PROGRESS ON AN INTEGRATIVE ENVIRONMENTAL AND ECOLOGICAL ASSESSMENT OF THE GULF STREAM CURRENT ENVIRONMENT OFF THE COAST OF CAPE HATTERAS, NC

Lindsay Dubbs[1], Michael Piehler, and Steve Lockhart
UNC Chapel Hill and UNC Coastal Studies Institute
Wanchese, NC, USA

Larisa Avens
NOAA Protected Resources Branch
Beaufort, NC , USA

Linda D'Anna
UNC Coastal Studies Institute
Wanchese, NC, USA

Matthew Waters
Auburn University
Auburn, AL, USA

Jinchun Yuan
Center of Excellence in Remote Sensing Education and Research, Elizabeth City State University
Elizabeth City, NC, USA

[1]Corresponding author: dubbs@email.unc.edu

INTRODUCTION

The North Carolina Renewable Ocean Energy Program (NCROEP) is a state funded, multi-institutional marine hydrokinetic research program established "to conceptualize, design, construct, operate, and market new and innovative technologies" that harness the ocean's energy while avoiding threats to "the health and wellbeing of the State's waters, sensitive lands, and residents [1]". The NCROEP has identified the evaluation of the Gulf Stream (GS) energy resource as one of its major research directions because of the GS's close proximity to the North Carolina (NC) coast and potential to provide substantial baseload energy [2,3]. The feasibility of harnessing the GS energy resource depends on several factors, among them, the ecological and environmental impacts of GS energy development, which is another primary research direction of the NCROEP. Our work is aimed at characterizing the GS's biogeochemistry and ecology. This baseline information will provide insights into how GS energy generation may influence the characteristics and existing ecological and human uses of the GC off the NC coast in the future. This ecological and environmental assessment is occurring in tandem with GS energy resource and economic assessments and research into technological considerations.

Previous NCROEP environmental research identified elements of the NC coastal ocean that are of concern for interaction with marine hydrokinetic energy installations, including protected marine mammals, sea turtles, and highly migratory fish species; recreational and commercial fisheries; and protected pelagic *Sargassum*, hard bottom, and coral habitats [4]. These protected elements of the marine environment that are directly addressed through the permitting process do not exist in a vacuum, and are part of a larger food web and complex ecosystem. Accordingly, our work addresses the permitted elements of the ecosystem and those that support the productivity of the GS, thereby contributing to a integrative understanding of the ecology and environment of the GS off the coast of Cape Hatteras, NC.

Characterization has focused on the large-scale distribution and biogeochemistry of different GS micro- and macroalgae communities and on the uses of the area by sea turtles, marine mammals, and humans. We also completed a series of experiments evaluating the effects of increased turbulence on pelagic *Sargassum* communities to begin to explore if changes in hydrodynamics introduced by hypothetical GS turbines would affect nutrient cycling and productivity of this ecosystem engineer [5]. Our

work relies upon collaboration between many experts with knowledge of various components of the GS ecosystem and the tools necessary to evaluate those components.

METHODS

Macroalgae distribution and abundance

The reflectance (%) spectra of *Sargassum* collected during seasonal GS sampling cruises off the coast of Cape Hatteras, NC (hereafter referred to as the study area) was measured. Reflectance spectra data were compared to remote sensing algorithms that have been used to previously map *Sargassum* distribution and extent [6].

Physicochemical and biological data collection

Seasonal variations in the physicochemical and biological characteristics of GS waters in the study area, both in the presence and absence of *Sargassum,* were monitored seasonally in 2015, 2016, and 2017. Physical, chemical and biological parameters were measured or collected for laboratory analysis and experiments (Table 1) at each of three sampling locations during each cruise.

TABLE 1. PHYSICAL CHEMICAL, AND BIOLOGICAL PARAMETERS THAT ARE REGULARLY MEASURED AT EACH SAMPLING LOCATION AND THROUGHOUT EXPERIMENTS.

Parameter	Method/Instrument
Salinity, temperature, dissolved oxygen, depth fluorescence, conductivity, pH	YSI 650 MDS logger and YSI 6600 multi parameter water quality monitor
Dissolved inorganic nutrients	Lachat quick-chem 8000 autoanalyzer
Dissolved carbon (C)	Shimadzu TOC 5000A
Particulate organic C and nitrogen	Perkin-Elmer 2400 series II CHN analyzer
Primary productivity	Light/dark bottle oxygen evolution
Phytoplankton species	Lugol's preservative& microscopy
Photosynthetic pigments	Shimadzu M 10av High Performance Liquid Chromatography
Nitrogen fixation	Acetylene reduction assay

Tagging and tracking of sea turtles

Our sea turtle tagging and tracking program includes two elements. The first element involves observing turtles and their diving behavior during seasonal GS cruises and attempting to catch, collect biological information from, and tag sea turtles that are encountered. The second research element was modeled after a recent neonate sea turtle tagging study conducted in Florida [7]. For our program, five hatchling loggerhead sea turtles were collected during excavations of nests in NC following emergence. These turtles are being reared in captivity to between 13 and 25 cm straightline carapace length (SCL) in size and weights ≥300 g. Microwave Telemetry PTT-100 9.5 g solar-powered satellite transmitters will be attached to the turtles' carapaces using a flexible acrylic-silicone-neoprene attachment and will comprise ≤5% of each turtle's weight [8]. To mitigate potential effects of increased hydrodynamic drag, tags will be positioned forward of the center of gravity and the silicone attachment will be tapered/smoothed, to reduce drag [9]. Following tag attachment, turtles will be released in the GS approximately 60 km east of Cape Hatteras within floating *Sargassum* mats.

Passive acoustic monitoring of marine mammals

Aural-M2 hydrophones (Multi-electronique) were deployed on the continental shelf slope, off the tip of Cape Hatteras in February and September 2015 in a pod also containing a CTD and ADCP. The hydrophones were retrieved from the ocean after 7 and 8-months of deployment, respectively. The sound files were recorded at a rate of 32,768 samples/s for 5 min out of every 0.5 h. The files were stored as large wav files, which are each a concatenation of 52 five-minute recordings. These sounds files were analyzed for high frequency vocalizations, including whistles and echolocation clicks, which were detected using Silbido (http://roch.sdsu.edu/Software.shtml) and a custom-developed program, respectively.

Stakeholder engagement and socio-spatial analysis

We have begun to conduct an assessment of the scope of the scientific and technical knowledge of the GS off of Cape Hatteras, NC by qualitatively interviewing stakeholders. The stakeholders of interest to our work include individuals in research, management, and policy communities who are involved in work on the continental shelf slope off the coast of NC.

Data about the stakeholders research efforts and interests are being compiled in a database. In addition, we are gathering qualitative information about the stakeholders' initial reactions to the idea of GS based energy and the types of information they would suggest collecting to better determine the effects on the environment and ecology of the GS.

RESULTS AND DISCUSSION

Macroalgae distribution and abundance

Reflectance spectra measured from *Sargassum* samples collected during seasonal cruises in November 2015, May 2016, and March 2017 showed the highest reflectance (%) in the short infrared wavelengths (>700 nm). The short infrared wavelengths were also used in remote sensing algorithms to track pelagic *Sargassum* distribution in a previous study [6]. The March

samples showed lower reflectance in the short infrared than those collected in May and November.

In the visible wavelengths (390-700 nm), *Sargassum* samples collected in November consistently showed lower reflectance (%) than in May and March, but the shapes of the spectra for the samples collected in the three different seasons were virtually identical.

The variations in spectral patterns may indicate a seasonal change in *Sargassum,* or that there are multiple sources of *Sargassum* to the study area. Analysis of reflectance spectra will continue in an attempt to distinguish seasonal patterns in reflectance and the difference between *Sargassum* distributions observed *in situ* versus those identified using remote sensing algorithms. It is important to understand *Sargassum* distribution in the study area because of the diverse biological community and nutrient cycling associated with pelagic *Sargassum* in the GS.

Physicochemical and biological data collection

The phytoplankton community associated with *Sargassum* was more abundant than that of the GS absent of *Sargassum* for five out of six cruises where *Sargassum* was present. Biomass (chl *a* concentrations) were at least 50% greater, and typically more than double those of samples from the GS where *Sargassum* was absent. In addition, the phytoplankton community associated with *Sargassum* was as, and frequently more, diverse than that of the GS community absent of *Sargassum* on all four dates for which we have algal pigment data. For all samples taken in the GS, regardless of *Sargassum* presence, diatoms, green algae and cyanobacteria were dominant communities. Dinoflagellates and cryptophytes were also present in GS samples, and dinoflagellates were consistently more abundant in samples associated with *Sargassum*.

Inorganic nutrient concentrations within *Sargassum* communities followed a similar pattern. Both DIN and SRP were higher than those of surrounding GS waters on four of six cruises when *Sargassum* was present. For both dissolved inorganic nitrogen and soluble reactive phosphorus, the exceptions, where concentrations were not higher in GS waters proximal to *Sargassum,* occurred on the June and September 2016 sampling occasions.

Our algal abundance and community composition data, supported by our inorganic nutrient data, suggest that *Sargassum* is not only important to the epibiont and macrofaunal communities associated with it, as has been reported previously [10], but may also support a unique plankton community.

Tagging and tracking of sea turtles

We have observed green (*Chelonia mydas*), loggerhead (*Caretta caretta*), and leatherback (*Dermochelys coriacea*) sea turtles in the GS on several research cruises. Observations and diving data are being shared with the Bureau of Energy Management supported Atlantic Marine Assessment Program for Protected Species to complement their aerial survey efforts and provide baseline information about the seasonal uses of the GS by sea turtles. Of note, during the September 14, 2016 GS research cruise, we sighted and captured four post-hatchling loggerhead sea turtles associated with *Sargassum*. The posthatchlings ranged from 6.5 to 9.7 cm straightline carapace length (SCL; mean = 7.7 cm +/- 1.4 cm SD); only the largest was of sufficient size to collect skin samples for genetic and stable isotope analyses and all were too small for tagging. Photographs were obtained to allow future identification using individual-specific scale patterns on the head and carapace. *Sargassum* and associated organisms in the vicinity of the turtle capture locations were also collected for stable isotope analysis, to allow investigation of trophic ecology for oceanic stage juvenile sea turtles.

Regarding the neonate sea turtle tagging program, the five post hatchling loggerhead sea turtles that were collected during excavations of nests in NC following emergence are being reared at the NC Fort Fisher Aquarium. The turtles will be tagged and released in the GS off of Cape Hatteras in June 2017.

Passive acoustic monitoring of marine mammals

From February to September of 2016, we did not observe any distinct temporal patterns in marine mammal vocalizations at the NCROEP ADCP/CTD/hydrophone mooring on the continental slope off the coast of Cape Hatteras, NC. However, we did observe a strong cluster of whistles in the 7-8 kHz frequencies, especially in the last three segments of the recordings (April-August 2015).

In addition to activity over the course of time, we are also interested in the relationships between the marine mammal vocalizations and the position of the GS. We observed a strong correlation between the duration of marine mammal click trains (per 5-min recording interval) and the bottom temperature at the mooring location. The warm GS typically flows over the mooring, and a decrease in temperatures of the water column over the mooring indicates that the GS has shifted offshore. We believe that the increase in marine mammal vocalizations with cooler temperatures above our mooring indicates a shift in the activity of marine mammals offshore,

along the western edge of the GS, as it shifts further offshore.

Stakeholder engagement and socio-spatial analysis

We have constructed an interview framework that involves contacting researchers and agency representatives conducting environmental (physical, chemical, and biological) research in the study area. Initial stakeholders of interest have been identified, and snowball is being used to find subsequent interviewees.

When interviewees are contacted, they are provided a web link to a form allowing them to provide information about the type of data they are collecting within the area of interest, the frequency and location of collection, and their collaborators. The resulting database, called the Gulf Stream off North Carolina Research Cooperative, will be available to all Cooperative participants. The goals for the database are to facilitate collaboration and reduce redundancy of research efforts. Follow-up interviews with Collaborative participants will yield qualitative information elucidating environmental and ecological concerns associated with GS-based energy.

CONCLUSIONS

Over time, our integrative analysis of the pelagic environment and ecology of the GS off the NC coast will provide a more comprehensive understanding of the distribution and function of primary producers in the GS and the use of the GS by protected species (*Sargassum*, sea turtles, and marine mammals) and humans. These baseline data will expose aspects of this dynamic and diverse area that might be influenced by the harnessing of GS energy. This research program can serve as an example to renewable ocean energy programs interested in integrating environmental assessment into all stages of ocean energy exploration and development.

ACKNOWLEDGEMENTS

We appreciate funding for this research from the NC Renewable Ocean Energy Program. The Technical Advisory Committee of the Program and former Director of the program, Dr. Billy Edge, and acting Director of the program, Dr. Mohamed Gabr have provided guidance and support for which we are incredibly grateful. Maggie Fuentes, Stephanie O'Daly, Corey Adams, Claire Johnson, Ted West, April Hall, Joanne McNeil, Shevon Valenski,
Mike Muglia, and Patterson Taylor have made valuable contributions to this research, for which we are grateful.

REFERENCES

[1] General Assembly of North Carolina 209. Session Law 2010-31, Senate Bill 897. AN ACT to modify the current operations and capital improvements appropriations act of 2009 and for other purposes.

[2] Hanson, H.P, Bozek, A., and Duerr, A. 2011. "The Florida current: A clean but challenging energy resource," EOS Transactions American Geophysical Union, **92**(4), pp. 29-36.

[3] Duerr, A. and Dhanak, M. 2012. "An assessment of the hydrokinetic energy resource of the Florida current," IEEE Journal of Ocean Engineering, **37**(2), pp. 281-293.

[4] Dubbs, L.L. Voss, C. Von Korff, B. Morton, J. Peterson, C.H. Fegley, S.R. and Piehler, M.M. 2012. "Building Capacity for Marine Hydrokinetic Energy: Atlas of Potential Synergistic and Conflicting Environmental, Ecological, and Human Use Considerations," Report to the North Carolina Renewable Ocean Energy Program

[5] Dubbs, L.L Piehler, M. and Colby, J. 2015. "An examination of pelagic *Sargassum* community primary productivity and nutrient cycling in the face of Gulf Stream based energy." *OCEANS 2015 - MTS/IEEE Washington*, Washington, DC, pp. 1-6.

[6] Gower, J. and King, S. 2008. "Satellite images show the movement of floating *Sargassum* in the Gulf of Mexico and Atlantic Ocean." Nature Proceedings<http://hdl.handle.net/10101/npre.2008.1894.1>

[7] Mansfield, K.L. Wyneken, J. Porter, W.P. and Luo, J. 2014. "First satellite tracks of neonate sea turtles redefine the 'lost years' oceanic niche." Proceedings of the Royal Society B, **281**, pp. 1-9.

[8] Mansfield, K.M. Wyneken, J. Rittschof, D. Walsh, M. Lim, C.W. and Richards, P.M. 2012. "Satellite tag attachment methods for tracking neonate sea turtles." Marine Ecology Progress Series, **457**, pp. 181-192.

[9] Jones, T.T. VanHoutan, K.S. Bostrom, B.L. Osatfichuk, P. Mikkelsen, J. Tezcan, E. Carey, M. Imlack, B. and Seminoff, J.A. "Calculating the ecological impacts of animal-borne instruments on aquatic organisms." Methods In Ecology and Evolution doi:10.1111/2041-210X.12109

[10] Coston-Clements, L., Settle, L.R. Hoss, D.E. and Cross, F.A. 1991. "Utilization of the *Sargassum* habitat by marine invertebrates and vertebrates - a review." NOAA Technical Memorandum NMFS-SEFSC-296, 32 p.