NOAA 'Omics Strategy

Strategic Application of Transformational Tools

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

NOAA Science & Technology Focus Areas:

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

February 2020

NOAA's 'Omics Strategy

Strategic Application of Transformational Tools

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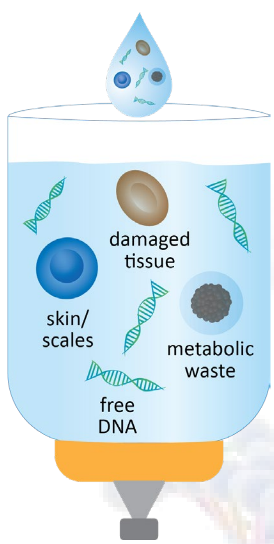
Advances in ‘omics methodologies can improve the ability to monitor and understand the biological communities of the oceans and Great Lakes. ‘Omics approaches can be faster, cheaper, less invasive, and can provide more information than traditional methods, and thus result in improved delivery of the National Oceanic and Atmospheric Administration's (NOAA) products and services. As such, techniques such as high-throughput DNA sequencing and subsequent bioinformatics analyses can aid national priorities including: fisheries management, aquaculture development, food and water safety, species and habitat conservation, seafood consumer protection, and natural products discovery.

An expansion in the use of ‘omics is underway at NOAA. Investment in ‘omics is essential to increase efficiency, improve ecosystem assessments and forecasts, advance stewardship, and promote the American Blue Economy, which is estimated to contribute $304 billion to the U.S. gross domestic product and 3.3 million jobs annually.[1] The Blue Economy includes the resources, services, and benefits provided by the oceans and Great Lakes, such as jobs, food, water, energy, recreation, and commercial products.

The present ‘Omics Strategy, together with the Uncrewed Systems, Artificial Intelligence, and Cloud Strategies is intended to dramatically expand NOAA’s applications of these four emerging science and technology focus areas by improving the efficiency, effectiveness and coordination of their development and usage across the agency.

Background

‘Omics approaches, from DNA sequencing to small molecule analysis, are being harnessed for a variety of mission-critical needs. ‘Omics measurements could indicate ecological status, with monitoring used to inform and track the efficacy of management actions by measuring biodiversity, population distributions, food web function, and organism abundance. Innovative techniques such as the analysis of “environmental DNA” (eDNA) characterize life forms that range from microbes to mammals, using a single sample of seawater or sediment without the need for slow sorting and counting methods. Mission applications that demand more detailed biological information include: sustaining fisheries; developing aquaculture; combating harmful and invasive organisms; improving seafood forensics and traceability; discovering pharmaceuticals and other beneficial compounds; and protecting vulnerable species and habitats, such as corals, that provide essential fish habitat and fuel tourist economies. ‘Omics methodologies, combined with autonomous sampling, offer a way to counter rising ship and labor costs. The demand for ‘omics information drives increasing computational demand, further motivating the agency focus described here.



eDNA can provide comprehensive biological data with increased efficiency, resulting in timely public access to information.

Recognizing the opportunities and challenges presented by the advent of ‘omics tools, the NOAA ‘Omics Strategy provides a framework to advance the application of ‘omics to address mission priorities. The strategy leverages NOAA’s current organizational structure to more effectively implement ‘omics through improvements in computational and analytical capacities, targeted research, technology transition, workforce proficiency, and partnerships across NOAA’s line offices, other federal agencies, academia, and extramural research and commercial communities. This strategy is consistent with recommendations from NOAA’s Science Advisory Board and administration priorities in Executive Order 13840,[2] including increasing economic productivity through the American Blue Economy.

Vision

NOAA will 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.

What is ‘Omics?

‘Omics refers to a suite of advanced methods used to analyze material such as DNA, RNA, proteins, or metabolites. ‘Omics tools have revolutionized biological study, with benefits applied to medicine, agriculture, and other industries. NOAA is using these tools to understand how to sustain and grow the benefits we receive from our oceans and Great Lakes.

Purpose

The overarching aim of the NOAA 'Omics Strategy[3] is to ensure investment in 'omics technologies to meet mission priorities. Through this strategy, NOAA seeks to maximize the value of 'omics by providing a deliberate and transparent approach to integrating 'omics tools into research and operations and thus deliver timelier scientific products and services to benefit society.

GOAL 1: Enhance infrastructure to meet the analytical demands of 'omics data.

New and increased capacities are needed to ensure that emerging environmental data are expertly collected, processed, analyzed, stored, and managed. 'Omics approaches generate large quantities of valuable data that must be made accessible and integrated into products and services used for management decisions. Development of computational capacity locally in NOAA's Laboratories and Centers and agency-wide access to cloud-based platforms are essential to the success of the 'omics enterprise. The 'Omics Strategy calls for 'omics approaches to be prioritized in NOAA budget guidance with emphasis on improved computational/bioinformatics capabilities and increased proficiency in its science and technical workforce. To maximize cost-effectiveness, this goal will be pursued in synergy with other NOAA strategies that focus on fostering cloud computing and artificial intelligence capabilities.

Objective 1.1. Provide adequate laboratory space in facilities and ships to collect, process, and store samples for 'omics analyses, and we will increasingly leverage UxS (Uncrewed systems) for data collection (see NOAA Uncrewed Systems Strategy).

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 Draft Cloud Strategy, November 2019).

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.

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.

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 with environmental data.

NOAA 'Omics Strategy

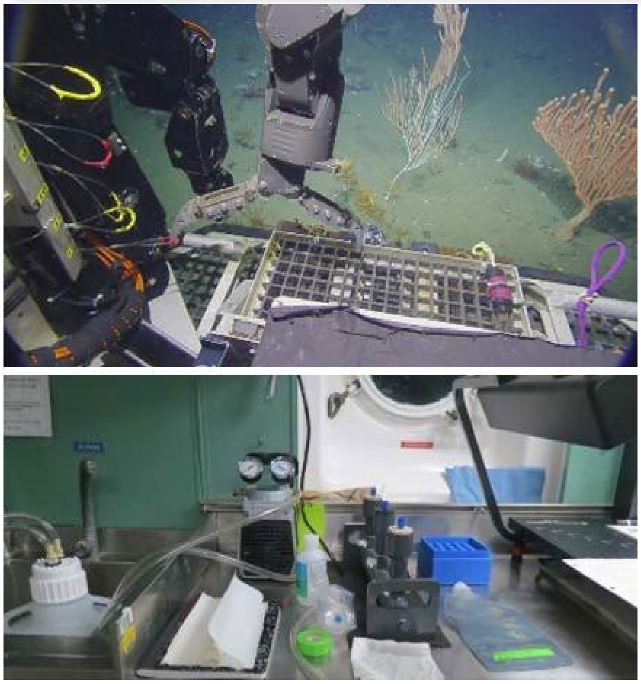
Goal 1: **Enhance infrastructure to meet the analytical demands of 'omics data.**

Goal 2: **Execute 'omics research targeted to support and advance the American Blue Economy.**

Goal 3: **Accelerate transition of 'omics research to applications.**

Goal 4: **Expand partnerships to advance 'omics research and applications across the agency.**

Goal 5: **Promote workforce proficiency in 'omics.**



This at-sea 'omics laboratory to promote biodiversity and deep-sea exploration represents a collaboration between NOAA's Northwest Fisheries Science Center and the Ocean Exploration Trust. Photo Credit: Ocean Exploration Trust.

[1] National Oceanic and Atmospheric Administration (NOAA), Office for Coastal Management. 2019. "NOAA Report on the U.S. Ocean and Great Lakes Economy." Charleston, SC: NOAA Office for Coastal Management. Available at http://coast.noaa.gov/digitalcoast/training/econreport.html.

[2] https://www.federalregister.gov/documents/2018/06/22/2018-13640/ocean-policy-to-advance-the-economic- security-and-environmental-interests-of-the-united-states.

[3] The NOAA Uncrewed Systems, Artificial Intelligence, 'Omics, and Draft Cloud Strategies are available at https://nrc.noaa.gov/NOAA-Science-Technology-Focus-Areas.

GOAL 2: Execute 'omics research targeted to support and advance the American Blue Economy.

State-of-the-art studies using 'omics technologies and tools can accelerate research transitions to benefit NOAA's American Blue Economy priority. 'Omics-informed data products and forecasts can improve preparation against ecological threats, which cost the U.S. billions of dollars annually. Similarly, they can foster markets and job creation. To this end, NOAA will invest in targeted research to address fundamental questions, establish baselines, and leverage on-going observational and exploration programs that can support and benefit from 'omics methodologies.

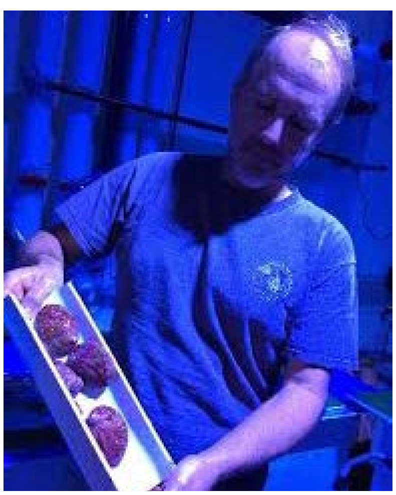
Objective 2.1. Improve detecting and monitoring of harmful algal blooms, toxins, pathogens, and invasive species to protect health and coastal economies.

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

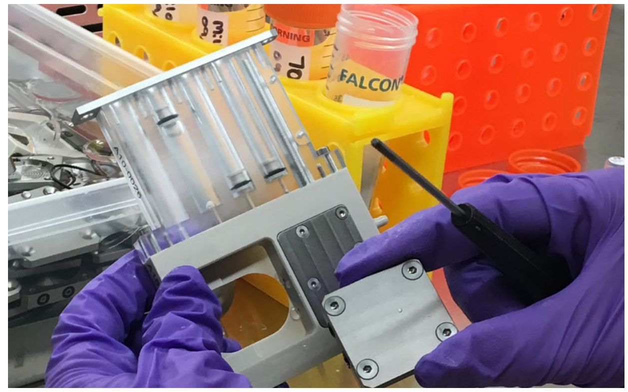
Objective 2.3. Foster the development of aquaculture by using 'omics to optimize animal health, yield, and product characteristics while supporting safe and sustainable farming practices.

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.

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.



NOAA researchers use 'omics to advance aquaculture and for the recovery of endangered species populations, such as these U.S. west coast white abalone displayed by NOAA fisheries biologist, Dr. John Hyde, at the Southwest Fisheries Science Center.



A sample collected from a Monterey Bay Aquarium Research Institute autonomous vehicle is prepared for 'omics analysis at the NOAA Great Lakes Environmental Research Laboratory by micro-biologist, Dr. Kelly Goodwin. Moving such technology into routine usage can provide comprehensive biological data in a timely and affordable manner.

GOAL 3. Accelerate transition of 'omics research to applications.

'Omics technologies can provide the power to augment existing data collections and possibly replace survey methods in some cases. NOAA will rapidly accelerate transition of 'omics research to NOAA operations (R20) and private-sector commercialization (R2C - together R2X). The process of moving research to applications is often depicted as a pipeline or funnel, but the R2X process is actually iterative and variable.[4] Elements for success include establishing present uncertainties, and understanding mission requirements, multi-disciplinary teams, and collaborations with end-users. The timeline for transition is sensitive to technological advancement and investment of resources, and it is dependent on the specifics of the use case, such as geographic location or the organism targeted by 'omics analysis. Combining technologies may accelerate research transitions. For example, routine mapping operations may be enhanced by pairing 'omics approaches with autonomous sampling or with acoustics or fluorescence profiling.

Establishing long-term 'omics observations provides an example of how current research could move into operations. Time-series applications include monitoring biodiversity to ensure the sustainable use of resources. Examples include vulnerable ecosystems, such as coral reefs. 'Omics may also inform restoration efforts by discovering and selecting for genes that confer resilience to stressors such as heat, pH, or disease.

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.

[4] The 'Omics Strategy is inclusive of "R2X" considerations, i.e., Research to Operations, to Applications, and to Commercialization, as well as the feedback to Research. As such, the 'Omics Strategy is meant to consider the full R2X2R feedback of activities.

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.

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

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

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 R2X.

GOAL 4. Expand partnerships to advance 'omics research and applications across the agency.

The fast pace of 'omics advancement necessitates communication and coordination across NOAA's lines and programs, across agencies nationally and internationally, and with the extramural community, including academic, commercial, and philanthropic partners.

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

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

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

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

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.

A well-trained workforce is critical to the NOAA 'omics enterprise. NOAA will enhance its workforce in order to accelerate the understanding of how marine and Great Lakes organisms and ecosystems adapt to environmental change or stress at local, regional, and global scales.

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

Objective 5.2. Provide training for 'omics data collection and bioinformatics [5] analysis to increase expertise within the current workforce.

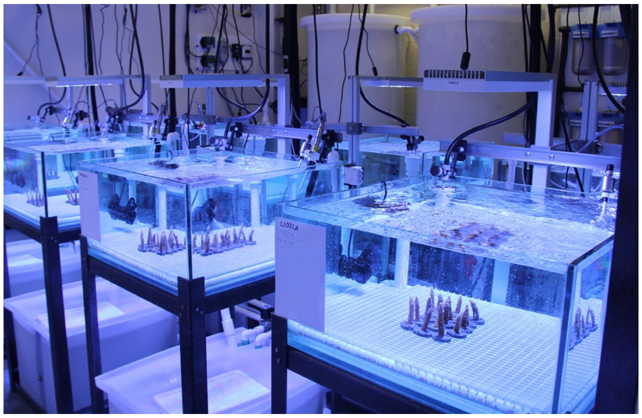
Objective 5.3. Recruit and retain information technology (IT) professionals and scientists with bioinformatics expertise to address current gaps in the ability to analyze and provide biological or environmental context to sequence data.

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.

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.

NOAA partners, Danny Garrett and Aaron Bosworth of the Washington Department of Fish and Wildlife, hold a non-native male walleye caught in Lake Washington that preys on endangered salmon resulting in adverse ecosystem and economic consequences. Developing 'omics methods to track invasive species, such as the eDNA sampling shown here, is a goal shared with NOAA and multiple partners. (Photo credit: Danny Garrett, WDFW)

[5] The ability to apply 'omics science to advance NOAA mission depends on having the necessary expertise in 'omics related computational science (bioinformatics). Bioinformatics combines biology, computer science, information engineering, mathematics, and statistics to analyze and interpret 'omics data.



The Experimental Reef Laboratory, associated with NOAA's Atlantic Oceanographic and Meteorological Laboratory and the University of Miami, allows scientists to vary coral stress and measure molecular-level responses to identify resilient strains that may be used in restoration efforts.

At-sea eDNA analysis conducted by NOAA Fisheries' Dr. Jeanette Davis during a U.S. west coast survey by NOAA ship *Bell M. Shimada* to estimate fish distributions and generate biomass indices.

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. A NOAA 'Omics Implementation Plan will further detail how the investment areas described in this strategy will be accomplished. Together with our advances in NOAA's other science and technology focus areas—Artificial Intelligence, Uncrewed Systems, and Cloud Computing—NOAA's 'Omics activities will significantly improve performance and demonstrate our exceptional environmental science leadership.

Acknowledgements

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References

Buttigieg P., Janssen F., Macklin J., Pitz K. The Global Omics Observatory Network: Shaping Standards for Long-term Molecular Observation. Biodiversity Information Science and Standards 3: e36712. https://doi.org/10.3897/biss.3.36712 (2019).

Eghtesadi-Araghi, P., Rice, J., Banks, M., Bissada, C., Escobar-Briones, E., Gaill, F., Juniper, S, Kawser, A., Kenchington, E., Preston, N., Procaccini, G., Nagappa, R., Rogers, A., Rommens, W., Zheng, S., Thorndyke, M. Use of Marine Genetic Resources. Chapter 29. In: The First Global Integrated Marine Assessment: World Ocean Assessment I, Cambridge University Press, Editors: United Nations, pp. 451-458, DOI: 10.1017/9781108186148.032 (2017).

FTAC-MM. Report of the Fast Track Action Committee on Mapping the Microbiome. Product of the Life Sciences Subcommittee of the National Science and Technology Council. https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/NSTC/ftac- mm_report_final_112015_0.pdf (2016).

Matlock G., Hilderbrand D., Gaynor J.E., Scheurer D., Valette-Silver N., Brown C., Green D., Phinney J., Turner E., Vo Dinh T. White Paper: No Transitions? No Outcomes! NOAA Technical Memorandum OAR PPE-2. ftp://ftp.library.noaa.gov/noaa_documents.lib/OAR/PPE/TM_PPE/PPE-2.pdf (2013).

Microbiome Interagency Working Group. Interagency Strategic Plan for Microbiome Research FY2018-2022. April 2018. Microbiome Interagency Working Group (MIWG), an interagency working group under the Life Science Subcommittee (LSSC) of the National Science and Technology Council (NSTC) Committee on Science (CoS). https://science.energy.gov/~/media/ber/pdf/workshop%20reports/Interagency_Microbiom e_Strategic_Plan_FY2018-2022.pdf (2018).

NAO. NOAA Administrative Order 216-105B: Policy on Research and Development Transitions. https://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_216/216- 105B.html. (2016).

National Marine Sanctuaries. Coral Reefs Support Jobs, Tourism, and Fisheries. http://floridakeys.noaa.gov/corals/economy.html. Accessed December 2018.

National Ocean Service. Economics: National Ocean Watch –GDP, https://coast.noaa.gov/digitalcoast/data/. Accessed March 2019.

National Ocean Service. https://coast.noaa.gov/states/fast-facts/economics-and- demographics.html. Accessed July 15, 2019.

NMFS OST. Fisheries of the United States 2016. Current Fishery Statistics No. 2016 (2017).

NOAA Artificial Intelligence Strategy. February 2020. https://nrc.noaa.gov/NOAA-Science-Technology-Focus-Areas.

NOAA Draft Cloud Strategy. November 2019. https://nrc.noaa.gov/NOAA-Science-Technology-Focus-Areas.

NOAA Uncrewed Systems. February 2020. https://nrc.noaa.gov/NOAA-Science-Technology-Focus-Areas.

The Economist Intelligence Unit. The Blue Economy: Growth, Opportunity, and a Sustainable Ocean Economy. https://www.woi.economist.com/content/uploads/2018/04/m1_EIU_The-Blue- Economy_2015.pdf. (2015).

Werner, C., Armor, J., Matlock, G. 3 April 2018. Emerging Technologies for NOAA Ocean Research, Operations, and Management in an Ecosystem Context. Response from NOAA to a Report from the NOAA Science Advisory Board. Preliminary Report. ftp://ftp.oar.noaa.gov/SAB/sab/Meetings/2018/April/EmergingTecnologies_Preliminary_ Response_SAB_3April2018.pdf (2018).

Yoder, J., Fluharty, D., Leong, J-A. Emerging Technologies for NOAA Ocean Research, Operations, and Management in an Ecosystem Context. Draft Report of the Ecosystem Science and Management Working Group (ESMGWG) to NOAA Science Advisory Board. https://sab.noaa.gov/sites/SAB/Meetings/2016%20Documents/November%202016%20D ocuments/Emerging%20Technologies%20Report_final%20with%20title%20page.pdf. (2016).