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Short communication

Nitrogen and carbon removal capacity by farmed kelp varies by species

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Abstract: An increasing body of evidence shows that seaweeds, including kelp, can be used as a tool to neutralize or remove excess nutrients and metals from the water column. Here we report on a preliminary field assessment showing potential nutrient and carbon removal differences by sugar kelp and ribbon kelp grown in common gardens. Seawater and tissue samples were collected systematically from two farms in Alaska. Results show differences between % N and % C content between ribbon kelp (*Alaria marginata*) and sugar kelp (*Saccharina latissima*). Results also show that tissue nitrogen in ribbon kelp varies sharply due to nitrogen availability in the water column. In contrast, the percentage of tissue N in sugar kelp remains comparatively stable. Our outcomes provide insight into potential differences in nutrient removal and harvest timing for different kelp species.

Keywords: *Alaria marginata*; common garden; mariculture; ribbon kelp; sugar kelp; *Saccharina latissima*

1. Introduction

Nutrient pollution in coastal systems caused by human activity can significantly impact marine life and human health [1-2]. The threats posed by eutrophication include reduced water clarity, toxic algal events, enhanced bacterial activity, and oxygen depletion that have additive or synergistic effects resulting in habitat degradation and economic loss [3-4]. In the United States, the Clean Water Act (CWA) mandates that each state develops a program to monitor and report on the quality of its waters [5]. In 2020, the Alaska Department of Environmental Conservation reported 69 water bodies as impaired (i.e., exceeding the amount or load of specific pollutants that the water can receive before falling under the standard), with 16 representing coastal systems. These systems are affected by high loads of urban sewage, domestic runoff, or fisheries waste disposal [6].

An increasing body of evidence shows that seaweeds, including kelp, can be used as a tool to neutralize or remove excess nutrients and metals from land-based and coastal finfish aquaculture, as well as urban, industrial, and agricultural runoff from coastal systems [7-11]. Studies also suggest that kelp farming can modulate carbon cycling, potentially offsetting effects by increased atmospheric CO2 [12-17]. Seaweed farming, specifically kelps, is a nascent maritime industry in Alaska. It focuses mainly on the farming of *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Alaria marginata* (ribbon or winged kelp). Aside from offering a slate of opportunities to boost fisheries, create jobs, and increase food security, kelp farming could accelerate nutrient removal and assist in managing coastal systems. Here we report on a preliminary field assessment showing potential nutrient and carbon removal differences by sugar kelp and ribbon kelp grown in common gardens.

2. Materials and Methods

Field assessments on the potential of sugar kelp and ribbon kelp to remove dissolved carbon and nitrogen from the water column were conducted in Southeast and Southcentral Alaska. Seawater and tissue samples were collected systematically from a commercial common garden in Doyle Bay (W Prince of Wales Island), and opportunistically from an experimental common garden in Prince William Sound (water samples n = 3; tissue samples n = 5, per species per garden). All samples were collected using Nutrient Extraction Toolkits, NET© (Umanzor et al. submitted), between March and May 2021.

Water samples were collected in triplicate (250 ml /sample) at 2 m from the surface using a hand-deployed horizontal water sampler. Samples were stored in HDPE bottles and maintaned in cool, dark conditions during transport to shore, after which they were frozen (-20 °C), and then shipped to the Mariculture Laboratory at the University of Alaska Fairbanks (UAF) in Juneau. Upon arrival, samples were thawed and immediately filtered through a 0.45 µM syringed filters (25-µM diameter, GF/C Whatman) for processing at the International Arctic Research Center using a SEAL Analytical QuAAtro39 segmented flow autoanalyzer to obtain the concentration of nitrate, nitrite, ammonium, phosphorus, and silicate.

Tissue samples from Doyle Bay were collected from the tip, center, and basal sections of the blades using a corer (5-cm diameter), while those from Prince William Sound were collected only from the center of the blades. All tissue was pat-dried with absorbent paper and placed in silica beads for shipping to the processing laboratories in Juneau. Upon arrival, samples were screened to ensure the absence of fungal development and oven-dried at 40 °C for 60 min. Once samples were completely dried, we ground and prepared them for C and N elemental analysis. C and N determination was conducted by combustion at the Alaska Stable Isotope Facility, UAF.

Boxplots were constructed to visually analyze the distribution of C and N concentrations in the tissue per kelp species and common garden. One-way Analysis of Variance were conducted to explore differences in tissue C and N between sugar kelp and ribbon kelp.

3. Results

The concentration of nutrients in the water column at Doyle Bay showed an overall decrease between March and May when kelp was harvested. Regardless of the relatively low levels of nitrate recorded in May at Doyle Bay, nutrient availability was higher than that in Port Gravina (Table 1).

Table 1. Nutrient concentration at two different kelp common gardens in SE and SC Alaska.

Doyle Bay	Nitrate (µM)	Nitrite (µM)	Phosphate (µM)	Silicate (µM)	Ammonium (µM)

March	5.66	0.11	0.7	12.09	0.42
April	2.25	0.09	0.4	1.39	0.61
May	0.64	0.01	0.09	0.6	0.49
Port Gravina					
May	0.21	0.01	0.07	0.4	0.3

The Analysis of Variance assessing differences between ribbon kelp and sugar kelp in Doyle Bay revealed that both species have significantly different %N and %C content ($P < 0.001$; Table 2; Figure 1), with ribbon kelp having a higher percentage of both (87.5% higher N, 29.8% higher C). Visual comparisons between ambient seawater nutrients (Table 1) and the boxplots (Figures 1A, 2A) show that tissue nitrogen in ribbon kelp varies as a function of nitrogen availability in the water column.

However, this mirrored response was not observed in sugar kelp, which maintained an average tissue concentration of approximately 0.75 %N in April and May despite significant nutrient fluctuation (Figure 1A and 1B). Changes in C:N ratios observed over time correspond to changes in nitrogen availability in the water column Figure 1C. Similarly, the boxplots from Port Gravina show that the mean %N and %C in ribbon kelp tissues are higher than in sugar kelp (Figure 2).

Table 2. Differences in the percent nitrogen, percent carbon, and carbon to nitrogen ratio in tissues as a function of kelp species of using one-way Analysis of Variance.

April				
% nitrogen	DF	MS	F-value	P-value
Species	1	24.861	370.7	< 0.001
residuals	28	0.067		
% carbon				
Species	1	194.06	39.33	< 0.001
residuals	28	4.93		
C:N				
Species	1	2786.1	156.8	< 0.001
residuals	28	17.8		
May				
% nitrogen	DF	MS	F-value	P-value
Species	1	0.907	17.1	< 0.001
residuals	27	0.053		
% carbon				
Species	1	576.8	94.47	< 0.001
residuals	27	167.9		
C:N				

Species	1	0.06	0.001	0.972
residuals	27	44.63		

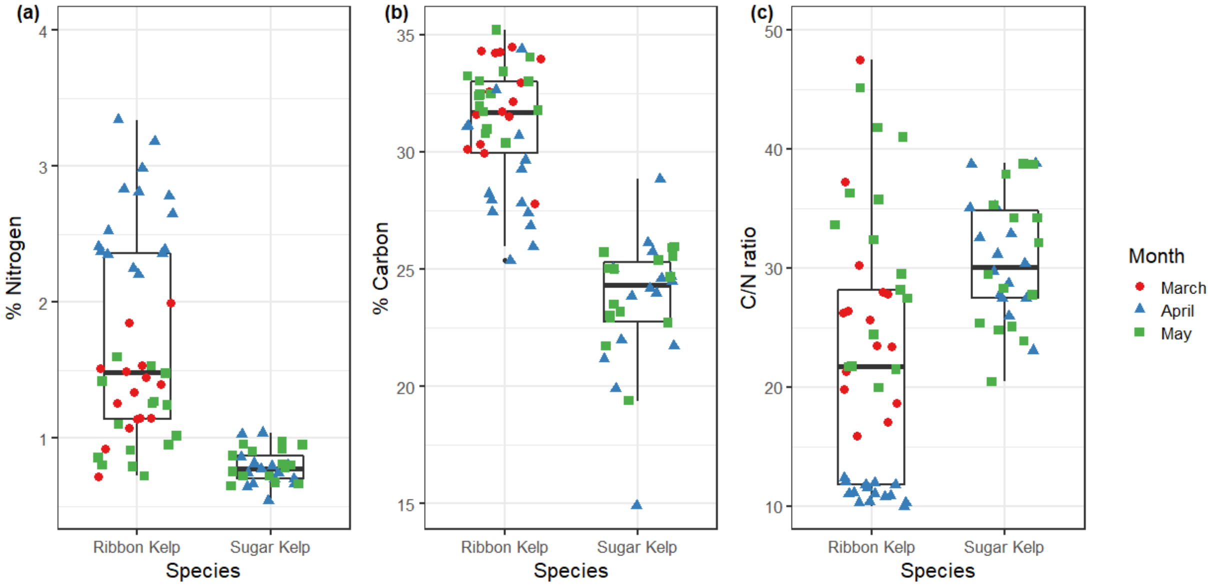

Figure 1. Tissue %N (a), %C (b), and C:N (c) ratio in ribbon kelp (*Alaria marginata*) and sugar kelp (*Saccharina latissima*) from a commercial common garden in Doyle Bay, AK, 2021.

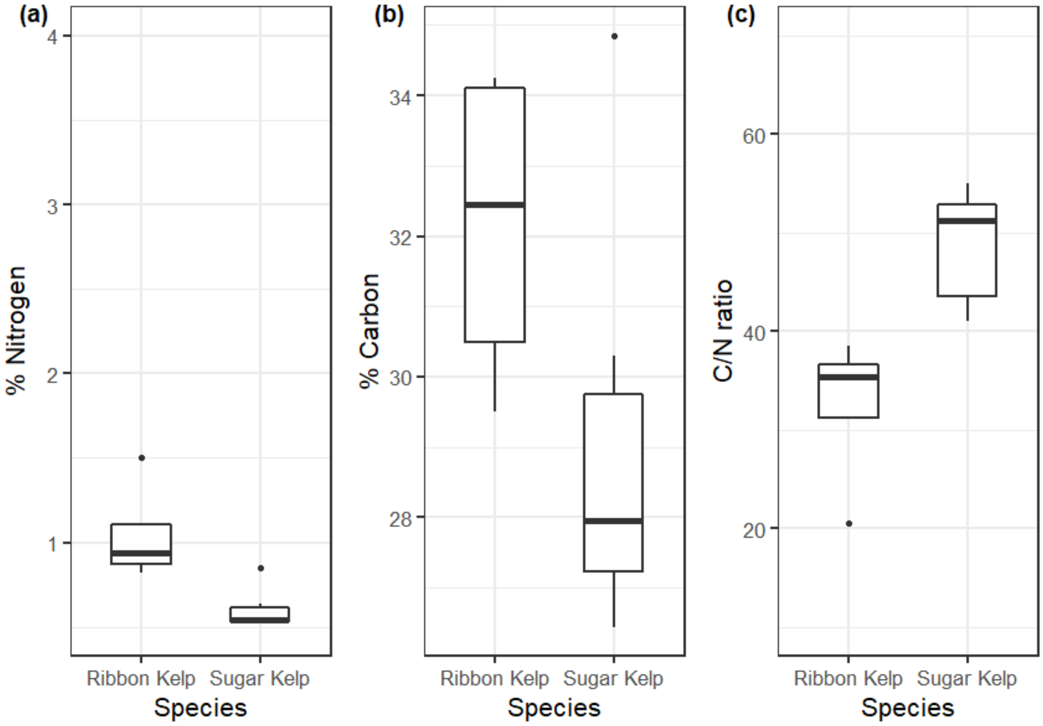

Figure 2. Tissue %N (a), %C (b), and C:N (c) ratio in ribbon kelp (*Alaria marginata*) and sugar kelp (*Saccharina latissima*) from an experimental common garden in Port Gravina, AK, 2021.

4. Discussion

Assessments of the contributions that kelp farming may have on removing excess nutrients and carbon from coastal waters suggest a net positive removal strategy [7, 18-19]. If developed with an ecosystem vision (see [20]), kelp farming would align with an ecological approach to managing coastal waters locally. Using kelp farming as a nutrient and carbon removal tool exploits the metabolic requirements of kelp to deliberately treat nearshore waters experiencing nutrient pollution, carbonate limitation, and localized acidification [21-22]. Considering that both species were cultivated in common gardens, our preliminary results suggest that ribbon kelp and sugar kelp have different metabolic requirements and hence, different removal capacities. Boxplot visual comparisons show that tissue nitrogen in ribbon kelp varies as a function of nitrogen availability in the water column, a widely supported finding [23-26].

Changes observed over time in the carbon to nitrogen ratios of *A. marginata* and *S. latissima* correspond to changes in nitrogen availability in the water column and what appears to be intrinsic metabolic requirements of ribbon and sugar kelp [27]. These results align with a study conducted in the Bay of Fundy, Canada. Here the weight of elemental nitrogen, phosphorus, and carbon were compared between winged kelp (*Alaria esculenta*) and sugar kelp (*S. latissima*) to determine nutrient removal ratios in salmon (*Salmo salar*) IMTA systems. In that study, authors describe *A. esculenta* as having almost twice the nutrient removal capacity per wet weight than *S. latissima* [10]. However, the expected successes in removing excess nutrients are modulated not only by seaweed species, but also by the interplay of species with their environment. While *A. esculenta* removed nearly twice the nutrients as ***S. latissima*** by weight, ***S. latissima*** grew more densely in the same environment so that the effective removal by the *A. esculenta* crop was closer to 1- or 1.5-fold rather than 2-fold. This highlights the importance of understanding site characteristics relative to species selection. We did not quantify density in this study. Still, it is important to note that harvested ribbon kelp biomass in Doyle Bay was 48.3% lower than harvested sugar kelp biomass (per meter of cultivation line).

Interestingly, biomass accumulation was 76.3% higher for ribbon kelp until mid-April (transition from replete to limited ambient nitrogen), after which ribbon kelp tissues began to lose pigmentation, and frond growth appeared to halt while erosion increased. It is possible that seed quality bolstered early ribbon kelp growth, but the crop's apparent response in late April and May are strong physiological indicators of nitrogen stress [see 28-29]. These indicators were minimal for adjacent sugar kelp, implying that ambient nitrogen was not limiting enough to affect the metabolism (see seasonal comparison in [28-29]) of sugar kelp and its nutrient removal capacity, where ribbon kelp's higher nitrogen metabolic demand becomes apparent.

For now, our outcomes provide insight into potential differences in harvest timing for different kelp species. They also highlight the relevance of monitoring nitrogen availability in the water column to select suitable farm sites. It is key to acknowledge that the reach of our results is limited in space and time. To address this limitation, we will increase the number of common gardens assessed and replicate this effort at the farm sites examined here to evaluate differences across farming seasons.

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