DISCLAIMER

Final Scientific/Technical Report

Assessing kelp nutrient bioextraction capacity in aquaculture farms in the US with implications for conservation and management

DE-AR00001448

Award:	DE-AR00001448
Lead Recipient:	University of Alaska Fairbanks
Project Title:	Assessing kelp nutrient bioextraction capacity in aquaculture farms in the US with implications for conservation and management
Program Director:	Dr. Schery Umanzor
Principal Investigator:	Dr. Schery Umanzor
Contract Administrator:	Kim Cox
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Public Executive Summary

This proposal aimed to assess the carbon and nitrogen bioextraction capabilities of sugar kelp farms across a broad geographic range encompassing both the East and West Coasts of the United States. To meet this objective, the project team first developed a cost-effective sampling toolkit using readily available materials and an illustrated protocol to guide kelp farmers in standardized sample collection. Farmers were trained to use the toolkit and prepare samples for shipment to the University of Alaska Fairbanks, where laboratory analyses were conducted to quantify carbon and nitrogen removal. Results were then shared with collaborating farmers, farm managers, regulatory agencies, and the general public to disseminate findings and gauge interest in the bioextraction services offered by kelp aquaculture.

The project also investigated temporal and species-specific differences in carbon and nitrogen removal as a complementary objective. This was achieved by collecting samples at three time points—60 days, 30 days prior to harvest, and at harvest—and focusing on two species: sugar kelp (*Saccharina latissima*) and ribbon kelp (*Alaria marginata*). Results showed that carbon and nitrogen removal varied depending on species, site, and sampling time, highlighting the importance of harvest timing and species selection in optimizing bioextraction outcomes.

To support implementation, the team designed a user-friendly and durable sampling toolkit, which underwent four iterations of refinement in close collaboration with participating farmers. The finalized kits were successfully deployed at 16 farm sites, including five on the East Coast and eleven in Alaska. The resulting dataset generated strong interest among kelp farmers, scientists, resource managers, and community stakeholders—particularly in Alaska, where most project efforts were concentrated. Notably, the commercial rights to the toolkit were licensed to Reed Mariculture, facilitating its broader adoption.

Overall, the project successfully achieved its goals by developing a practical and effective toolkit, collecting robust data on kelp-mediated carbon and nitrogen removal, and promoting awareness of the potential bioextraction services offered by farmed kelp.

Acknowledgements

The project PI and collaborators formally acknowledge all financial support provided by ARPA-E. The PI also acknowledges the participation of Green Wave, Woods Hole Oceanographic Institution, Oyster Wrench, Atlantic Sea Farms, Stonington Kelp Co. Blue Evolution, Seagrove Kelp Co., Native Conservancy, Kodiak Island Sustainable Sea Farm, Noble Ocean Farm, Alaska Seagreens, Alaska Sea farms, and Angie Bowers at the University of Alaska Southeast for their effort in collecting water and kelp samples. This project was also supported by NOAA Fisheries at Auke Bay Laboratories in Juneau, Alaska, the Isotope Lab, and Water Nutrient Analysis Lab at the University of Alaska Fairbanks.

Table of Contents

Accomplishments and Objectives

This award allowed the University of Alaska Fairbanks to accomplish several key objectives. The project focused on assessing the carbon and nitrogen bioextraction capabilities of sugar kelp farms in a wide geographical region, encompassing the USA's East and West Coasts**.**

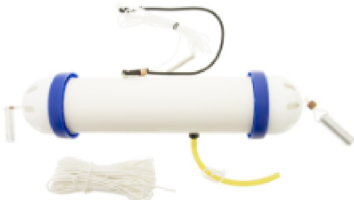
Objective 1. Develop a tissue and water sample collection toolkit for the determination of carbon and nitrogen in water and kelp tissue samples.

The complete, durable, and easy-to-use nutrient extraction toolkit (NET) was assembled and field-tested in collaboration with kelp farmers from the East and West Coasts of the US. After four iterations, the PI and collaborators approved the desirable kit. Reed Mariculture, a California-based company, has licensed a kit version. A sample list of items in the toolkit is below (Section 3: What is included in your box). The section is part of a booklet accompanying a modified NET toolkit created to collect tissue samples and environmental parameters linked to the farm sites.

Section 3. What is included in your box?

Briefcase:

This plastic case will enable you to easily transport all materials required during onboard operations.



Water sampler:

This plastic cylinder with stoppers at each end is used to collect water samples at a desired depth without the danger of mixing water samples from different depths.

Plastic bottles:

Your kit is equipped with Nalgene bottles of two different sizes (30 ml and 250 ml). Use the big bottles to pour the unfiltered water samples collected with the Niskin sampler. Use the small bottles to store your filtered water samples.

Syringe and filters:

In this kit, the 50-60 ml polypropylene syringe and non-sterile filters complement each other. The filters will be attached to the end of your syringe to filter contents as they are being forced out.

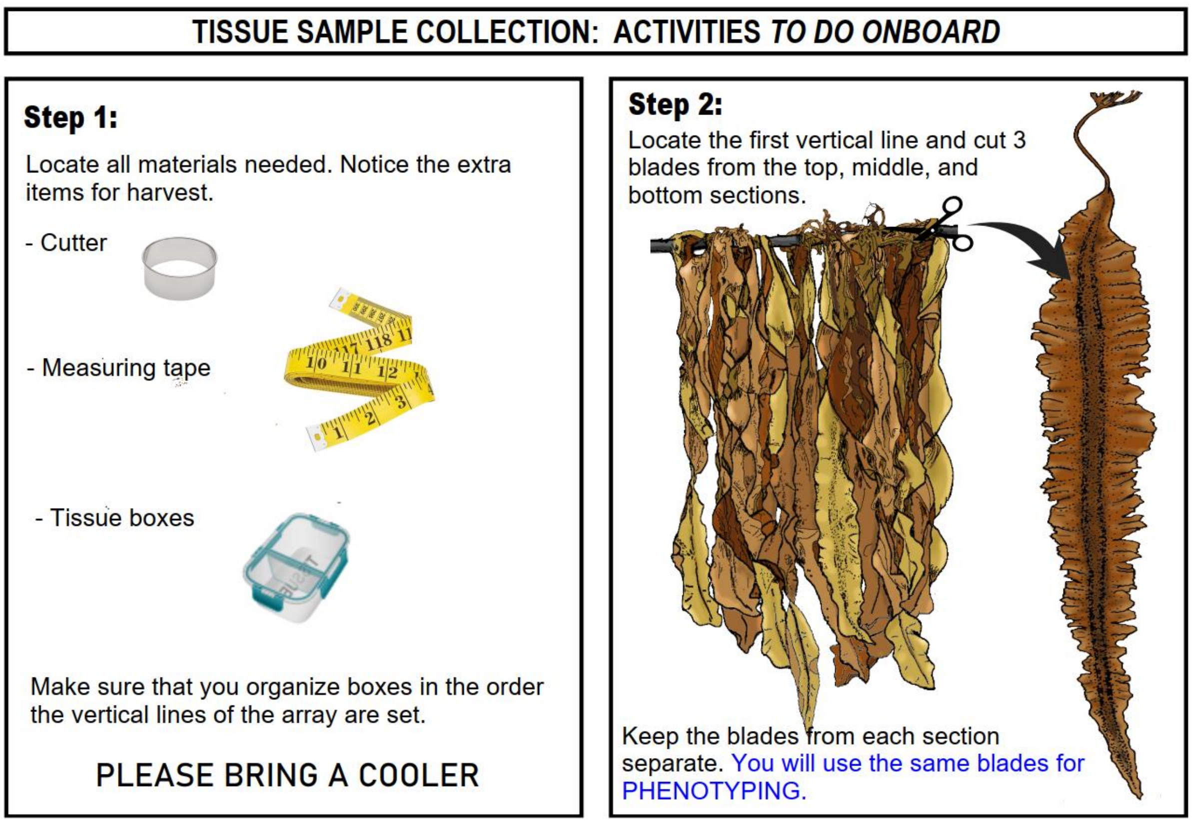
Thermometer:

The thermometer provided is alcohol based. It is encased in a rugged plastic housing to prevent major damage. The housing is positively buoyant. Secure/tie it to the Niskin water sampler to obtain temperature measurements at different depths.

Objective 2. Design an illustrated protocol integrating field and toolkit elements.

The graphic protocol consists of four pages (8.5"x 14") with instructions, including images and limited key text. It has two parts: the first describes field or onboard procedures for collecting tissue and water samples, and the second describes on-land sample storage and shipping procedures to the pertinent processing labs. A final version was achieved after four or five iterations with farmers.

The complete NET protocol is as follows:

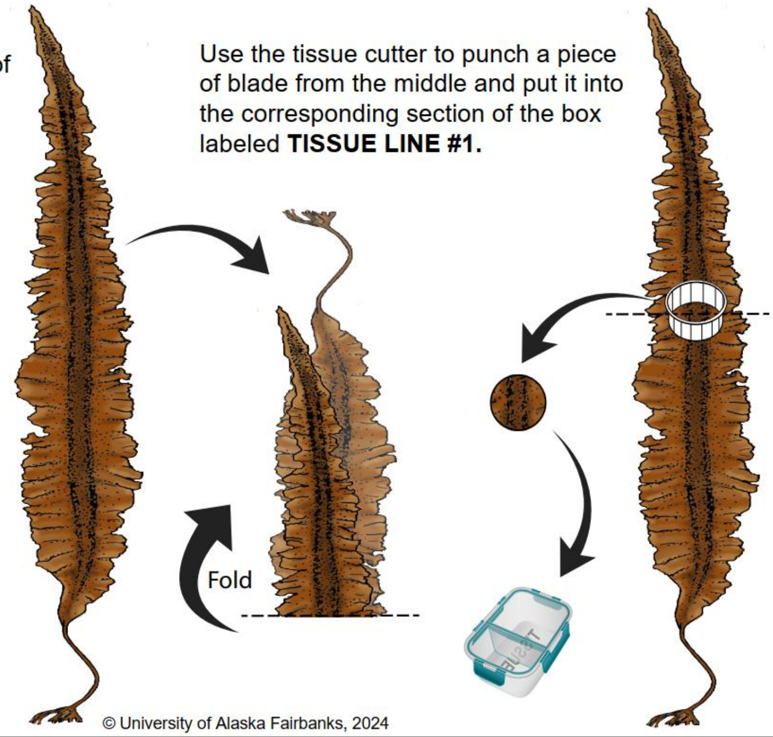


Step 3:

Fold one blade and find the middle of it

Boxes for line #1

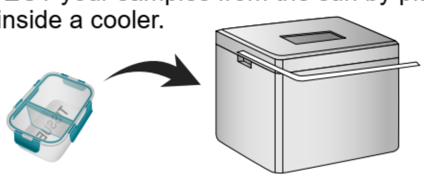
Use the tissue cutter to punch a piece of blade from the middle and put it into the corresponding section of the box labeled **TISSUE LINE #1.**



See Step 4 on next page...

Step 4:

PROTECT your samples from the sun by placing them inside a cooler.

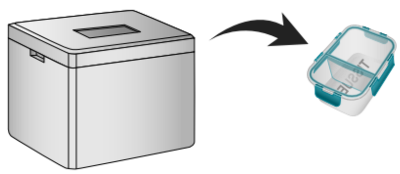


<u>REPEAT</u> these steps for all blades, making sure samples are placed in the right section of the corresponding box. At the end you should have 9 circles for line #1.

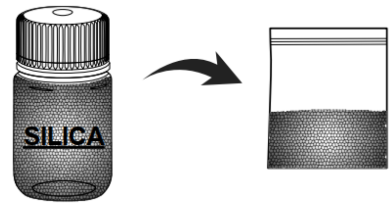
<u>REPEAT</u> these steps for the other three lines. At the end you should have 36 circles, organized by line number and section.

ACTIVITIES *TO DO ON LAND*

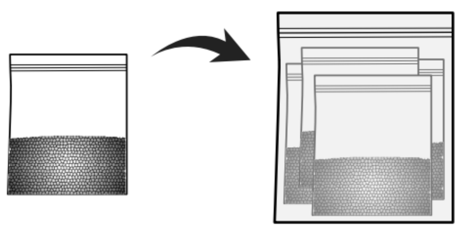
Step 1:
Take the tissue samples out of the cooler and pat-dry each one with the paper towels provided.



Step 2:
Add one to two capful of silica to the prelabeled bags.



Step 3:
Store all bags inside a bigger bag and keep them in a dry place until shipping.



Each bag is labeled to hold the 3 samples you place in each compartment of the tissue boxes. PLEASE make sure that the label in the compartment and bags correspond.

Objective 3. Determine productivity and nitrogen (N) and carbon (C) removal by kelp farms.

Comparisons of tissue nitrogen and carbon content, carbon-to-nitrogen (C:N) ratios, biomass yield, and total extraction outputs were conducted across kelp farms located in Southport (ME), Portsmouth (NH), Block Island (RI), Stonington (CT), and Thimble Island (CT) in New England, as well as Woody Island in Alaska. These farms were sampled over two consecutive farming seasons (2019–2020 and 2020–2021). Additionally, two farms in Kodiak, Alaska, were sampled over two years between 2020 and 2022.

Results revealed significant differences across farms and years. Some sites reported reduced biomass yields, which were partly attributed to the COVID-19 lockdowns that decreased nutrient inputs in certain areas, such as Long Island Sound. Intra-site comparisons also suggested that harvest timing varied among locations. For instance, when harvesting typically occurs, kelp harvested toward the end of May often exhibited lower tissue nitrogen and higher carbon content, indicating reduced biomass quality.

These findings are critical for evaluating whether a given farm acts as a carbon source or sink at the time of harvest and can help optimize farm management practices for both productivity and ecological benefits.

Supplementary objectives

Objective 4. Assess differences in tissue nitrogen and carbon content between farmed sugar kelp and ribbon kelp grown in common gardens.

Data revealed significant differences between sugar kelp (Saccharina latissima) and ribbon kelp (Alaria marginata) in both tissue nitrogen (%N) and carbon (%C) content, reflecting distinct patterns in nitrogen uptake and utilization between the two species. The results also indicated that optimal harvest timing varies by species. In particular, ribbon kelp exhibited peak nitrogen content in April—earlier than the typical May harvest—suggesting that adjustments in harvest schedules may improve biomass quality.

This objective led to the publication of two peer-reviewed articles. The first, Umanzor and Stephens (2023), evaluated the nutrient and carbon removal capacities of A. marginata and S. latissima cultivated in common gardens in Alaska. The study highlighted species-specific differences in nitrogen and carbon content, emphasizing the need to tailor kelp farming strategies based on species-specific nutrient dynamics.

Umanzor, S., & Stephens, T. (2023). Nitrogen and Carbon Removal Capacity by Farmed Kelp *Alaria marginata* and *Saccharina latissima* Varies by Species. Aquaculture Journal, 3(1), 1–6. https://doi.org/10.3390/aquacj3010001

The second publication, Stephens et al. (2024), investigated whether seawater nitrogen concentrations can reliably predict the baseline composition of farmed kelp. The findings have important implications for optimizing harvest timing and improving the nutritional quality of kelp biomass.

Stephens, T.; Li, Y.; Yarish, C.; Rogers, M.C.; Umanzor, S. Does Seawater Nitrogen Better Predict the Baseline Farmed Yield for Sugar Kelp (*Saccharina latissima*) Rather than the Final Yield? Phycology 2024, 4, 370-383. https://doi.org/10.3390/phycology4030020

Objective 5. Assess the effect of sporophyte density per area on tissue nitrogen and carbon content.

This assessment involved outplanting Alaria marginata on cultivation lines spaced at intervals of 1, 2, 3, 4, and 6 feet to evaluate the effects of spacing on tissue nitrogen content. Results showed that blades grown at the closest spacing (1 ft) had tissue nitrogen concentrations approximately 0.7% lower than those grown at the widest spacing (6 ft). While this nearly 1% difference suggests a potential influence of spacing on nitrogen assimilation, the tissue nitrogen levels across all treatments remained within expected ranges and did not indicate nutrient limitation. Furthermore, carbon-to-nitrogen (C:N) ratios for all treatments were below 20, which supports the conclusion that kelp blades maintained a healthy physiological state regardless of line spacing.

Key tasks and milestones were outlined in Attachment 3: Technical Milestones and Deliverables at the outset of the project. Below is a summary of actual performance against these predefined milestones.

Table 1. Key Milestones and Deliverables.

Tasks	Milestones and Deliverables
Task 1: Design and test the toolkit and protocol 1.1 Design and test the toolkit in controlled and field conditions 1.2 Design an illustrated protocol 1.3 Send the toolkit and protocol to kelp farmers.	Q1: One effective sample collection kit and protocol ready to use. **Actual Performance:** (7/23/2021) After four iterations with farmers, the final version of the Nutrient Extraction Toolkit (NET) was completed.
Task 2: Conduct training and workshops 2.1 Train farmers on how to use the toolkit to collect samples 2.2 Modify the toolkit and protocols based on farmers' insight 2.3 Disseminate results through workshops and conferences	Q1: Propose our toolkit and protocol as a standard procedure. **Actual Performance:** (1/4/2022) Farmers prefer NET as the collection set for tissue and water sampling. However, given the lack of revenue systems for nitrogen and carbon removal, NET was of limited use outside research scenarios. However, Green Wave uses a version of the kit for its climate program with farmers. A modified

	version of the kit is currently being used for site assessments.
Tasks	**Milestones and Deliverables**
Task 3. Determine productivity & nitrogen (N) and carbon (C) removal 3.1 Process tissue and water samples 3.2 Data analysis	Q1: Collect and process 100% of the projected samples. **Actual Performance:** (11/30/2021) All complete sets of samples (n >780) were processed and analyzed for carbon and nitrogen determination. A subset of the data and outputs was published in Aquaculture Journal in 2022. The final set will be published within the next months.

Project Activities

The University of Alaska Fairbanks led a project to evaluate the carbon and nitrogen bioextraction potential of sugar kelp farms located on both the East and West Coasts of the United States. As part of this effort, the team developed a Nutrient Extraction Toolkit (NET) to standardize sample collection and processing, along with an illustrated protocol to guide field implementation. The project successfully produced a fully functional NET toolkit and an improved methodology for collecting and analyzing kelp samples.

Comparative assessments of kelp farms in New England and Alaska revealed significant differences in biomass yield, tissue nitrogen and carbon content, and carbon-to-nitrogen (C:N) ratios across both sites and years. These findings underscore the influence of geographic and environmental variability on the nutrient dynamics of sugar kelp. The resulting data provided key insights into the productivity and bioextraction capacity of sugar kelp farms, contributing to a broader understanding of their role in nutrient cycling and ecosystem services across diverse coastal regions.

Project Outputs

A. *Journal Articles*

- Umanzor, S., Good, M., Bobrycki, T., Kim, J.K., and Yarish, C. (2022). Building community capacity in site suitability assessments and determination of nutrient removal related to kelp mariculture. World Aquaculture Society Magazine, September issue.

- Umanzor, S., & Stephens, T. (2023). Nitrogen and Carbon Removal Capacity by Farmed Kelp *Alaria marginata* and *Saccharina latissima* Varies by Species. Aquaculture Journal, 3(1), 1–6. https://doi.org/10.3390/aquacj3010001

- Stephens, T.; Li, Y.; Yarish, C.; Rogers, M.C.; Umanzor, S. Does Seawater Nitrogen Better Predict the Baseline Farmed Yield for Sugar Kelp (*Saccharina latissima*) Rather than the Final Yield? Phycology 2024, 4, 370-383. https://doi.org/10.3390/phycology4030020

B. *Media Reports*

Nutrient Extraction by Farmed Kelp Could Make Cents.
https://www.greenwave.org/holdfast- blog/nutrient-extraction-by-farmed-kelp-could-make-cents

Nutrient Extraction Toolkit (NET) & Quantification and Projection of Nutrient Removal.

https://www.uaf.edu/oipc/companies/UAF%20Technology%20%20Nutrient%20Extraction%20Toolkit%20and%20Quantification%20and%20Projection%20of%20Nutrient%20Removal.pdf

Kelp help: Study shows clean-water benefits of kelp.
https://www.kstk.org/2023/02/06/kelp-help- study-shows-clean-water-benefits-of-kelp/

An overlooked opportunity for kelp farms to double as pollution cleanup sites.
https://www.anthropocenemagazine.org/2023/02/an-overlooked-opportunity-for-kelp-farms-to- double-as-pollution-cleanup-sites/

Kelp Farms Could Help Reduce Coastal Marine Pollution
https://www.labmanager.com/kelp- farms-could-help-reduce-coastal-marine-pollution-29607

C. Networks/Collaborations Fostered

UAF- kelp farmers data collection network

D. Awards, Prizes, and Recognition

IDEAs Award (2022) https://www.uaf.edu/oipc/inventors/ideas/

Follow-On Funding

Additional funding committed or received from other sources (e.g., private investors, government agencies, nonprofits) after the effective date of ARPA-E Award.

Table 2. Follow-On Funding Received.

Source	Funds Committed or Received
EVOS Trustee Council	$800,000.00
Center ICE, UAF	$15,600.00