories. [**BCEs**, **OWG**, NMFS/Science Centers, OAR/'Omics, NOS]
1.2.4. By 2025, obtain and maintain computing resources to provide each NOAA region adequate access to bioinformatics computing infrastructure. [**BCEs**, NMFS/Science Centers]

Objective 1.3. Expand the databases that identify genetic sequences and develop bioinformatics tools needed to manage and interpret time series data, including impacts of large-scale environmental change through biodiversity monitoring.

1.3.1. By 2023, develop a coordination network to establish guidelines for NOAA's contribution of accurate entries to sequence databases. [**OWG**, **BCEs**, NOS/IOOS/MBON]
1.3.2. By 2023, expand public sequence databases by contributing sequences from research cruise samples and from voucher specimens. [**BCEs**, OAR/'Omics, NMFS/Science Centers, NMNH, NOS/IOOS/MBON]
1.3.3. By 2025, apply bioinformatics tools and pipelines to the establishment and maintenance of time series data. [**BCEs**, OAR/'Omics, NMFS/Science Centers, NOS/IOOS/MBON]

Objective 1.4. Create a central repository to share protocols, standards, and house bioinformatics pipelines to support a community of practice across laboratories and programs.

1.4.1. By 2023, promote the use of existing repositories (e.g., protocols.io, GitHub, Ocean Best Practices Repository) to share NOAA protocols, code, and sequence analysis pipelines. [**OWG**, **BCEs**, NOS/IOOS]
1.4.2. By 2023, establish an online information center for initiatives, data policies, activities, meetings and 'omics research and development (R&D) to support coordinated research and operational applications. [**OWG**, **BCEs**]
1.4.3. By 2024, establish and share protocols for 'omics sampling, processing, curation and archival in alignment with national and international standards of practice (e.g., GSC, NMDC, etc.). [**OWG**, **BCEs**]

Objective 1.5. Leverage computational approaches such as machine learning (ML) and artificial intelligence (AI) to help interpret genetic variation and recognize relationships within environmental data.

1.5.1. By 2022, engage in national interagency discussion of a coordinated strategy to leverage artificial intelligence (AI) for 'omics analysis, synthesis, and projections (e.g., biodiversity projections). [**Cross-Strategy**, BCEs, OWG]
1.5.2. By 2022, establish initial data management plans, metadata guidelines, governance rules, and archiving best-practices to consistently and efficiently manage the large volume of 'omics data through the entire data lifecycle. [**Cross-Strategy**, BCEs, OWG]
1.5.3. By 2024, support or leverage machine learning and AI to identify patterns in deeply dimensional data to help interpret 'omics data and recognize relationships with environmental parameters. [**Cross-Strategy**, BCEs, OAR/'Omics, NMFS/Science Centers]
1.5.4. By 2025, apply machine learning and AI to integrate sequence data into models of habitat-occupancy and habitat-diversity. [**BCEs**, NMFS/Science Centers, OAR/'Omics]

During a summer 2020 autonomous 'omics mission, one MBARI AUV was bitten by a shark. Researchers pulled several fragments of shark teeth from the hull of the vehicle. Left image: Brian Kieft © 2020 MBARI; Right image: Ben Yair Raanan © 2020 MBARI

'Omics in the time of COVID

Ecosystem sampling is critical to better understand the productivity of marine ecosystems and disruptions can have consequences for research and subsequent resource management. Information about ecosystem state is needed whether or not manned sampling is an option. Autonomous underwater vehicles (AUVs) can navigate to places where ship sampling might not be possible due to weather, hazards, or environmental sensitivity.

Recently, uncrewed capability came in handy when NOAA ship operations were curtailed due to the Covid-19 pandemic. In collaboration with AOML and the Marine Biodiversity Observation Network, samples for 'omics analysis were successfully collected by an AUV developed by the Monterey Bay Aquarium Research Institute (MBARI). This success points to the utility of autonomous 'omics sampling and the need to continue their development. Learn more about the July 2020 mission, including the AUV being attacked by a shark at https://www.mbari.org/canon-2020 (Yamahara et al. 2019; https://doi.org/10.3389/fmars.2019.00373).

Goal 2. Research to Support the Blue Economy

Objective 2.1. Improve detecting and monitoring of harmful algal blooms, toxins, pathogens, and invasive species to protect health and coastal economies.

2.1.1. By 2024, develop antibody detection methods to improve detection and monitoring of harmful algal bloom species. [**NOS/NCCOS**]
2.1.2. By 2024, use metabolomic and metaproteomic approaches to improve understanding of coral diseases and inform mitigation. [**NOS/NCCOS**]
2.1.3. By 2024, use community eDNA profiles to characterize HAB dynamics to aid bloom prediction. [**NOS/IOOS**/MBON, OAR/'Omics]
2.1.4. By 2024, utilize 'omics capabilities integrated into autonomous platforms to improve monitoring of biological threats. [**BCEs**, OAR/'Omics, NMFS/Science Centers, NOS/IOOS/MBON]
2.1.5. By 2025, routinely use qPCR or sequencing technologies to improve monitoring of HABs, pathogens, or invasive species. [**BCEs**, OAR/'Omics, NMFS/Science Centers, NOS/NCCOS]
2.1.6. By 2025 and if provided additional funding, manage competitions aimed at improving the detection, monitoring, and/or mitigation of HABs and invasive species using 'omics-related technologies. [**OAR/Sea Grant**]

Objective 2.2. Support consumer protection and sustainable fishing practices by using genetic analysis to identify fraudulent and illegally sourced seafood products.

2.2.1. By 2022, develop 'omics-based field tests for forensics to identify illegal, unreported, and unregulated (IUU) species and protected populations. [**NMFS/NWFSC**, **NMFS/OLE**]
2.2.2. By 2024, develop verified, validated, and calibrated sequence libraries for priority seafood products. [**NMFS/NWFSC**, **NMFS/OLE**, BCEs]

Objective 2.3. Foster the development of aquaculture by using 'omics to optimize animal health, yield, and product characteristics while supporting safe and sustainable farming practices.

2.3.1. By 2022, fund ongoing 'omics-related research activities through the state Sea Grant programs. [**OAR/Sea Grant**]
2.3.2. By 2025, use 'omics assessments to determine the relationship between farm conditions and animal health status for use in restoration aquaculture. [**NMFS/Science Centers**, NOS/NCCOS, BCEs]
2.3.3. By 2025, improve ability to manage seed sets of wild recruited aquaculture species through eDNA understanding of spawning, transport, and settlement processes. [**NOS/IOOS**/MBON]
2.3.4. By 2025, use 'omics approaches to identify resilient coral genotypes for propagation (nurseries) and DNA screening technologies for improved reproduction of stony corals for coral reef restoration activities. [**BCEs**, NOS/NCCOS, OAR/'Omics, SECORE]
2.3.5. By 2025, support safe farming practices by using 'omics detection technologies to assess environmental impacts. [**BCEs**, NMFS/Science Centers]
2.3.6. By 2025 and if provided additional funding, manage a competition specifically for projects that improve 'omics-based aquaculture research and products. [**OAR/Sea Grant**]

Objective 2.4. Sustain fisheries resources and protect vulnerable species using 'omics to increase the breadth, depth, and throughput of information used to evaluate target populations' structure and distribution, generate indices of abundance, and characterize the food webs that support them.

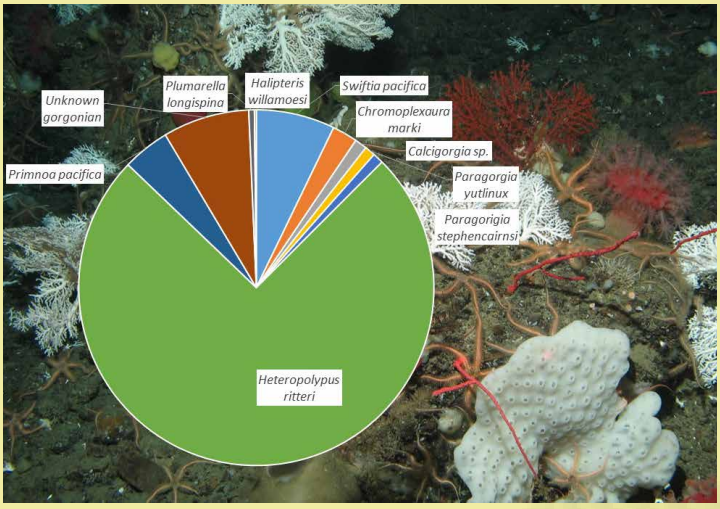
2.4.1. By 2022, conduct 'omics research to better understand the sensitivity, adaptation, and resilience of living marine resources to large ecosystem stressors including changes in climate and acidification. [**BCEs**, NMFS/Science Centers, NOS/NCCOS, NOS/CRCP, OAR/OAP, OAR/'Omics]
2.4.2. By 2022, provide whole genome baseline data to monitor protected and commercially important species. [**BCEs**, NMFS/Science Centers, NOS/NCCOS, BCEs]
2.4.3. By 2022, employ microbiome characterization, such as metagenomic or metatranscriptomic analysis, to evaluate food web linkages that support marine fisheries and protected species. [**BCEs**, OAR/'Omics, NMFS/Science Centers]
2.4.4. By 2024, use eDNA monitoring to evaluate baseline occupancy of targeted fisheries, protected species, and communities in essential fish habitat in relation to environmental conditions and risk factors. [**NMFS/Science Centers**, NOS/NCCOS, BCEs]
2.4.5. By 2024, develop genetic marker sets from genomic data to facilitate rapid, cost-effective monitoring of population structure and diversity. [**NMFS/Science Centers**, BCEs]
2.4.6. By 2025, apply 'omics analyses to identify disease-resilient coral genotypes and undertake selective breeding to propagate resistant genotypes. [**NOS/NCCOS**, **NOS/CRCP**, OAR/'Omics, NMFS/Science Centers, BCEs]
2.4.7. By 2025, use metabolomic, transcriptomic, proteomic, and epigenetic methods to determine the physiological status of key species, including age and stress levels. [**BCEs**, NOS/NCCOS, OAR/'Omics, NMFS/Science Centers]

Objective 2.5. Advance the exploration of biodiversity and bioprospecting to discover natural products that may have medical or other commercial value and provide international leadership in the use of marine genetic resources while protecting biodiversity.

2.5.1. By 2022, fund bioprospecting to characterize biodiversity, identify novel species, and to discover natural products that may have medical or other commercial value. [**OAR/OER**]
2.5.2. By 2022, promote national/international 'omics assessment programs to develop routine generation of biodiversity indicators in areas of high economic importance (energy, mining, aquaculture, etc.) and in areas of special concern such as National Marine Sanctuaries. [**NOS/IOOS/**MBON, OAR/'Omics]
2.5.3. By 2023, further application of eDNA for biodiversity assessments through deployment of autonomous devices for 'omics analysis. [**OAR/'Omics**, **NMFS/Science Centers**, OAR/OER, IOOS/MBON, BCEs]
2.5.4. By 2024, catalog biodiversity in important marine ecosystems through investment in 'omics species identification vetted by morphological identification of voucher specimens. [**BCEs**, NMFS/Science Centers, OAR/OER, NOS/IOOS/MBON, NOPP-BIWG, NMNH]
2.5.5. By 2025, catalog biodiversity through maintenance of 'omics time series in oceans and the Great Lakes. [**BCEs**, OAR/'Omics, NMFS/Science Centers, NOS/IOOS/MBON]

'Omics tools aid the documentation of deep-sea coral community biodiversity

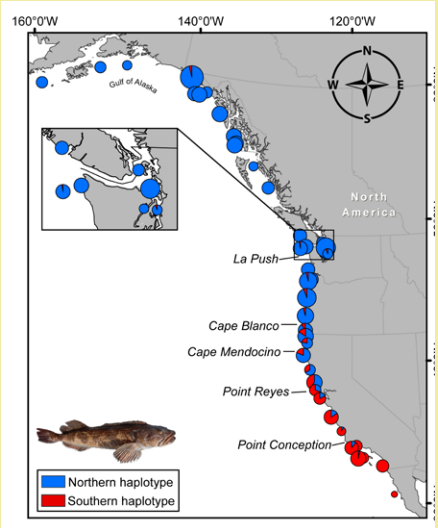
Deep-sea corals and sponges are an important source of complex, biogenic habitat that support remarkably complex communities in deep waters around the globe. In U.S. waters, they are managed as a critical source of Essential Fish Habitat. Partnerships among the NMFS Northwest Fisheries Science Center, Deep-sea Coral Research and Technology Program, Ocean Exploration Trust (OET), NOAA Office of Ocean Exploration and Research (OER), the National Marine Sanctuaries, and others have promoted the application of 'omics tools to document biodiversity and connectivity in these communities. Beginning in 2016, ongoing environmental DNA (eDNA) collections have been made in deep-sea coral and sponge communities in the northeast Pacific Ocean and processed at the NWFSC (Everett and Park 2018; https://doi.org/10.1016/j.dsr2.2017.09.008). eDNA analysis is an important component of the ongoing Deep-sea Coral West Coast Initiative, as well as with samples taken through partnerships with OET in locations including American Samoa and Hawaii. eDNA analysis is providing a more detailed picture of community diversity in these habitats that improves understanding of the relationship between fisheries species and deep-sea corals and sponges. Additional 'omics tools, such as RAD-tag sequencing, is used to gain a better understanding of the connectivity among individual deep-sea coral communities, which is a critical component for management (Everett et al. 2016; https://doi.org/10.1371/journal.pone.0165279, Morrison, Stone and Everett, in preparation).



eDNA collected during the 2018 WCDSCI EXPRESS cruise is being used to characterize the wide biodiversity of corals found in the EFH Conservation area at Mendocino ridge, including potentially novel species and species not detected in visual surveys. (Photo Credit: WCDSCI, MARE).

Strong, cryptic genetic population boundary in lingcod discovered with 'omics tools

Lingcod, a commercially and recreationally valuable species of groundfish, are distributed across international and state borders in the eastern Pacific Ocean, and as such, stocks are assessed and managed primarily along the political boundaries at the international (Canada–United States–Mexico) and national levels (Oregon–California). Within the United States, separate northern and southern lingcod stock regions (divided at the Oregon–California border) have been used by the Pacific Fishery Management Council and federal stock assessors. This delineation was implemented due to observed differences in commercial landings data and history of exploitation rather than reflecting distinct breaks in lingcod genetic structure, biology, or distribution. 'Omics tools were used to assess stock boundaries, finding a major break between cryptic northern and southern stocks near Point Reyes in California – a genetic break due to chromosome structural variation between the groups (Longo et al. 2020, https://doi.org/10.1111/eva.13037). The work is an important future consideration for stock assessment models.



The distribution of northern (blue) and southern (red) genetic stock groups of lingcod identified with 'omics data shows a transition near latitude ~38.3°

Goal 3. Accelerate Transitions

Objective 3.1. Conduct field trials to define operational requirements, calibrate 'omics approaches with traditional methodologies, and clarify design specifications to accelerate production of validated approaches.

3.1.1. By 2022, integrate 'omics technologies into Mussel Watch contaminant surveys in the Great Lakes and coastal ecosystems to correlate biological response to environmental stressors. [**NOS/NCCOS**, GLRI]
3.1.2. By 2023, utilize field trial data to refine the operational requirements for autonomous 'omics instruments. [**OAR/'Omics**, OAR/OER, MBARI, NMFS/Science Centers]
3.1.3. By 2024, groundtruth eDNA metabarcoding at a community level with traditional metrics of community diversity. [**NMFS/Science Centers**, OAR/'Omics]
3.1.4. By 2025, improve understanding of eDNA fate and transport and impacts to whole organism quantification. [**BCEs**, NMFS/Science Centers, NOS/IOOS/MBON, OAR/'Omics]
3.1.5. By 2025, improve capacity to link site-specific eDNA detection and quantification to probable spatio-temporal sources, through novel methods to age and trace eDNA, combined with oceanographic transport models. [**NOS/IOOS/MBON**]
3.1.6. By 2025, define eDNA survey power for specific long-term monitoring sites and surveys (e.g., sampling frequency, replication), to establish current limits on detecting system changes or refine survey designs for specified power. [**NMFS/Science Centers**, NOS/IOOS/MBON, BCEs]

Objective 3.2. Promote a unified approach to sample and metadata collection, sample processing, and data deposition in publicly searchable archives to promote interoperability, and time series establishment.

3.2.1. By 2022, adapt the CruisePack data packaging tool to include metadata associated with 'omics sample collection. [**NESDIS/NCEI**]
3.2.2. By 2022, update metadata controlled vocabularies (e.g. GCMD) to include 'omics terms and variables. [**NESDIS/NCEI**, OAR/'Omics, OWG]
3.2.3. By 2023, communicate with the NOAA 'omics data community to inform NOAA-wide data guidelines that are inclusive of 'omics metadata. [**NESDIS/NCEI**, BCEs, NOAA EMDWG, OWG]
3.2.4. By 2023, promote standardized sequencing and bioinformatic pipelines that result in high-quality and publicly searchable archived 'omics data. [**OWG**, OAR, NMFS, NOS/NCCOS, NESDIS/NCEI]
3.2.5. By 2024, work with cloud and high-performance computing cluster (HPCC) architects familiar with a range of bioinformatics practices to build and test architectures and evaluate feasibility and cost-effectiveness of moving bioinformatics workflows to the cloud. [**Cross-Strategy**, OWG, BCEs]
3.2.6. By 2025, further 'omics standards and interoperability between 'omics, biodiversity, and environmental observations by promoting adoption of biological Essential Ocean Variables (EOVs), Essential Biodiversity Variables (EBVs), and links to existing databases with relevant ocean observation data (e.g., OBIS, GBIF, PANGAEA, NCEI, nucleotide databases, IOC Ocean Best Practices System). [**NOS/IOOS/MBON**, OAR/'Omics, NESDIS/NCEI, OWG]

Objective 3.3. Develop and integrate 'omics ecosystem indicators into reports, models, and forecasts to benefit seafood safety, public health, and economic protection.

3.3.1. By 2023, develop 'omics ecosystem indicators from eDNA samples. [**BCEs**, OAR/'Omics, NMFS/Science Centers]
3.3.2. By 2023, use close-kin mark-recapture (CKMR) to improve stock and population assessments of economically valuable fisheries. [**NMFS/Science Centers**, OAR/'Omics]
3.3.3. By 2024, pair 'omics health and ecosystem indicators data with traditional forecasting and hindcasting models. [**NMFS/Science Centers**, OAR/'Omics]

3.3.4. By 2024, facilitate and validate rapid, cost effective genetic analysis for population monitoring. [**NMFS/Science Centers**]
3.3.5. By 2025, integrate near-real time 'omics data on toxicity/virulence into environmentally driven biophysical models underpinning HAB and pathogen forecasts. [**NOS/NCCOS**, NMFS/Science Centers]

Objective 3.4. Combine 'omics with existing and emerging technologies to synergize the strengths of individual approaches and thus hasten the innovation of operations.

3.4.1. By 2022, integrate 'omics technologies into laboratory toxicity testing and experimental mesocosm studies to include, but not limited to, metagenomics and transcriptomics. [**NOS/NCCOS**]
3.4.2. By 2023, analyze combined eDNA and passive and active acoustic data for animal detection, evaluating the quantitative relationships between detection methods. Transition resulting data into stock assessment reports, biodiversity assessment, and to regional offices responsible for protected species management. [**NMFS/Science Centers**, MBARI, NOS/IOOS/MBON, OAR/'Omics, BCEs]
3.4.3. By 2023, examine biogeographic distribution of 'omics variables in the context of remote sensing and other products. [**NOS/IOOS/MBON**, OAR/'Omics]
3.4.4. By 2025, develop the use of autonomous eDNA sampling to determine baseline occupancy/spatial distribution of harmful algae, fish, protected species, and microbiomes to gauge effects of environmental disruption. Work in conjunction with aerial mapping, ROV, and acoustic surveys. [**OAR/'Omics**, **NMFS/Science Centers**, MBARI]

Objective 3.5. Develop transition plans with NOAA Line Office Transition Managers (LOTMs) to outline steps for technology transfer and provide incentives and support for 'omics transitions (R2X).

3.5.1. By 2021, use approved data calls to identify NOAA 'omics-related technologies which are ready for transition. [**LOTMC**, NRDD, RTA/TPO]
3.5.2. By 2022, help researchers develop research to commercialization transition plans for appropriate activities. [**RTA/TPO**]
3.5.3. By 2023, increase awareness and utilization R2X mechanisms, including funding programs, cooperative agreements, and demonstration opportunities. [**RTA**, Cross-Strategy, OWG]

Goal 4. Partnerships to Advance Applications

Objective 4.1. Establish a NOAA 'Omics Executive Committee, chaired by the Chief Scientist or designee, to guide the 'Omics Working Group (OWG) to share information, opportunities, and promote the priorities outlined in this strategy across the agency.

4.1.1. By 2021, have the 'Omics Executive Committee (OEC) collaborate with other NOAA Science & Technology Strategies to create synergistic opportunities for coordinated implementation. [**Cross-Strategy**, NSC, OWG, BCEs]
4.1.2. By 2021, activate the 'Omics Working Group (OWG) and needed subcommittees to help prioritize and guide implementation efforts. [**NSC**]
4.1.3 By 2022, formulate a governance structure for 'omics implementation and science management. [**OEC**, NSC]
4.1.4. By 2023, develop a NOAA 'omics landing page to identify labs, programs, and people working in 'omics in support of NOAA's mission. [**NSC**, OWG, BCEs]

Objective 4.2. Engage existing national and international groups working to enhance 'omics technology improvement, standardization, long-term observations, and data and sample archival.

4.2.1. By 2022, help organize national and international workshops and interagency meetings to advance 'omics applications, including eDNA. [**NOS/IOOS/MBON**, OAR/'Omics, POGO, GLOMICON, NOPP-BIWG, AORA]
4.2.2. By 2023, participate in national and international interlaboratory calibration exercises. [**OWG**, BCEs, OAR/'Omics, GLOMICON]
4.2.3. By 2023, work with national and international consortia to develop storage, archive, and database solutions for data and metadata. [**OWG**, BCEs, NOS/IOOS/MBON, NESDIS, NMDC]
4.2.4. By 2025, promote collaborations with international agencies with fishing fleets and integrate fisheries sampling programs to enable 'omics data collection for highly migratory species. [**NMFS/Science Centers**, International Partners]

Objective 4.3. Prioritize 'omics research in existing interagency funding opportunities to advance 'omics research and development.

4.3.1. By 2021, offer yearly opportunities to the Ruth Gates Coral Restoration Innovation Grants to promote long-term survival of corals by supporting the 'omics-related science needed to incorporate resilient corals into restoration activities and to enhance the efficiency of asexual and sexual coral restoration. [**NOS/CRCP**]
4.3.2. By 2021, support eDNA investment and integration of eDNA with other methods for biodiversity and ecosystem assessment. [**NOS/IOOS/MBON**, OAR/'Omics, BCEs]

4.3.3. By 2023, fund a series of projects studying how genetics influence reproductive success of corals and establishing a seedbank and spawning stock to enhance fecundity of corals listed under the U.S. Endangered Species Act (ESA). [**NOS/CRCP**, NMFS/Science Centers]

Objective 4.4. Foster coordinated and collaborative projects across agencies and internationally to advance 'omics applications.

4.4.1. By 2021, maintain interagency partnerships to advance 'omics applications, biobanking, and the bioeconomy. [**OWG**, OAR/'Omics, NMNH, USGS, NOPP-BIWG, GEDWG, IWBDS]
4.4.2. By 2021, develop and administer a questionnaire to determine the scope and extent of eDNA samples across the NMNH units, federal agencies, and other potential partners to assess and formulate strategy, budget, and other requirements to establish a national repository for eDNA. [**NMFS/S&T**, NMNH, OAR/'Omics, NOS/NCCOS]
4.4.3. By 2021, maintain interagency partnerships to highlight the use of environmental information and 'omics capacity for public health applications. [**OHFIWG**, OAR/CPO, NMFS/S&T, OAR/'Omics]
4.4.4. By 2021, utilize a Marine Microbiome group under the Galway Statement on Atlantic Ocean Cooperation to support the All Atlantic Ocean Research Alliance and help implement the UN Decade of Ocean Science for Sustainable Development. [**OAR/'Omics**, **OAR/OIA**, AORA]

Objective 4.5. Build and sustain partnerships with the private and academic sectors using existing vehicles to encourage engagement with federal 'omics research and development and to increase the potential for commercialization.

4.5.1. By 2021, define 'omics-specific sub-topic requests for Small Business Innovation Research (SBIR) Program grants. [**RTA/TPO**]
4.5.2. By 2022, initiate connection with philanthropic organizations to better develop, test, and commercialize natural products newly discovered. [**OAR/OER**, BCEs]
4.5.3. By 2022, develop an inventory of critical 'omics R&D gaps across NOAA that could be provided by external (private sector) partners through a cooperative agreement. [**OWG**, BCEs]
4.5.4. By 2022, fund and implement joint science-industry workshops focused on methods and standard operating procedures for eDNA sampling, sample processing, and data management. [**NOS/IOOS**]
4.5.5. By 2023, conduct targeted outreach to the private sector to solicit gap filling capabilities and partnership opportunities, including socially disadvantaged small businesses and small businesses located in underserved communities. [**RTA/TPO**]
4.5.6. By 2023, identify existing NOAA 'omics technologies that are available for commercial adoption (via open source or license agreement). [**RTA**, TPO, NRDD]
4.5.7. By 2024, seek commercial partners for identified 'omics technologies. [**RTA/TPO**]

Goal 5. Promote Workforce Proficiency

Objective 5.1. Conduct a baseline needs assessment to inform goal implementation.

5.1.1. By 2021, conduct an internal NOAA survey to receive input from multiple lines, programs, offices, and experts to assess needs related to integrating 'omics into the agency. [**OWG**]
5.1.2. By 2022, conduct cost benefit analyses of core services setup versus programmatic setup throughout Science Centers. [**BCEs**, OWG]

Objective 5.2. Provide training for 'omics data collection and bioinformatics analysis to increase expertise within the current workforce.

5.2.1. By 2023, commit to training a diverse and inclusive cadre of ocean scientists and ocean explorers on eDNA sampling protocols. [**BCEs**, NMFS/Science Centers, OAR/'Omics, OAR/OER, NOS/NCCOS]
5.2.2. By 2022, commit annual support to external training workshops and conferences specialized in 'omics including, but not limited to, eDNA data collection, analysis, and applications. [**BCEs**, OAR/'Omics, NMFS/Science Centers, NOS/NCCOS]
5.2.3. By 2022, offer online and open-access training resources on major phases of 'omics workflows, including sample collection, sample processing and sequencing, bioinformatics analysis, and data management. [**BCEs**, OAR/'Omics, NMFS/Science Centers, NOS/NCCOS]
5.2.4. By 2025, and if provided additional funding, hire an 'omics liaison to represent each of the six Sea Grant regions. These liaisons will promote 'omics research and collaboration across the Sea Grant network and will be managed through the National Sea Grant Office. [**OAR/Sea Grant**]

Objective 5.3. Recruit and retain information technology (IT) professionals and scientists with bioinformatics expertise to address current gaps in the ability to analyze and provide biological or environmental context to sequence data.

5.3.1. By 2021, fully support a bioinformatics specialist to evaluate the effectiveness of computational resources used for 'omics projects to determine gaps and future IT and bioinformatics personnel needs. [**BCEs**, NMFS/NWFSC]
5.3.2. By 2022, support postdoctoral researchers to foster new methodologies and approaches for 'omics data analysis. [**BCEs**, OAR/'Omics, NMFS/Science Centers, NOS/NCCOS]
5.3.3. By 2023, support system administrators and bioinformatics specialists for IT maintenance and assistance, including local resources. [**BCEs**, NMFS/Science Centers, OAR/'Omics, NOS/NCCOS]
5.3.4. By 2025, create federal positions to funnel 'omics and bioinformatics expertise into the agency. [**OEC**]

Objective 5.4. Develop opportunities for job details in laboratory facilities to provide career development for staff, interns, and fellows, and to promote 'omics projects and data integration.

5.4.1. By 2022, continue to sponsor and fund student projects and fellowships in 'omics-related fields. [**BCEs**, NMFS/Science Centers, OAR/'Omics, NOS/NCCOS]
5.4.2. By 2022, hire postdoctoral researchers to foster new methodologies and approaches for 'omics data analysis. [**BCEs**, NMFS/Science Centers, OAR/'Omics, NOS/NCCOS]
5.4.3. By 2022, utilize existing NOAA educational and fellowship opportunities with minority serving institutions (MSIs) and historically black colleges and universities (HBCUs) to train and recruit the next generation of 'omics scientists and data managers. [**NOS/CCME**, **EPP**, OAR/'Omics, NESDIS/NCEI, NMFS/Science Centers]
5.4.4. By 2023, identify projects and training opportunities in NOAA laboratory facilities and the NMNH that leverage current permanent or temporary staff to implement 'omics technologies. [**NMFS/Science Centers**, **NMFS/S&T**, OAR/'Omics, OAR/OER, NMNH]

Objective 5.5. Focus assignments in the NOAA Rotational Assignment Program (NRAP) to target offices where a cross-pollination of 'omics expertise would raise overall proficiency.

5.5.1. By 2023, identify and designate projects and opportunities for rotational assignments, learning, and cross-pollination of ideas. [**BCEs**, NMFS/Science Centers, OAR/'Omics, NOS/NCCOS]
5.5.2. By 2023, develop an External Rotational Assignment Program (ERAP) in 'omics with external partners. [**BCEs**, NMFS/Science Centers, OAR/'Omics, NOS/NCCOS]

Conclusion

NOAA is committed to continued development and implementation of 'omics technologies to address complex challenges across its multiple missions. The NOAA 'Omics Strategy identifies goals and objectives to develop the proficiency, projects, and partnerships needed to integrate 'omics into mission areas to promote a sustainable ocean economy. This NOAA 'Omics Strategic Plan further details how the investment areas described in the Strategy can be accomplished. Together with advances in NOAA's other science and technology focus areas - Artificial Intelligence, Unmanned Systems, Data Cloud Computing, and Citizen Science - NOAA's 'Omics activities will significantly improve performance and demonstrate our exceptional environmental science leadership.

List of Abbreviations

AI	Artificial Intelligence
AOML	Atlantic Oceanographic and Meteorological Laboratory
AORA	Atlantic Ocean Research Alliance
BCE	Bioinformatics Center of Excellence (pending new budget initiative)
CCME	Center for Coastal and Marine Ecosystems
CKMR	Close-kin Mark Recapture
CPO	Climate Program Office
CRCP	Coral Reef Conservation Program
eDNA	Environmental DNA
EMDWG	Enterprise Metadata Working Group
EPP	Educational Partnership Program
ESA	Endangered Species Act
GBIF	Global Biodiversity Information Facility
GCMD	Global Change Master Directory
GEDWG	Government eDNA Working Group
GLERL	Great Lakes Environmental Research Laboratory
GLOMICON	Global Omics Observatory Network
GSC	Genomics Standards Consortium
HAB	Harmful Algal Bloom
HBCU	Historically Black College and University
HPCC	High-Performance Computing Cluster
IWGBDS	Interagency Working Group on Biological Data Sharing
IOC	Intergovernmental Oceanographic Commission
IOOS	Integrated Ocean Observing System
IUU	Illegal, Unreported, and Unregulated
qPCR	Quantitative Polymerase Chain Reaction
LOTMC	Line Office Transition Managers Committee
MBARI	Monterey Bay Aquarium Research Institute
MBON	Marine Biodiversity Observation Network
ML	Machine Learning
MSI	Minority Serving Institution
NCCOS	National Centers for Coastal Ocean Science
NCEI	National Centers for Environmental Information
NESDIS	National Environmental Satellite, Data, and Information Service
NIST	National Institute of Standards and Technology
NMDC	National Microbiome Data Collaborative
NMFS	National Marine Fisheries Service, inclusive of all Science Centers
NMFS - NWFSC	National Marine Fisheries Service, Northwest Fisheries Science Center
NOAA	National Oceanic and Atmospheric Administration
NOPP	National Oceanographic Partnership Program
NOPP-BIWG	NOPP Biodiversity Interagency Working Group
NMNH	Smithsonian National Museum of Natural History
NOS	National Ocean Service
NRAP	NOAA Rotational Assignment Program
NRC	NOAA Research Council

NRDD	NOAA Research and Development Database
NWFSC	Northwest Fisheries Science Center (NMFS)
OAP	Ocean Acidification Program
OAR	Oceanic and Atmospheric Research
OAR/'Omics	Encompasses 'omics activities in OAR Laboratories (primarily AOML, GLERL, PMEL) and Cooperative Institutes
OBIS	Ocean Biodiversity Information System
OEC	'Omics Executive Committee
OER	Office of Ocean Exploration and Research
OIA	Office of International Activities
OLE	NMFS Office of Law Enforcement
OHFIWG	One Health Federal Interagency Working Group
OTF	'Omics Taskforce
OWG	'Omics Working Group
PCR	Polymerase Chain Reaction
PMEL	Pacific Marine Environmental Laboratory
POGO	Partnership for Observation of the Global Ocean
R2X	Research transitions to (understanding, applications, operations, commercial)
R&D	Research and Development
ROV	Remotely Operated Vehicle
RTA	Office of Research, Transition and Application
SBIR	Small Business Innovation Research
SECORE	Southeast Coastal Ocean Observing Regional Association
TPO	Technology Partnerships Office
UxS	Uncrewed Systems
USGS	United States Geological Survey

Supplemental Information

NOAA 'Omics Strategy Fact Sheet (2020).

NOAA 'Omics Strategy: Goodwin, K.D., Davis, J., Strom, M.S., Werner, C. NOAA 'Omics Strategy: Strategic Application of Transformational Tools. https://doi.org/10.25923/1swn-rj62 (2020).

NOAA 'Omics White Paper: Goodwin, K.; Certner, R.; Strom, M.; Arzayus, F.; Bohan, M.; Busch, S.; Canonico, G.; Cross, S.; Davis, J.; Egan, K.; Grieg, T.; Kearns, E.; Koss, J.; Larsen, K.; Layton, D.; Nichols, K.; O'Neil, J.; Parks, D.; Poussard, L.; Werner, C.; NOAA 'Omics White Paper: Informing the NOAA 'Omics Strategy and Strategic Plan. https://doi.org/10.25923/bd7z-zb37 (2020).