Potential impact of 'omics and other emerging genetic technologies on NOAA's mission

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Within NOAA, biology/ecosystems play a key role in the research, management, and policy conducted and implemented by the agency. Currently, NOAA most often uses 'omics approaches to examine DNA or RNA. The "environmental intelligence" captured in 'omics and bioinformatics research increasingly provides data at a scope and detail never before available, opening up ever new possibilities to enhance NOAA's ability to accomplish its mission.

Technologies in molecular biology have recently become powerful and relatively inexpensive tools to improve: surveillance and monitoring of the occurrence of organisms in natural environments (Kelly et al. 2014a, Kelly et al. 2014b); measuring and analyzing the biophysical functioning of organisms and ecosystems; understanding of how organism's physiology and health respond to changing environmental conditions; *and* management of species, including changes in their DNA. The "-omics" help accomplish the first three goals, while gene editing and gene drives change the DNA of organisms for management goals.

'omics to improve surveillance, monitoring or occurrence, functioning, and health of organisms

In general, "omics" refers to **genomics** (study of the entire set of genes and other information encoded in the DNA of an organism), **transcriptomics** (the study of all the messenger RNA molecules in an organism, which indicates the environment-specific expression of the genome), and **proteomics** (the study of all the proteins produced by an organism). Rapid increases in the speed, and decreases in the cost of these technologies has led to their increasing use to diagnose, for example, which microorganisms are present, which nutrients are in shortest supply, and what other stresses, limitations, or diseases are affecting organisms' physiology and functioning in their environment, e.g., HABs. Collectively these approaches are often referred to as functional genomics. All of these technological and conceptual advances depend on simultaneous and rapid advances and increasingly sophisticated applications of **bioinformatics**, which is the pipeline of algorithms that researchers create to make sense out of the avalanche of genetic information gathered from an organism or the environment.

Most recently, improvements in **gene editing** technologies to alter the genome (and thus alter the transcriptome and proteome) have garnered great attention, and are being employed or planned for a wide range of environmental management goals as well as hoped-for economically profitable activities including aquaculture, and biomedical applications.

Gene editing and gene drives to manage organisms

Time magazine's 23 June 2016 cover story on gene editing declared: "One of the most exciting breakthroughs in science is here. CRISPR is a new technology that can edit DNA with remarkable precision, and it has the potential to change human lives forever . . . CRISPR is already being used on crops, insects and more" (Park 2016). Applications could certainly involve fishes and other marine species for which NOAA has responsibility.

When these gene editing technologies are used to alter the germ cells of an organism, they become heritable. When germ cell editing is combined with a **gene drive**, the genetic modification sweeps through the species' population, replacing all variants of the target gene with the desired version of the gene (which can be, for example, a lethal gene leading to the extirpation of the species).

While *Time* was almost breathless in its enthusiasm for applications of gene editing and gene drives, many scientists have been cautious, especially about gene drives, which may deliver harmful side effects as well as potential benefits in many applications (NASEM 2016 ; Specter 2016). Applications of gene editing and gene drives do or may include modification of fishes or other species to confer more desirable traits for human exploitation; make species more tolerant of changing conditions (e.g., temperature, pH, salinity); confer resistance to pathogens or parasites; and eradication of parasites, pathogens, vectors of disease, and other harmful species, including invasive species.

Relevance to NOAA mission

Environmental applications for omics, gene editing, and gene drives are likely to have increasing relevance to that part of **NOAA's mission "to conserve and manage coastal and marine ecosystems and resources."**

Environmental intelligence**:** 'Omics will add to scientists' ability to detect, monitor, and predict environmental changes and their effects on human health and the health of ocean and coastal ecosystems, leading to broader application of these approaches to other regions and improved national efforts in ecosystem monitoring and management. Gene editing could be added to the ecosystem management toolbox, but would require rigorous risk analysis before any application.

Value-added products**:** NOAA does and could increase its contributions to publically available genetic data repositories (e.g, GenBank) and bioinformatics tools. With its combination of biological and engineering aquatic sensing capabilities, NOAA could contribute to research, development and potential commercialization of field-deployable genetic-based sensing platforms. There are non-profits and for profit companies in this space, but NOAA would bring a unique and powerful combination of capacities.

Units and activites of NOAA that are or could create and deploy new uses of 'omics and gene editing include the following.

Atlantic Oceanographic and Meteorological Laboratory (AOML)

Coral Reef Conservation Program (CRCP)

Functional Genomics and Bioinformatics**:** Scientists in several programs at the Northwest Fisheries Science Center use functional genomics approaches in their research to: assess the diversity of populations of marine organisms, evaluate how changes in the aquatic habitats affect fish and other organisms, and search for ways to develop sustainable aquaculture practices.

Global Genomic Observatories: EU-US collaboration piloted via Ocean Sampling Day. Implemented standardized sample protocols and metadata collection according to the minimum information standards (MIxS) established by the Genomic Standards Consortium (EU Micro B^3).

Great Lakes Aquatic Nonindigenous Species Information System**:** Scientists at the Great Lakes Environmental Lab (GLERL) are utilizing eDNA to monitor aquatic nonindigenous species in the Great Lakes.

Marine Biodiversity Observing Network (M-BON)

NOAA-CalCOFI Ocean Genomics (NCOG) Project: 'Omics technologies added to one of the oldest ecosystem/fisheries assessment (*ecoforecasting*) programs. Utilize upwelling regimes to allow short-term hypothesis testing with development of ecological indices.

Systematics Lab

Ocean Acidification Program (OA)

Southwest Fisheries Genomics Research: This research at the Southwest Fisheries Science Center is supported by NOAA's state-of-the-art conservation genetics laboratory and genetics tissue archive, with an emphasis on marine mammals and sea turtles. The latter houses a continually growing world-wide sample collection enriched by international scientific collaborations.

Recommendations for NOAA

Because NOAA's capacity to develop and apply or even evaluate and communicate about these new technologies is likely to be limited by slow changes in the NOAA scientific workforce, **we recommend that NOAA invite multiple speakers to one or more SAB meetings to increase the knowledge of NOAA leadership about these technologies, when/where they are likely to provide opportunities and/or challenges to the NOAA mission, and what existing or future governance mechanisms exist for these technologies with respect to the NOAA mission.** Speakers and subsequent discussion by the SAB and leadership are likely to lead to further, more specific recommendations about NOAA research and regulatory planning and activities, priorities for future NOAA Cooperative Institutes, and the future NOAA workforce.

Suggested potential speakers:

James P. Collins, School of Life Sciences, Arizona State University, ecologist who co-chaired 2016 NAS study on gene drives, former NSF division director.

Ruth Gates, U Hawaii Institute of Marine Biology, coral acclimation and adaptation to climate change, coral microbiome.

Kelly Goodwin, NOAA Southwest Fisheries Science Center, 'OMICS Transformational Tools, Systematically applied

Gregory E. Kaebnick, The Hasting Center, philosopher, ethicist; member of NAS gene drive committee. Ethics, cost-benefit, risk assessment of synthetic biology.

Ryan Kelly, School of Marine and Environmental Affairs, University of Washington -- PhD in marine genomics, JD from Berkeley.

Simon A. Levin, Dept of Ecology and Evolutionary Biology, Princeton University—ecologist, NAS member

Linda Rhodes, NOAA Northwest Fisheries Science Center, Environmental sample processor – robotic application of ' omics.

Forest Rohrer, Biology Dept, San Diego State U, microbial ecologists using metagenomics to study bacteria and viruses as a major player in coral reefs and other marine communities.

Mark Saito, WHOI, iron and other limitations of marine phytoplankton studied with proteomics and metagenomics; informatics; Moore Foundation Fellow.

Joseph Travis, Dept. of Biological Sciences, Florida State U., ecologist, served on NAS gene drive committee, evolution of life histories in fishes

Madeleine van Oppen, School for BioSciences, U of Melbourne, ARC Cenre of Excellence for Coral Reef Studies. microbial symbiosis in corals, adaptation/acclimatisation to climate change, genetic manipulations to enhance stress tolerance and fitness of corals

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