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Bigelow | Laboratory for Ocean Sciences

Bigelow Laboratory for Ocean Sciences

Final Scientific/Technical Report

Optimizing cost-effective and benchmarked industry standards to quantify nutrient bioextraction by seaweed

DE-AR0001169

Award:	DE-AR0001169
Sponsoring Agency:	USDOE, Advanced Research Project Agency – Energy (ARPA-E)
Lead Recipient:	Bigelow Laboratory for Ocean Sciences
Project Team Members:	Clarkson University, Atlantic Sea Farms, Tenj Aquarium Design + Build
Project Title:	Optimizing cost-effective and benchmarked industry standards to quantify nutrient bioextraction by seaweed
Program Director:	Dr. Nichole Price
Principal Investigator:	Dr. Nichole Price, Dr. Stephen Archer, Dr. Rachel Sipler
Contract Administrator:	John McKown, Jason Grundy, James McManus, Beth Orcutt
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Public Executive Summary

Interest in the utility of seaweed farms to mitigate coastal eutrophication, or nutrient loading, has grown commensurate with the recent rise of the farmed seaweed industry in the U.S. But economic valuation of this ecosystem service remains elusive in part because of challenges in quantifying this spatiotemporally variable biological process with reproducible and comparable metrics. Regulatory bodies that permit wastewater discharge or lease area for aquaculture farms require water quality testing and reporting of dissolved total nitrogen (N) in nearshore marine environments. These metrics must meet EPA standards for testing and reporting (e.g., Total Kjeldahl Nitrogen - TKN). However, these metrics are inherently highly variable over space and time in dynamic nearshore systems, and expensive to evaluate with sufficient breadth to constrain this variance, creating a critical bottleneck to direct quantification of farmed seaweed net uptake rates in situ.

Our research program used controlled pulse-chase laboratory experiments with a widely farmed sugar kelp species, *Saccharina latissima*, to quantify N uptake rates on the same samples, contrasting multiple methods (stable isotopes, elemental analyses, disappearance of ammonium and nitrate from the media, and simple surface-volume ratios) and explored the significance of sample storage and preparation, ontogeny, tissue type, nutrient availability, and intraspecific variation to N assimilation estimates.

We discovered that sugar kelp can uptake several forms of dissolved inorganic nitrogen (DIN) – nitrate, nitrite, and ammonium – but do so at different rates depending on the age of the seaweed, specific tissue type (greatest in vegetative growth areas), and the conditions to which they may have become acclimatized (faster if initially nutrient-starved). Up to 82.1% ± 27.3% of the biomass of sugar kelp comes

from DIN. Thus, elemental analysis may be a cost-effective path forward for verification and comparable with the more expensive isotopic approaches currently used.

Our outputs include set of recommended industry standards for analyzing nitrogen content in algal biomass, benchmarked against existing water quality testing standards, to evaluate nutrient bioextraction effectiveness of seaweed farms. We also provided, in two peer-reviewed manuscripts, evidence that farming seaweed downstream of waste water treatment facilities is more cost effective at mitigating eutrophication than facilities upgrades when kelp used as food.

Acknowledgements

The facilities team at Bigelow Laboratory was critical to addressing operationall issues in the seawater suite and environmental growth chamber. Friends of Casco Bay[1] were influential partners in helping us identify the correct levels of eutrophication and nitrogen species to explore. We'd also like to acknowledge ARPA-E for financially supporting our research, and to the Shelby Cullom Davis Charitable Fund and the Maine Technology Institute for providing cost-share, as well as all the other members of the project team:

Dr. Stephen Archer, Bigelow Laboratory for Ocean Sciences, Co-PI
Dr. Shane Rogers, Clarkson University, Co-PI
Dr. Rachel Sipler, Bigelow Laboratory for Ocean Sciences, Key Personnel
Dr. Brianna Stanely, Bigelow Laboratory for Ocean Sciences, Postdoc
Dr. Jingjing Wu, Clarkson University, Postdoc
Brittney Honisch, Bigelow Laboratory for Ocean Sciences, Senior Research Associate
Gabriella Iacono, Bigelow Laboratory for Ocean Sciences, Technician
Peter Craig, Bigelow Laboratory for Ocean Sciences, Technician

[1] The Casco BayKeeper program provided integral data on nitrogen concentration levels around seaweed farms in this region for several decades to contextualize our work. https://www.cascobay.org/

Accomplishments and Objectives

This award allowed Bigelow Laboratory for Ocean Sciences to demonstrate a number of key objectives. The focus of the project was on building a cost-effective framework for evaluating the ecosystem service of inorganic nitrogen uptake for farmed seaweed to help build and N removal offset credit industry.

A number of tasks and milestones were laid out in Attachment 3, the Technical Milestones and Deliverables, at the beginning of the project. The actual performance against the stated milestones is summarized here:

Table 1. Key Milestones and Deliverables

Tasks	Milestones and Deliverables
Task 1: Experiments to optimize sample storage and preparation 1.1 Sample storage 1.2 Sample preparation	Q2: Sample processing best practices established for subsequent experimentation **Actual Performance:** (June 1, 2020) Our team needed to acquire a new lyophilizer, to accommodate demand for this project. The extended lead time for equipment commensurate with the start of the global pandemic slowed progress, but the task was 100% only a few months after the target completion date. The protocols developed during this time period were applied thereafter.
Task 2: Experiments to identify major sources of variance in N uptake and comparing candidate proxies 2.1 Develop sample collection protocol 2.2 Tissue type 2.3 Ontogeny 2.4 Eutrophication level	Q8: Series of four experiments completed. **Actual Performance:** (January 9, 2023) Our team experienced significant delays in sourcing custom-made aquaria and affiliated parts in order to conduct experiments due to the global pandemic. Once the equipment was finally in hand, it took longer than anticipated to troubleshoot technical challenges. We requested, and were given, a no-cost extension of one year. By the end of the extension we were able to 100% complete all tasks. Deliverables included multiple oral presentations at scientific and trade conferences. Our team also executed two complex techno-economic analyses that were published in peer-reviewed journals.

Project Activities

Our project focus was to understand and quantify major contributions to variance in the measurment of dissolved inorganic nitrogen uptake by seaweed in order to discover the cheapest proxy with requisite accurage to develop a nitrogen offset credit trading market. The approach we took was to conduct a series of comparative laboratory press-pulse experiments. Our expectation was that elemental analysis could be sufficient, if our underlying hypotheses were supported. These hypotheses are that standardizing sample collection (tissue type and seaweed age) and normalizing uptake rates to historical nitrogen exposure eliminates the largest sources of variance. We were able to demonstrate that not only can elemental analysis be a valid approach, but that inorganic nitrogen removal by seaweeds is of great economic value to waste water management facilities.

Project Outputs

A. Journal Articles

Wu, J., Rogers, S. W., Schaummann, R., Higgins, C., & Price, N. (2022). Bioextractive aquaculture as an alternative nutrient management strategy for water resource recovery facilities. *Water Research, 212*, 118092.

Wu, J., Rogers, S. W., Schaummann, R., & Price, N. N. (2023). A Comparison of Multiple Macroalgae Cultivation Systems and End-Use Strategies of *Saccharina latissima* and *Gracilaria tikvahiae* Based on Techno-Economic Analysis and Life Cycle Assessment. *Sustainability, 15(15),* 12072.

B. Papers

None

C. Status Reports

Scientific assessment of climate change and its effects in Maine. Report issued 2020 by the Scientific and Technical Subcommittee of the Maine Climate Council (Dr. Price is an appointee)

Maine Won't Wait One-Year Progress Report, 2021. Report issued 2021 by the Scientific and Technical Subcommittee of the Maine Climate Council (Dr. Price is an appointee)

D. Media Reports

None

E. Invention Disclosures

None

F. Patent Applications/Issued Patents

None

G. Licensed Technologies

None

H. Networks/Collaborations Fostered

None

I. Websites Featuring Project Work Results

None

J. Other Products (e.g. Databases, Physical Collections, Audio/Video, Software, Models, Educational Aids or Curricula, Equipment or Instruments)

None

K. Awards, Prizes, and Recognition

None

Follow-On Funding

Our team was fortunate to receive additional funding from other government agencies, philanthropic foundations, and for-profit entities after the effective date of our ARPA-E Award.

Table 2. Key Milestones and Deliverables

Source	Funds Received
USDA Organic Research and Extension Initiative (OREI) grant 2021-51300-35226	$2,900,000
USDA AFRI NIFA Sustainable Agriculture Systems (SAS) grant 2021-69012-35919	$10,000,000
USDA ARS Contract 0208-32000-001-042-S	$2,200,000
Stonyfield Organic contract awarded to Bigelow Laboratory	$50,000
Farmers Advocating for Organics (Organic Valley) award to Bigelow Laboratory	$25,000
World Wildlife Fund grant to Bigelow Laboratory	$300,000