



Communication

# Nitrogen and Carbon Removal Capacity by Farmed Kelp *Alaria marginata* and *Saccharina latissima* 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 in 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 the %N and %C content between *Alaria marginata* and *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 [3–7]. 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 [8]. Multiple programs and techniques, including point sampling and satellite imaging, are implemented to achieve monitoring goals [9,10]. In 2020, the Alaska Department of Environmental Conservation reported 69 bodies of water as impaired—i.e., exceeding the amount or load of specific pollutants that the water can receive before falling under the standard—with 16 categorized as coastal systems. These systems are affected by high loads of urban sewage, domestic runoff, or fisheries waste disposal [11].

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 [12–16]. Studies also suggest that kelp farming can modulate carbon cycling, potentially offsetting effects by increased atmospheric CO<sub>2</sub> [17–22]. Seaweed farming, specifically of kelps, is a nascent maritime industry in Alaska. The industry is currently active in farming *Saccharina latissima* (sugar kelp) and *Alaria marginata* (ribbon kelp) at scale, with great interest in learning how to scale and *Nereocystis luetkeana* (bull kelp) as a commercial crop. Aside from offering a slate of opportunities to boost fisheries, create jobs, and increase food security, kelp farming could accelerate nutrient removal to assist in regenerative management of nutrient cycles in coastal systems. Here we report on a preliminary field assessment showing potential nutrient and carbon removal differences in sugar kelp and ribbon kelp grown in common gardens.



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## 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 Alaska and Southcentral Alaska. Seawater ( $n = 3/\text{month}$ ) and tissue samples ( $n = 5/\text{month}$ ) were collected systematically from a commercial common garden in Doyle Bay (Prince of Wales Island) once per month in March, April, and May 2021, and opportunistically from an experimental common garden in Port Gravina (Prince William Sound) in May 2021, only. All samples were collected using Nutrient Extraction Toolkits, NET<sup>®</sup> [23].

Seawater samples were collected in triplicate (250 mL/sample) at a 2 m depth from the surface using a hand-deployed horizontal water sampler. The samples were filtered through 0.45  $\mu\text{M}$  syringed filters (25- $\mu\text{M}$  diameter, GF/C Whatman) and stored in HDPE bottles and maintained in cool, dark conditions during transport to shore, after which they were immediately frozen ( $-20\text{ }^{\circ}\text{C}$ ) and shipped to the Mariculture Laboratory at the University of Alaska Fairbanks (UAF) in Juneau. Upon arrival, samples were thawed and filtered again for processing at the International Arctic Research Center using a SEAL Analytical QuAAtro39 segmented flow autoanalyzer ( $\pm 0.5\%$  measurement error) to obtain the concentration of nitrate, nitrite, ammonium, phosphorus, and silicate. Replicates for seawater reference materials were routinely ran to ensure the accuracy of all readings.

All tissue samples were collected using a 5 cm diameter leaf corer. For each kelp replicate collected in Doyle Bay, three sub-samples were collected per blade (from the tip, middle, and basal sections). In Port Gravina, tissue samples were collected from the middle section of the blade (halfway between distal tip and basal meristem) for each replicate, only. All tissue samples were 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  $40\text{ }^{\circ}\text{C}$  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. Standard samples and replicates of the field samples were run at ten-sample intervals to ensure accuracy and consistency of measurements.

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 (ANOVA) tests 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 as the season progressed from March to May, when the kelp crops were harvested. Nutrient availability in Port Gravina was lower than that recorded in Doyle Bay in May (Table 1).

**Table 1.** Nutrient concentrations (+/- SD) at kelp common gardens in Doyle Bay, Prince of Wales Island, AK (both *Alaria marginata* and *Saccharina latissima* cultivated in the site).

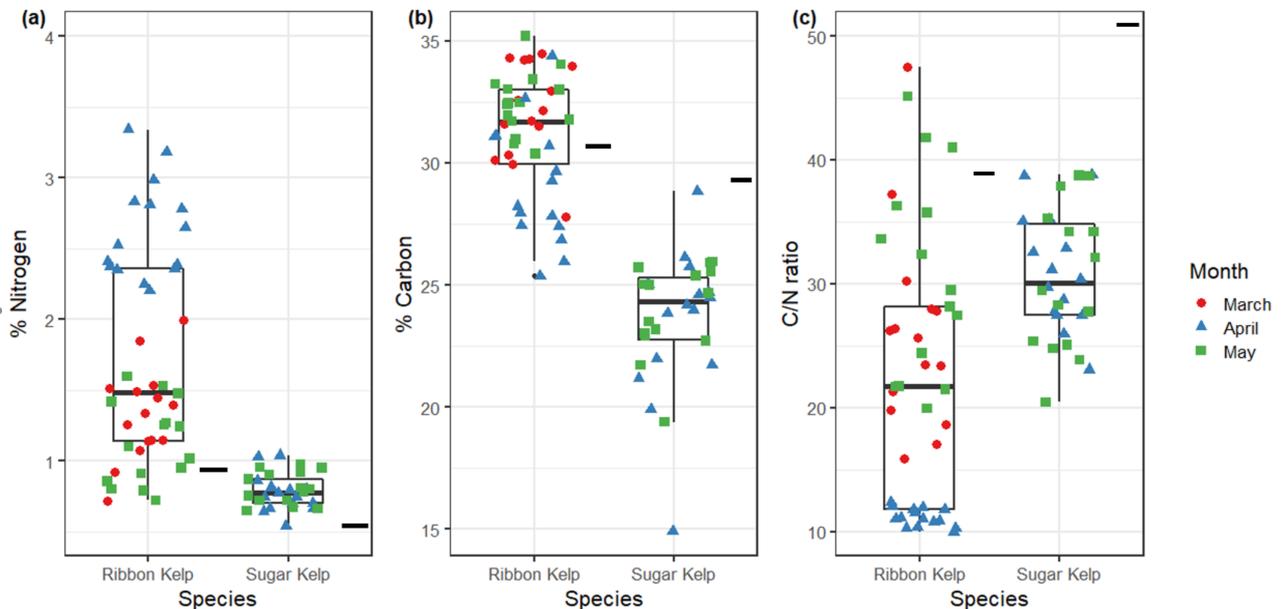
Doyle Bay	Nitrate ( $\mu\text{M}$ )	Nitrite ( $\mu\text{M}$ )	Phosphate ( $\mu\text{M}$ )	Silicate ( $\mu\text{M}$ )	Ammonium ( $\mu\text{M}$ )
March	$5.66 \pm 1.73$	$0.11 \pm 0.02$	$0.70 \pm 0.10$	$12.09 \pm 1.43$	$0.56 \pm 0.04$
April	$2.25 \pm 0.08$	$0.09 \pm 0.005$	$0.40 \pm 0.02$	$1.39 \pm 0.16$	$0.61 \pm 0.08$
May	$0.64 \pm 0.03$	$0.01 \pm 0.005$	$0.09 \pm 0.04$	$0.60 \pm 0.04$	$0.49 \pm 0.05$
Port Gravina					
May	$0.21 \pm 0.03$	$0.01 \pm 0.00$	$0.07 \pm 0.01$	$0.40 \pm 0.30$	$0.30 \pm 0.04$

The One-way Analysis of Variance (ANOVA) tests 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). Across the months observed, ribbon kelp tissues had a higher percentage of both elements; nitrogen was 87.5% higher

and carbon was 29.8% higher. The ANOVA tests assessing differences in the C:N ratio between ribbon kelp and sugar kelp in Doyle Bay revealed that mean C:N content was significantly different in April ( $p < 0.001$ , Table 2), where the ratio was lower for ribbon kelp. The mean ratios were statistically similar in May ( $p = 0.972$ , Table 2; see Figure 1).

**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. DF = Degrees of Freedom, MS = Mean Square.

April				
	DF	MS	F-value	p-value
% nitrogenSpecies	1	24.861	370.7	<0.001
residuals	28	0.067		
% carbonSpecies	1	194.06	39.33	<0.001
residuals	28	4.93		
C:NSpecies	1	2786.1	156.8	<0.001
residuals	28	17.8		
May				
	DF	MS	F-value	p-value
% nitrogenSpecies	1	0.907	17.1	<0.001
residuals	27	0.053		
% carbonSpecies	1	576.8	94.47	<0.001
residuals	27	167.9		
C:NSpecies	1	0.06	0.001	0.972
residuals	27	44.63		



**Figure 1.** Tissue %N (a), %C (b), and C:N ratio (c) in *Alaria marginata* and *Saccharina latissima* from a commercial common garden in Doyle Bay, Prince of Wales Island, AK, 2021. The short black bar next to the jittered data points shows the average values that were measured for Port Gravina, AK, in May 2021.

Similarly, the boxplots from Port Gravina show that the mean %N and %C in ribbon kelp tissues are higher than those recorded in sugar kelp (Figure 1). We do not, however, have sufficient data from Port Gravina to run statistical comparisons for %N, %C, and C:N.

Visual comparisons between ambient seawater nutrients (Table 1) and the boxplots (Figure 1a) suggest that tissue nitrogen in ribbon kelp varies as a function of nitrogen availability in the water column. Likewise, changes in C:N ratios observed over time

correspond to changes in nitrogen availability in the water column (Figure 1c). We do not have adequate data to determine whether this mirrored response is observed in farmed sugar kelp.

#### 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 [12,24,25]. Kelp farming, therefore, lends itself as an ecological or ecosystem approach to manage coastal waters locally (see [26]). Using kelp farms as nutrient and carbon removal tools exploits the metabolic requirements of kelp to deliberately treat nearshore waters that may be subject to nutrient pollution, carbonate limitation, and localized acidification [27,28]. Considering that both species observed in this study were cultivated in common gardens, our preliminary results suggest that *Alaria marginata* and *Saccharina latissima* have different metabolic requirements and, hence, that the removal capacity for nitrogen and carbon are species-specific. 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 in the literature [29–32].

Changes observed over time in the C:N ratios of *A. marginata* and *S. latissima* correspond to changes in nitrogen availability in the water column and what appears to be their intrinsic metabolic requirements [33]. These results align with a study conducted in the Bay of Fundy, Canada, where 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 [15]. In that study, authors describe *A. esculenta* as having almost twice the nutrient removal capacity per unit of wet weight than *S. latissima*.

The expected successes in removing excess nutrients are modulated not only by the seaweed species, however, but also by the interplay between the species and their environment. While *A. esculenta* removed nearly twice the amount of 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 despite nitrogen and carbon being 87.5% and 29.8% higher in *A. marginata* compared to *S. latissima*, respectively, the harvested biomass for *A. marginata* was 48.3% lower than that harvested for *S. latissima* in Doyle Bay per same effort. This may suggest that *A. marginata* is a more effective species for removing nitrogen in Doyle Bay and that *S. latissima* is more effective at removing carbon when all biomass is considered.

While the harvested biomass for *S. latissima* was higher (standardized by effort), the initial accumulation of biomass was 76.3% higher for *A. marginata* until mid-April in Doyle Bay, at about the time that ambient nitrogen concentrations transitioned from replete to limited. After mid-April, the tips of *A. marginata* blades began to lose pigmentation, the blades lightened in color, and frond growth slowed while erosion at the tips of the blades increased. Such responses are typically visual indicators of nitrogen stress (see [34,35]). These indicators were minimal for the adjacent farmed *S. latissima*, highlighting its lower physiological demand for nitrogen and ability to remove carbon when ambient nitrogen is limited (see seasonal comparison in [34,35]).

As such, the work presented here also informs upon the importance of the timing of bulk harvest. In Alaska, many farmers target late May or June as a harvest window because they want to leverage the longer daylengths to maximize biomass (late to increase at higher latitudes). For the farms included in this work, however, our data suggest that not only is an earlier harvest window more appropriate (based on C:N ratios, [34]) but that it may be necessary to coordinate different harvest windows for different species of kelp—e.g., harvest *A. marginata* in early April and *S. latissima* in early May to preserve nutrient drawdown services in Doyle Bay. The timing would vary by location. This is

necessary because the margin between kelp farms serving as nutrient sinks versus nutrient sources is thin. In a study monitoring carbon flux in three Japanese kelp farms [36], results as to whether a kelp farm is a sink or source for carbon were mixed and suggested that it depends on how long the condition of site allows the kelp to live in an autotrophic versus heterotrophic state. In our study, the low-nitrogen condition of the sites likely shortens the time in which those farms serve as sinks, and we propose that the high-nitrogen demand of *A. marginata* can further shorten that window.

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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