# Realizing the Potential of eDNA Biodiversity Monitoring Tools in the Marine Environment with Application to Offshore Renewable Energy

## Offshore Renewable Energy and Biodiversity

The United States is planning to install 30 gigawatts of offshore wind energy by 2030. Offshore renewable energy development (ORED) is a critical component of global strategies to decarbonize the electricity sector and address the effects of climate change (U.S. Department of Energy, 2023a). However, placement and operation of ORED infrastructure is expected to alter the marine habitat for various fish and wildlife species. For example, new infrastructure and associated human activity offshore may overlap with animal migrations or foraging (Cook and others, 2018). The composition of biological communities can change, with species' distribution shifts likely (Li and others, 2023). To avoid negative effects on fish and wildlife and their habitats, Federal agencies—including the National Oceanic and Atmospheric Administration, the U.S. Department of the Interior, the U.S. Department of Energy, as well as State agencies and others—need to understand how these developments may alter the marine environment and biodiversity. This information helps natural resource managers by supporting regulatory requirements and informing strategic resource management and conservation efforts. Efforts are underway to assess effects on species of conservation concern, which include species that have either demonstrated considerable decline in their populations, are naturally rare, or have a limited distribution.

The U.S. Geological Survey (USGS) researches the biological diversity and distribution of species to support management, conservation, and resource use decisions. USGS scientists advance detection and monitoring technologies to assess changes in fish and wildlife populations, biodiversity, and the health of ecosystems. Offshore wind energy is a growing source of renewable energy worldwide; the United States had more than 50 gigawatts of wind energy in the offshore pipeline in 2023, with an additional 30 gigawatts planned by 2030 (U.S. Department of Energy, 2023b). However, the effects on fish and wildlife and their habitats are not well understood. New and cost-effective tools for measuring changes in biodiversity in response to offshore renewable energy development can help to inform natural resource management and project permitting decisions.

Photograph by Gary Norton, U.S. Department of Energy, 41187

## eDNA in the Marine Environment

Federal and State agencies study and monitor natural resources offshore as part of their resource management practices. However, collecting biological monitoring data in ocean environments is challenging and costly owing to the natural diversity and complexity of marine communities (United Nations Educational, Scientific and Cultural Organization, 2017). Traces of genetic material (deoxyribonucleic acid [DNA] and ribonucleic acid [RNA]) from organisms, like fish, reptiles, and mammals, can be collected from the environment and analyzed to determine which species were likely present in sampled locations. Emerging technologies that integrate the collection of this environmental DNA (eDNA) and RNA (eRNA) (hereafter referred to as “eDNA”) with autonomous robotic samplers are being developed to enable critical insight about marine biodiversity from the relatively simple, fast, and inexpensive act of collecting a water sample, while reducing the need for expensive research vessels and personnel time (fig. 1). When eDNA sampling is automated with robots, comprehensive monitoring of genetic material from microbes to mammals can occur at a frequency and number of locations not otherwise feasible, providing the high resolution and more complete assessment of marine life needed for accurate monitoring. This allows scientists to track species in time and space to produce baseline genetic material information and assess potential changes in biodiversity.

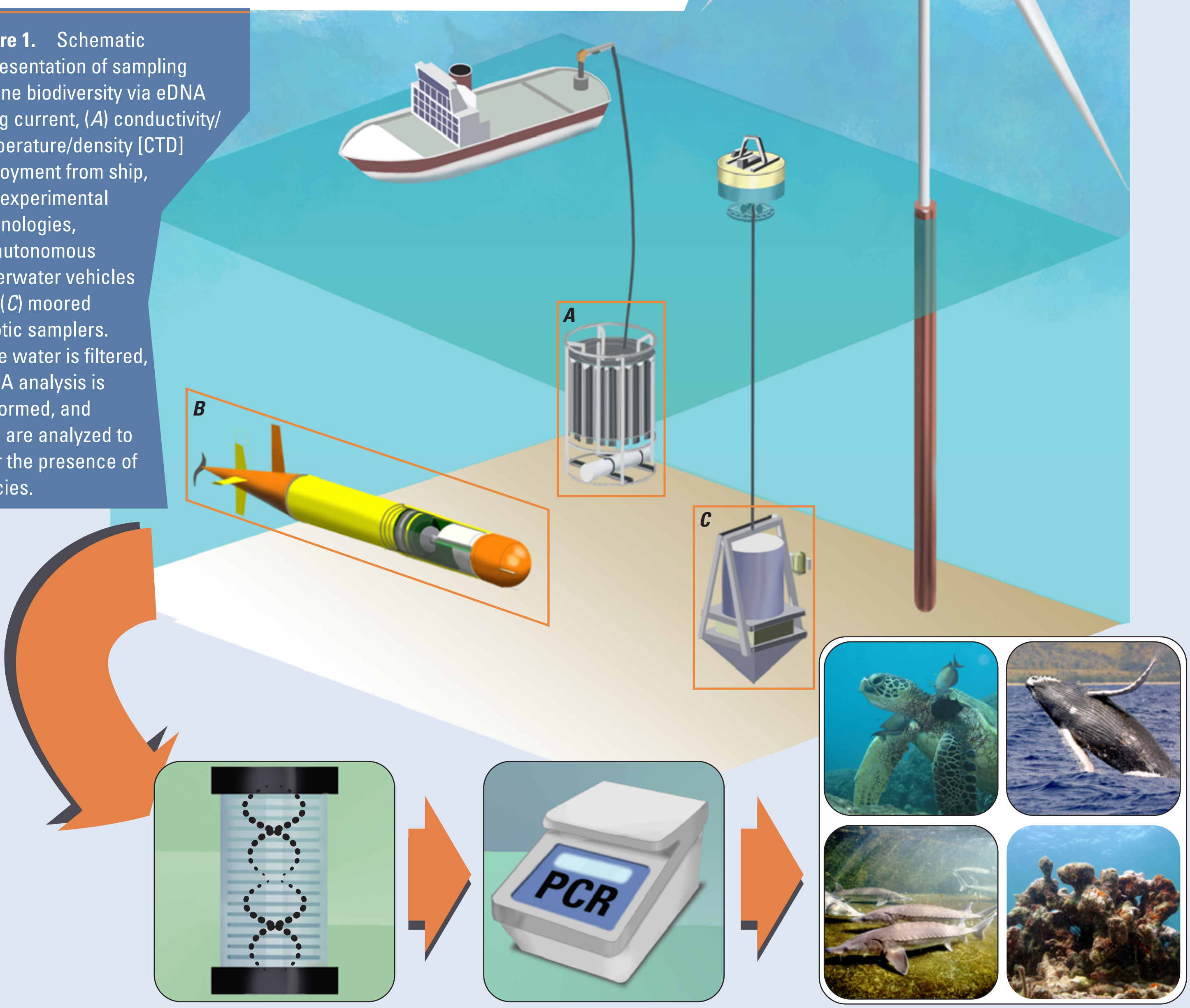



**Figure 1.** Schematic representation of sampling marine biodiversity via eDNA using current, (*A*) conductivity/temperature/density [CTD] deployment from ship, and experimental technologies, (*B*) autonomous underwater vehicles and (*C*) moored robotic samplers. Once water is filtered, eDNA analysis is performed, and data are analyzed to infer the presence of species.

## Research and Development Needs

Like all emerging technologies, robotic eDNA sampling and data interpretation have unresolved knowledge gaps and limitations that must be overcome to realize the potential of eDNA as an effective biodiversity monitoring tool. Continued engineering advancements are needed in autonomous vehicles used for sampling to include eDNA collection at various water depths and for onboard processing. Key challenges with eDNA data interpretation include improving the accuracy of species identification from eDNA, linking eDNA observations to species presence at various sites that are sampled since eDNA can be transported away from its source organisms, determining where and when to deploy robotic eDNA samplers to optimize detections of multiple species of interest, and developing modeling approaches to detect changes in eDNA accurately and precisely over time and space.


## eDNA Research and Development Roadmap

The USGS is uniquely positioned to leverage research and development (R&D) advances already achieved in their research programs to respond to these outstanding biodiversity monitoring needs for ORED. The USGS is a leader in the field of eDNA and has, among many additional topics, helped advance robotic eDNA samplers, has extensive experience working in the offshore environment, and has developed novel and actionable statistical methods and standards for monitoring applications (see sidebar 1, sidebar 2, and sidebar 3). The USGS is working with partners to respond to the R&D needs identified in this fact sheet and ensure alignment and coordination with the objectives of the national strategy on aquatic eDNA and associated implementation plans (Kelly and others, 2024). Advancing these key eDNA R&D needs is intended to result in better, faster, and less expensive use of robotic eDNA sampling for biodiversity monitoring applications and inform the development of new tools, like autonomous vehicles, onboard processing, and air eDNA sampling in conjunction with water sampling.

## Key eDNA Research and Development Advances Needed for Offshore Renewable Energy Development Applications

### Validate robotic eDNA sampler use in the marine environment to monitor biodiversity changes in a cost-effective and reproducible way.

- Evaluate relative performance of robotic eDNA samplers to manual eDNA sampling and other sampling approaches to understand their limitations and added value.
- Identify best practices for ensuring that eDNA results from robotic eDNA samplers and manual sample collections are interoperable.

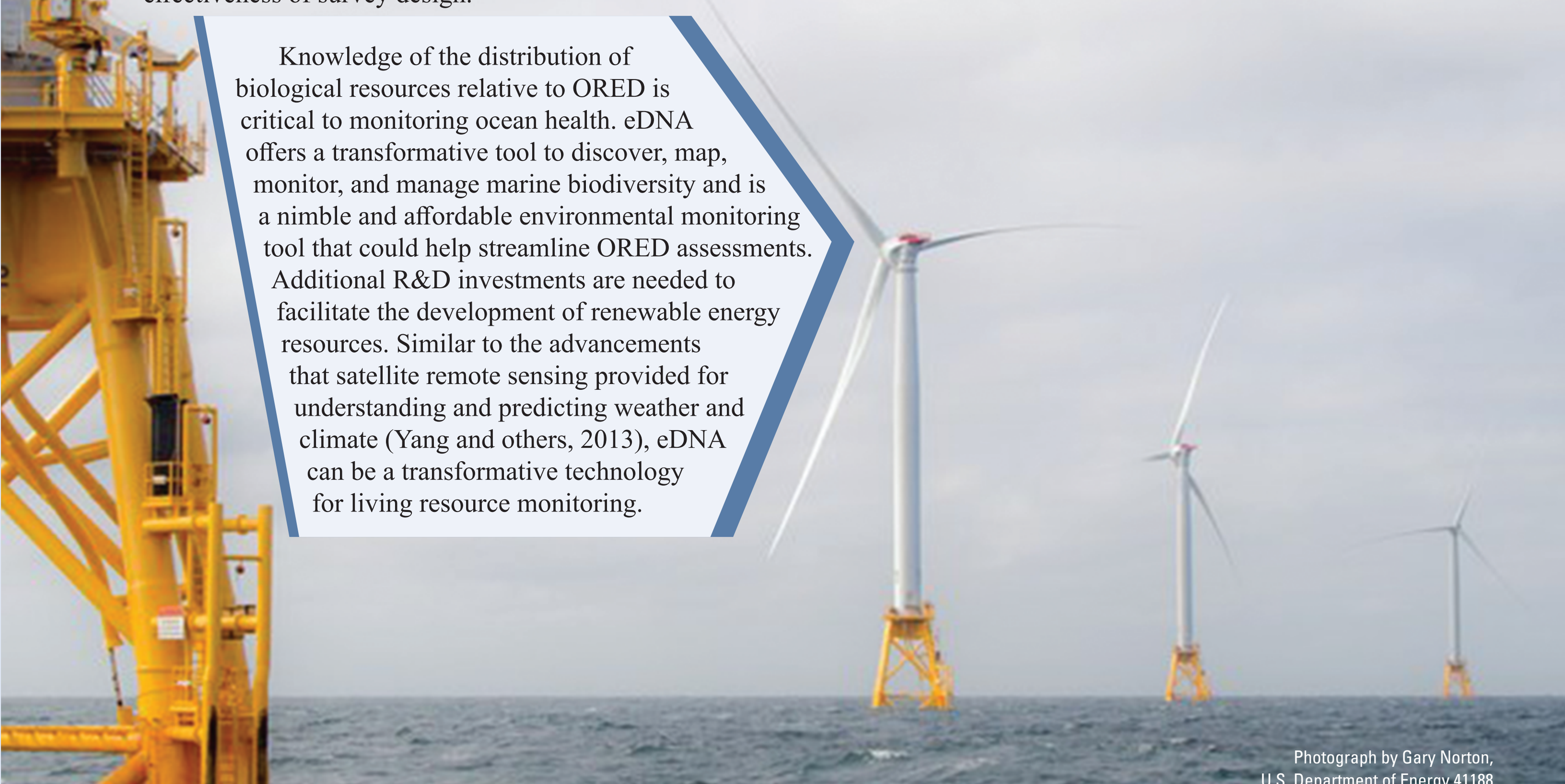
### Assess the strengths and limitations of ecological inferences derived from eDNA sampling compared to other sampling approaches.

- Make progress toward a complete, curated species DNA sequence reference database to identify species more accurately when using eDNA approaches.
- Identify critical biotic and abiotic parameters that bias ecological inferences, like eDNA breakdown and movement.
- Develop and validate eDNA modeling approaches to improve species occurrence and distribution inferences and allow comparison of results to other survey tools.

### Develop analytical tools that quantify offshore fish and wildlife distributions for planning and monitoring ORED.

- Develop and validate eDNA modeling advances and visualization tools to produce interactive distribution models for species of conservation concern.
- Develop and validate multimethod approaches that harness the strengths of different survey tools, such as bioacoustics and microscopy, to enhance eDNA inferences. These models should provide superior information and enable comparisons among different field methods, ultimately enhancing the effectiveness of survey design.

Knowledge of the distribution of biological resources relative to ORED is critical to monitoring ocean health. eDNA offers a transformative tool to discover, map, monitor, and manage marine biodiversity and is a nimble and affordable environmental monitoring tool that could help streamline ORED assessments. Additional R&D investments are needed to facilitate the development of renewable energy resources. Similar to the advancements that satellite remote sensing provided for understanding and predicting weather and climate (Yang and others, 2013), eDNA can be a transformative technology for living resource monitoring.



Photograph by Gary Norton, U.S. Department of Energy 41188

## U.S. Geological Survey Expertise in eDNA Applicable to the Marine Environment

### Sidebar 1. Marine eDNA Sampling and Metabarcoding Analyses

The U.S. Geological Survey (USGS) brings a wealth of expertise as a world leader in characterizing biological resources and related processes at, and beneath, the seafloor (for example, Brannock and others, 2023; U.S. Geological Survey, 2023; Cordes and others, 2024). As a part of ongoing studies by the National Oceanic and Atmospheric Administration (2023) and the U.S. Geological Survey (2023), the USGS has collected eDNA samples from the surface to the sea floor (60- to 4,500 meter-depth) using remotely operated vehicles and (ship-based and autonomous) conductivity temperature depth instruments to investigate the biological communities in living marine habitats. eDNA analyses provide critical information about species' DNA presence at the sea floor and in the water column that link the deepwater food web to more productive surface waters. Coupled with environmental data, the eDNA data provide baseline characterization of biodiversity, help define water masses and food webs, and offer a detailed glimpse into ecosystem functioning.


Photograph by Kaitlin Kovacs, U.S. Geological Survey

### Sidebar 2. Robotic eDNA Samplers

Programmable eDNA robots that can obtain samples at high frequencies across time and locations have the potential to serve as efficient, sensitive, and cost-effective tools for baseline biodiversity assessments as well as long-term monitoring following offshore renewable energy development (ORED). U.S. Geological Survey (USGS) researchers have completed proof-of-concept experiments where robotic eDNA samplers were installed at river streamgages to monitor for invasive mussels, introduced fishes, and human and fish pathogens (Sepulveda and others, 2020). They have documented that robotic eDNA samplers, which collected multiple samples a day for weeks to months, decreased false-negative detection rates and provided a more complete picture of biodiversity. USGS researchers have also deployed robotic eDNA samplers in autonomous underwater vehicles in the Great Lakes to monitor fish communities. USGS researchers are collaborating with the Monterey Bay Aquarium Research Institute to design, validate, and implement robotic eDNA samplers that are scalable, robust, and relatively easy to operate, and provide high-quality data for decision making. These new samplers are tailored for routine use and monitoring applications.

Photograph by James Birch, Monterey Bay Aquarium Research Institute (MBARI).

### Sidebar 3. Study Design and Statistical Analysis for Actionable Science

The U.S. Geological Survey (USGS) has led the development of statistical (occupancy) models to address the challenges of imperfect species detection, which can result in some sites appearing to be unoccupied (false-negative) or occupied (false-positive) by a species when the opposite is true. Occupancy models solve these problems and produce unbiased estimates of occupancy and related parameters. They also provide insight on the location and timing of surveys required to achieve monitoring objectives, like achieving a specified precision for an occupancy estimate of marine mammals at offshore renewable energy development (ORED) sites. Occupancy models are applicable and informative to a broad range of ecological questions, including those in the marine environment, where imperfect species detection under the water's surface is an inherent challenge. USGS scientists have led recent efforts to expand the use of occupancy models to eDNA data to minimize inference bias attributed to false-negative or false-positive detections, such as studies conducted on vulnerable manatee populations (Hunter and others, 2018). Software packages, such as EDNAOCCUPANCY (Dorazio and Erickson, 2018) and msocc (Stratton and others, 2020), developed by USGS scientists to fit eDNA data, are included in these efforts. Current USGS efforts on eDNA occupancy models include the incorporation of quantitative eDNA concentration data to better model occupancy of rare species using their equally rare eDNA and the development of both multispecies eDNA occupancy approaches and multimethod approaches to integrate eDNA data with other survey methods like acoustics, imagery, and trawl data.

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