1. Title:

An ecological and oceanographic baseline to inform offshore wind development over the continental shelf off the coast of New Jersey.

2. Investigator(s) name(s) and institution(s):

Dr. Josh Kohut and Dr. Grace Saba
Rutgers, The State University of New Jersey
Center for Ocean Observing Leadership

Project Managers: Kira Lawrence (BPU) and Renee Reilly (DEP-DSR)

3. Motivation/Objective:

The MAB is bounded by Long Island, New York to the north and New Jersey to the west, and is separated by the Hudson Shelf Valley extending from the mouth of the Hudson River out to the continental shelf-break. The physical oceanography of this region is influenced by local topography, freshwater input from rivers and estuaries, large scale atmospheric patterns over the North Atlantic, and tropical or winter coastal storm events. Therefore, the ocean characteristics on the MAB shelf, including the planned offshore wind energy areas, undergoes remarkable variability across time scales from days and weeks to seasons, years, and decades. The "Cold Pool", a region of cold remnant winter water near the bottom of the water column, develops seasonally, persisting from spring to fall on the continental shelf in the Northeast US (Houghton et al., 1982), and is an important driver of biological patterns (e.g., Malone et al. 1983, Sullivan et al. 2000, Steves and Cowen 2000, Sullivan et al. 2005). This intense ocean variability drives an equally variable ecosystem from the primary producers to the highly migratory fisheries and marine mammals throughout the existing and planned lease areas. The tight coupling between the ocean conditions and the habitat preference of local and migratory species lead to a distribution that can significantly vary from season to season and year to year. Furthermore, the MAB is situated in one of the most rapidly warming regions in the world and is vulnerable to both ocean and coastal acidification. These long-term environmental changes are associated with observed and projected changes in species distributions, biomass, and diversity. Therefore, these time scales of variability – from seasons (at a minimum) to years - must be considered in approaches to quantify and potentially isolate potential offshore wind impacts on these marine ecosystem processes and changes.

New Jersey has set a goal to procure half of its energy from renewable resources by 2030. Offshore wind power will play a critical role in achieving the renewable energy goal to create a more sustainable economy in the state (NJ Executive Order No. 8, 2018). Fisheries also play a critical role in the state economy. New Jersey fisheries landings generated $166 M in revenues in 2015, with sea scallop ($98 M) and ocean quahog ($11 M) accounting for close to two-thirds of landings revenues for the year. Including importers, fisheries industries account for over 31,000 New Jersey jobs and almost $1.3 B in income for NJ (NMFS, 2017). The continental shelf off New Jersey has been experiencing ocean warming since the 1970's, and the phenology of the system has also shifted including earlier spring transitions and later fall cooling (Friedland and Hare, 2007). Notably, the overall warming trend is projected to continue where under a doubling of CO_2

warming could increase by 3-4°C in the next 70 years (Saba et al., 2016). Ocean warming has led to vulnerability in approximately half of the U.S. Northeast Shelf species (Hare et al., 2016), and the dominant response of fish species to ocean warming has been distribution range shifts poleward. Furthermore, NJDEP published the 2020 New Jersey Scientific Report on Climate Change which states, "New Jersey is at increased risk to the effects of ocean acidification due to its economic dependence on shellfish harvests, with southern New Jersey counties ranking second in the United States in economic dependence on shelled mollusks" (New Jersey Department of Environmental Protection, 2020).

With offshore wind construction scheduled to begin in the next couple years, it is critical that oceanographic and ecological baseline monitoring begin immediately. In this proposal, we provide an opportunity for baseline monitoring and research to not only support the offshore wind planning process, but also provide valuable information relevant to ongoing environmental and ecological change in New Jersey' productive coastal waters. By deploying a glider-based program, we will simultaneously map oceanographic and ecological parameters that will inform each of the RMI research priorities. Leveraging our significant glider experience and existing resources, we will be able to quickly and efficiently stand up a comprehensive monitoring program specific to the coastal waters off NJ overlapping with planned offshore wind development. In the following sections we provide details on our proposed plan with three deployment strategies. These sections are organized by task. Task 1 is the glider deployments themselves, task 2 is the data management including archive, access, and quality control, and task 3 is the data analysis relevant to RMI research priorities.

4. Proposed Research:

Task 1: Glider Deployments

We propose a glider-based ocean monitoring program that will sample the necessary oceanographic and ecological parameters to provide a baseline dataset that will inform the responsible development of offshore wind. Slocum gliders are autonomous underwater vehicles that navigate ocean waters collecting high-resolution data at various depths throughout the water column (Schofield et al., 2007). The gliders have proven to be particularly robust vehicles in the coastal waters of the NYB, completing missions supporting hurricane response (Glenn et al., 2016), water quality monitoring for federal and state agencies (Kohut et al., 2014), and numerous other scientific insights about this complex coastal system (Castelao et al., 2008; Glenn et al., 2008; Oliver et al., 2013; Miles et al., 2015; Glenn et al., 2016; Oliver et al., 2017). Sensors integrated into the glider will sample multiple parameters approximately every one to two seconds along the glider transects. Data are collected from surface to bottom, east to west, and north to south providing a detailed three-dimensional view of ocean and ecological conditions within and around the existing and planned offshore wind lease areas.

We propose a comprehensive deployment strategy that will optimize and maximize measurements for oceanographic and ecological baseline assessment in relation to New Jersey's offshore wind development activity. The deployment schedule and sensor configuration considers the significant seasonal variability in both the oceanography and ecology within the region of interest, the large suite of parameters that are needed to address the full scope of the RMI research priorities, and the known realities of operating a glider monitoring program off the NJ coast including required maintenance and calibration schedules, glider endurance, and mitigating sensor interference. We have estimated resources and equipment that will guarantee delivery of the scheduled deployments and resulting data given our experience with these gliders including known uptime, maintenance, and sensor calibration schedules. It is based on the Rutgers glider experience specific to the coastal waters off NJ. We have been operating gliders in this region since 1999 with well over 200 of our over 500 global deployments occurring in this region. These deployments include experience with all sensors described below.

We will conduct a seasonal baseline survey with a pair of gliders deployed in each season over two years with a full complement of available sensors to simultaneously map oceanographic and ecological variables. To accommodate the larger sensor suite and mitigate interference between active and passive sensors this approach will deploy two gliders paired for each seasonal mission. One glider will be equipped with a CTD to determine water depth, temperature, salinity, and density, an optics puck measuring chlorophyll-a and colored dissolved organic matter (CDOM) fluorescence, an optode measuring dissolved oxygen, and a DMON passive acoustics sensor for marine mammal monitoring and detection. The second glider will be equipped with an optics puck and an Acoustic Zooplankton Fish Profiler (AZFP; Chave et al., 2018) multi-frequency echo sounder for active acoustic detection of pelagic organisms. Similar to the first glider, the second glider will have a CTD, but this CTD package will also include an integrated pH sensor for ocean acidification applications. Both gliders will also carry a fish telemetry receiver to track tagged species moving through the region.

Glider Endurance and Sensor Interference: In order to simultaneously measure all of these above listed variables without sacrificing data quality and glider endurance, two separate gliders deployed in tandem are required. Sensor interference must be considered when deploying this specific suite of sensors. For example, we cannot deploy an active and a passive acoustics sensor on the same glider without interference. Similar interference must also be considered between the dissolved oxygen optode and the AZFP echosounder. Additionally, the more sensors deployed on a single glider will require more of the battery capacity, reducing the glider deployment endurance. Under this proposed configuration, our tandem glider deployments will maximize the suite of sensors deployed, ensure the necessary endurance to complete the mission, and mitigate known interference between the sensors.

Active Acoustic Configuration: Depending on the configuration of the transducers' frequencies, the AZFP sensor can be used to detect with high confidence either (but not both) smaller organisms like zooplankton or larger organisms like pelagic fish. Zooplankton (e.g., copepods) are a major food source for many pelagic fish and squid species and some baleen whales (e.g., North Atlantic right whale) and therefore are a key link in the trophic food chain. Therefore, understanding zooplankton distributions and abundance would inform locations of North Atlantic right whale foraging hotspots relative to offshore wind development areas. Pelagic fish, specifically small pelagics such as herring, mackerel, butterfish, and menhaden, are not only another major food source for other fish and mammal (e.g., humpback whale) species, but are also targets of local fisheries. Therefore, we must select an active acoustic frequency range for these seasonal surveys. Given the focus areas of the RMI and the tendency for current offshore wind monitoring programs to target active acoustic detection of pelagic fish using traditional vessel-based observations, we recommend a hybrid approach. This approach will allocate two budgeted AZFP sensor units with a configuration that would dedicate one unit for zooplankton (with 125, 200, 455 kHz frequencies) and one unit for pelagic fishes (with 38, 125, 200 kHz frequencies). We will then rotate usage of each AZFP seasonally to target dominant predator-prey interactions. For example, deploying the AZFP-zooplankton unit during months when North Atlantic right whales are actively migrating through the area (November – April) to capture interactions with copepods and other zooplankton and deploying the AZFP-pelagic fish unit during summer and fall to capture humpback whale interactions with sandlance and/or menhaden. We will consult with the RMI program to ensure each sensor is deployed to maximize impact across the RMI research priorities.

In addition to these paired seasonal missions, we will deploy a third glider equipped with the CTD/pH, optics puck, optode, and VEMCO receiver 3 times each year. These deployments will fill coverage gaps in the seasonal glider deployments from the onset of seasonal stratification associated with the Cold Pool formation in the spring to the physical breakdown in the fall. Recognizing that the exact timing of Cold Pool formation and breakdown varies from one year to the next (Chen and Curchitser, 2020), this deployment strategy will ensure that the 2-year baseline contributes to cold pool/offshore wind research priorities (Miles et al., 2021) by capturing these key ocean events and the concurrent ecological response.

Deployment Schedule: The exact timing of each 3-4 week deployment will be determined jointly by the RMI team and Rutgers University based on weather, environmental, and other logistical variables. But in general, the targeted paired deployment dates for each year will be: January-February (Deployment 1), April-May (Deployment 2), July-August (Deployment 3), and October-November (Deployment 4). As with the paired deployments, the three cold pool resolving deployments will be determined jointly by the RMI team and Rutgers University based on weather, environmental, and other logistical variables. But in general, the targeted deployment dates for each year will be: 3 deployments between May-October to fill the coverage gaps between the seasonal paired deployments listed above.

All proposed glider missions would cover the same spatial extent and transect (Fig. 1). The zig-zag glider missions will cover an area from Sandy Hook down to Cape May, from near shore extending out across the shelf. This will ensure that the monitoring occurs both on established long-term transects for historical context and within offshore wind lease areas. Furthermore, the equipment acquired through this proposal will not only support the baseline monitoring proposed over our two-year study period, but be available for future RMI initiatives. This equipment can serve as a resource to the RMI program moving forward in a similar way to our partnership with NJDEP and our nearshore coastal monitoring glider. That glider and sensor payload purchased over 10 years ago, has supported NJDEP coastal monitoring effort each year since. Deployments are coordinated with NJDEP to ensure its use meets the needs of the monitoring or research program. Similarly, we expect the pool of equipment acquired through this proposal can be maintained as a resource the RMI program can use to support initiatives over the life of the program. Additionally, our existing glider equipment that is configured to meet the baseline sensor and deployment requirements within this proposal are available to account for unforeseen delays in calibration and delivery delays of new equipment.

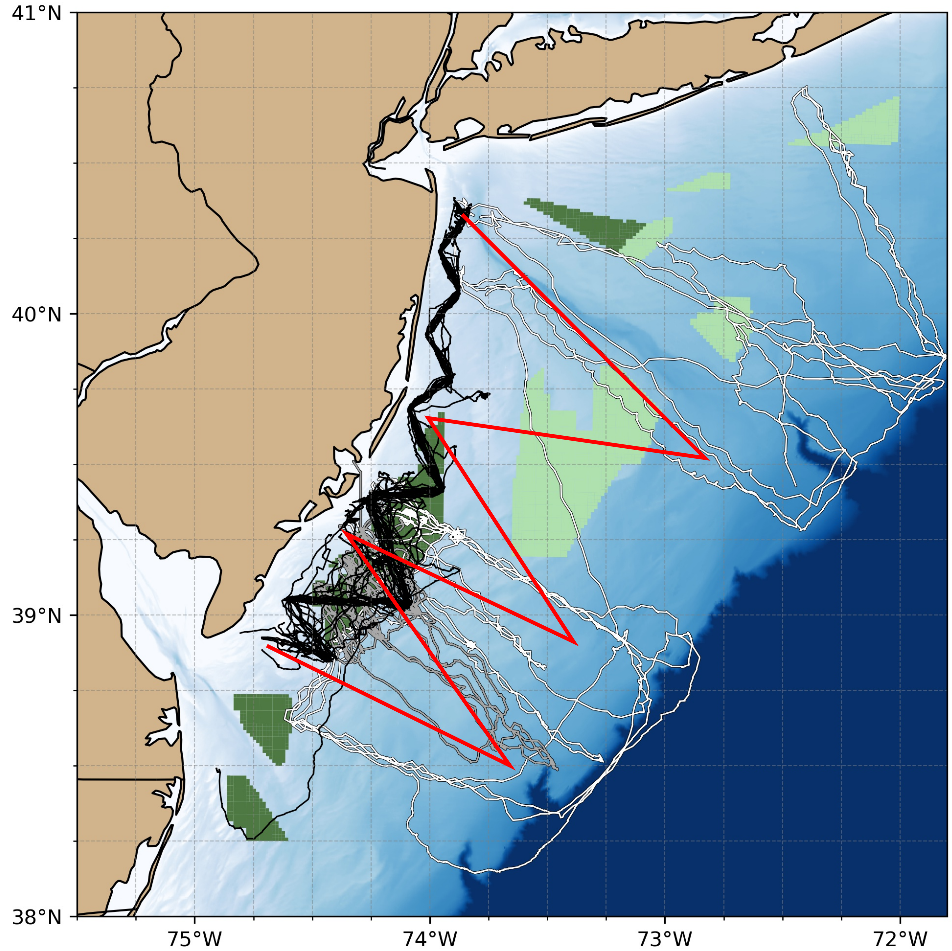

Figure 1. Map indicating the coverage of three relevant glider missions including NJDEP water quality (black), NOAA and NYSDEC pH (white), and Ørsted Marine Mammal Monitoring (Grey). The proposed environmental coastal survey track is shown in red. All these deployments occur within the footprint of a nested HF radar surface current network. The offshore wind lease areas are also shown in shades of green.

To summarize, this deployment strategy will provide seasonal resolution data that allows for a large range of parameters that will support multiple RMI research priorities – including physical and chemical variables, and biological variables spanning from phytoplankton and zooplankton to pelagic fish and marine mammals. The additional spring through fall deployments will provide baseline physical, chemical, and biological information but with greater temporal coverage. This will allow us to resolve the evolution of the local seasonal stratification (formation and breakdown of the Cold Pool) as well as the ability to capture distinct, biologically-important episodic events (e.g., upwelling, storms, intrusion of warm core rings and the onset and breakdown of the Cold Pool) that might otherwise not be detected in the more punctuated seasonal monitoring program. This monitoring strategy increases our ability to characterize the true variability of the system throughout a year, which can then be used as a baseline to observe potential impacts of offshore wind development and operation and/or compare to observations of future environmental and biological fluctuations and long-term changes in New Jersey's coastal system. These data will also provide baseline information to support future hypothesis-driven research within the RMI research priority areas.

Task 2: Data QA/QC, Management, and sharing

The data management for the physical and chemical data will be based on the considerable infrastructure already in place at Rutgers University to support glider operations as part of Integrated Ocean Observing System (IOOS). Kohut and Saba are part of the Mid-Atlantic regional component of IOOS, MARACOOS. This involvement will ensure that the glider datasets will be managed in a way consistent with the IOOS federally certified process. Additionally, Kohut has been partnering with NJDEP for the past 12 years to run annual glider deployments along the inner NJ shelf dedicated to a water quality mission. The data management infrastructure and experience across these projects will enable us to quickly stand up a data management approach that will quickly deliver quality controlled data to a broad end user community. This approach is based on a centralized data service that provides quality control standards and easy access to data and metadata. For each deployment the complete dataset will be stored locally on the glider. In addition, a subset of the data files recorded by the glider will be transferred back to shore via the Iridium satellite communication system in near real-time. These files are then archived to a fileserver at Rutgers University, where they are backed up daily. Glider surfacing events will occur approximately every 2 to 3 hours during the mission. With each connection, email will be automatically sent to our glider team with information on glider health (battery voltage, vacuum pressure, and location). The raw data stream will be processed to be consistent with both the IOOS national glider plan, the NSF Ocean Observing Initiative (OOI) data management plans, and the Quality Assurance Project Plan established between Rutgers University, NJDEP and USEPA. Scientific (i.e., temperature, conductivity, depth, and acoustics) parameters will be merged with the glider navigational parameters (i.e., location and time) and stored in organized data structures, which are saved to the RU fileserver in near real-time. Real-time glider health and deployment status will be available at: https://marine.rutgers.edu/cool/data/gliders/. This webpage will include plots of relevant scientific parameters (temperature, salinity, density, chlorophyll concentration, etc.) and maps showing the glider's path and intended waypoints. These processed datasets will be made available in near real-time in the trajectory NetCDF file format via the Thematic Real-time Environmental Data Distribution System (THREDDS). While the glider is on a mission, the real-time distributed data will be considered provisional until the complete dataset is quality controlled after recovery. Once the glider has been recovered, files containing the full datasets will be downloaded and the previous steps repeated, providing the end user with the complete scientific and navigational data streams.

Partnering with Woods Hole Oceanographic Institution (Mark Baumgartner), the near real-time detection data from the glider-mounted DMON will be reviewed twice daily by an analyst after Baumgartner et al. (2019, 2020) and the results of the analysis will be available on the robots4whales.whoi.edu website, displayed in the Whale Alert app, and disseminated by text and email messages to stakeholders and other interested parties. We will make the near real-time analyst results available automatically for display in other data distribution platforms, including the Mid-Atlantic Regional Association Coastal Ocean Observing System (MARACOOS) website and Mysticetus platform (an application used to track wildlife detections by the wind energy sector). Recorded audio from the DMON will be archived with the NOAA Northeast Fisheries Science Center's PAM data repository and displayed on their Passive Acoustic Cetacean Map (PACM).

Glider AZFP raw data binary files will be stored hourly on a data card that will be removed after deployment for analyses. Pitch, roll, GPS fixes, and depth data will be calculated from glider measurements and converted into files compatible with Echoview software. Raw acoustic data will be linked to the other glider sensor data (temperature, salinity, etc.) by time stamp and processed using Echoview (Echoview Software Pty. Ltd., v 12.0). Echoview's Background Noise Removal (De Robertis and Higginbottom, 2007), Impulse Noise Removal, and Transient Noise Removal (Ryan et al., 2015) algorithms will be used to clean the raw acoustic data from each frequency. Then from each frequency, mean volume backscattering strength (MVBS or *Sv*, dB) and area backscatter coefficient (ABC or *sa*, m^2 m^{-2}) will be exported in 1 m × 1 m bins according to Reiss et al. (2021) for additional MATLAB processing of zooplankton and fish identification, school detection, and biomass (e.g., Demer et al., 1999; Fernandes et al., 2002; Gorska et al., 2005; Jech and Michaels, 2006).

Task 3: Reporting and Data Product Development

In addition to the real-time and post mission baseline data delivery outlined in task 2, we will prepare the following project summary reports for submission to the RMI leadership team:

Annual Report: Proposed project dates are 03/01/2022-02/29/2024. On an annual basis, we will submit to the RMI Program Managers a prepared summary of glider surveys completed each calendar year. Reports shall be submitted by March 31st for the previous calendar year's activities (i.e., reporting period). Each report will summarize the mission data collected and status of data QA/QC, delivery, and access, and will include applicable data products (see below).

Final Report: Upon completion of the contract period, we will prepare a non-proprietary/non-confidential Final Report. The report will include a summary of the missions completed in task 1 and a summary of the data shared via the various entities described in task 2. This report will be submitted within 3 months of the completion of the final glider mission.

Data Product Development: Under this subtask we will complete initial analysis of the various datasets collected across the glider deployments described in task 1. Through this effort we will apply the baseline data provided by the glider monitoring program as input to a series of analyses and products developed by our faculty and students. The specific products and analysis completed will be determined following consultation with the RMI leadership team. Potential topics include (but are not limited to):

- Mapping seasonal trends in ecologically relevant oceanographic parameters within and around existing and planned wind energy lease areas.
- Developing seasonal climatologies for carbonate chemistry by combining data collected during this proposed project with historical glider-based data.
- Developing maps that simultaneously map seawater pH and aragonite saturation state with biological metrics of interest (acoustically-determined biomass of zooplankton or small pelagic fishes, spatial overlays of commercially important shellfish habitats).
- Exploring overlap between oceanographic features and distribution of fishes and marine mammals, between marine mammal predators and their prey.

We will enlist data analysts from our Masters in Operational Oceanography program to conduct the baseline product development. They are qualified to complete this work as they are required to develop products and analyze oceanographic and ecological datasets for a specific purpose. To do this they apply data skills acquired through a mandatory series of glider and software intensive camps completed the summer before they begin their thesis work. As part of their degree requirement, they must complete a product development/data analysis task that translates large ocean and ecological datasets into knowledge that will inform decision making. Graduates from this program in 2021 completed projects that developed QA/QC and processing criteria for glider integrated sensors included in our baseline proposal including: *"Standard Operating Protocol for Sea-Bird Scientific deep ISFET-based pH sensor integrated into a Slocum Webb Glider"; and "Developing open-source analysis pipeline for a glider based Acoustic Zooplankton Fish Profiler (AZFP)"*

Given their work, students now integrated into this proposed program can build on their foundational effort to apply those developed best practices in their own analysis and or product development. In so doing, they can translate the baseline glider data provided by our data QA/QC software technician into specific products and analysis consistent with the research and monitoring objectives of the RMI. We have included funds to complete 6 product development/data analysis projects over our two-year study period. Weekly oversight by faculty (Kohut and Saba) will ensure the work is completed and included in the series of reports listed above. These data analysis and project development tasks are well aligned with the student skillsets and program requirements associated with this applied oceanographic and ecological Master's degree program. Additionally, compared to the alternative of hiring a full-time software technician to complete the same tasks, this qualified student workforce will save our overall budget $168,000.

5. Total Project Budget: $2,503,552.00

6. Resources:

The Rutgers team (Kohut and Saba) has extensive experience in glider operations for oceanographic research ranging in focus from ocean physical dynamics to ocean acidification to fisheries and marine mammals. Slocum Gliders have been operated jointly by COOL scientists and Teledyne Webb Research Corporation engineers in science experiments since 1999, transitioning to sustained deployments by the COOL Operations Center in 2003. Since then, gliders operated by COOL have logged over 300,000 km of sampling in remote places such as Antarctica, Alaska, South Africa, Brazil, Sri Lanka, Norway, and in regions closer to home including the New York – New Jersey Bight, offshore Massachusetts, Virginia, Florida and California. This expertise and experience will be applied to this project.

The Rutgers University Center of Ocean Observing Leadership Facilities

J. Kohut and G. Saba (Faculty Members of RUCOOL)

The Rutgers University (RU) Center of Ocean Observing Leadership (COOL) integrates across interdisciplinary scientific research, education and outreach and the application of an operational ocean observing system. Faculty and students comprising the scientific teams participate in collaborative research programs in which academic, industry and government partnerships are forged between physicists and biologists, between scientists and engineers, and between observationalists and modelers. The education group is the focal point for outreach activities to the K-12 community and to non-science majors within Rutgers. The Operations Center maintains a sustained coastal ocean observatory that provides real-time ocean data to the research and education groups and also serves as the training ground for students in the Master's Operational Oceanography program.

The COOL Operations Center maintains the worlds most advanced coastal ocean observatory. State-of-the-art sampling capabilities are continuously upgraded as new technologies developed and demonstrated by the research group are immediately transitioned into the operational setting of the Center. Cost-effective sustained spatial sampling of the coastal ocean is accomplished with a variety of new platforms and sensors that include: (1) the local acquisition of satellite imagery from an international constellation of thermal infrared and ocean color sensors, (2) a triple-nested multi-static HF radar network for surface current mapping and waves, and (3) a fleet of long-duration autonomous underwater gliders equipped with physical, chemical, and biological sensors. Raw datasets are shared with a variety of super-users throughout the U.S. for real-time backups, data archiving, and advanced product generation. Operational data products are produced and visualized in real time for use by scientists, educators, decision-makers and the general public.

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