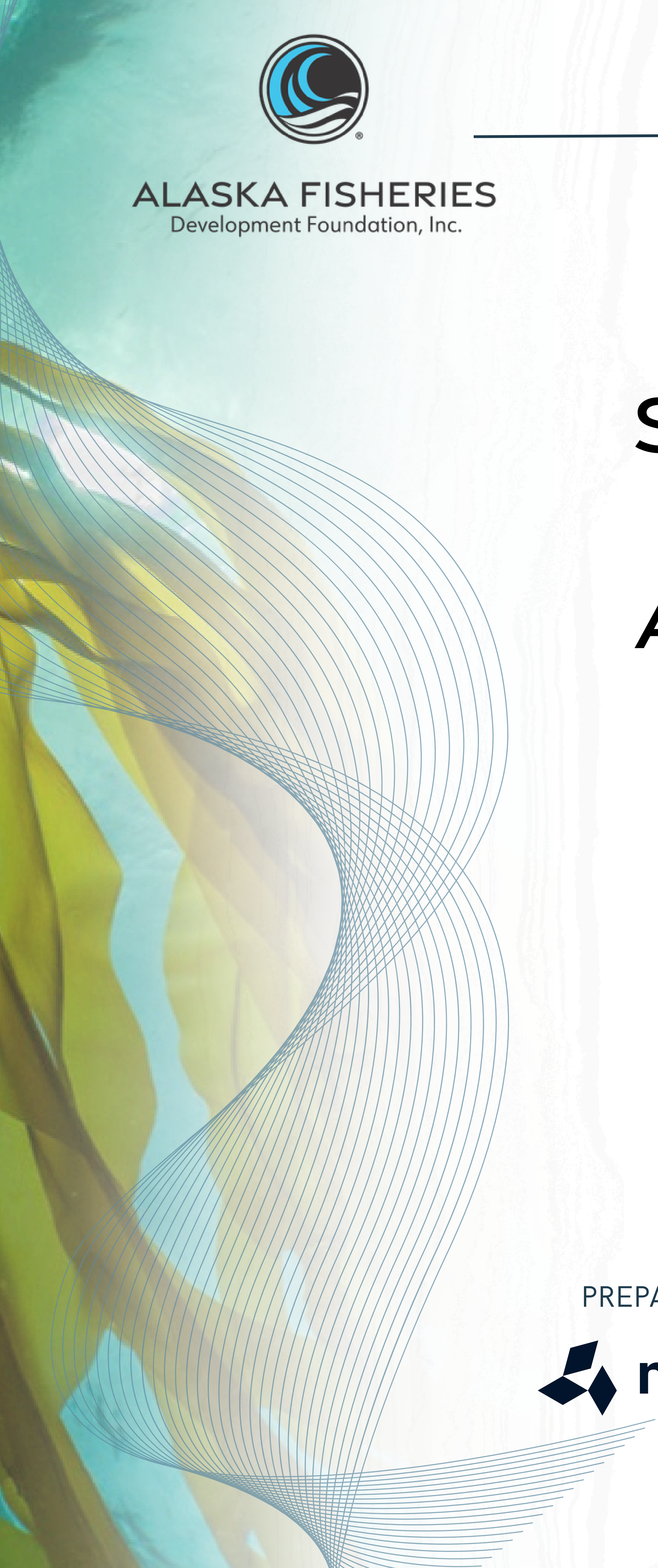

ALASKA FISHERIES
Development Foundation, Inc.

JANUARY, 2026

ALASKA SEAWEED TISSUE ANALYSIS

Industry Report on 2024 Data

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marine biologics

TABLE OF CONTENTS

SECTION 1 - EXECUTIVE SUMMARY

In 2024, Alaska Fisheries Development Foundation (AFDF) facilitated a seaweed sampling effort that looked at a diverse range of seaweed species from around Sitka and Kodiak, Alaska. Samples were collected primarily from wild sources and featured 17 distinct species of brown, red, and green seaweed. Collected samples were analyzed by Celignis Analytical in Ireland, where full compositional content was measured, including minerals, carbohydrates, polysaccharides, pigments, ash, and metals. This study revealed the incredible variety of native seaweed types across Alaska and the diversity in their chemical composition.

Marine Biologics supported this initiative by leading the analysis, standardization, and interpretation of the dataset. Reference the interactive data dashboard.

The Seaweed Tissue Analysis Program is part of the Research and Development component of the Alaska Mariculture Cluster (AMC), funded by the Economic Development Administration (EDA) Build Back Better Regional Challenge (BBBRC) grant and led by Southeast Conference. The program is administered by the Alaska Fisheries Development Foundation (AFDF), a subaward recipient.

NUTRITION

The seaweed samples displayed a varied macronutrient profile (minerals: 15-60% DW; carbohydrates: 20-80% DW; protein 5-25% DW; Fat: 0-7% DW). The mineral profile was predominantly Na, K, and Cl with some species containing up to 16% DW potassium. Potassium-rich samples were found from *G. pacifica* (red), *N. luetkeana* (Bull kelp, brown), and *D. mollis* (Dulse, red). Other micronutrients of note included Ca and Mg: *A. clathratum* (Sieve kelp) was rich in calcium (up to 3.7% DW), while *Ulva* (green) was the most magnesium-rich of the samples tested (up to 3.7% DW). Carbohydrate contents up to 55-70% DW was observed for samples of *H. nigripes* (Split kelp) and *S. latissima* (Sugar kelp). Much of the total carbohydrates were measured as fiber (50-70%), with much of it soluble. The overall carbohydrate amount did show some seasonal trends with late season (June) seaweeds often higher than analogous early season (April) samples. High protein levels (22-26% DW) were observed for *Ulva* and *D. mollis* samples, but there were no samples with elevated levels of essential amino acids. Lipid content up to 6.5% DW was measured for *Fucus* samples. Vitamins, while varied, were at levels too low to be considered a nutrient source.

SAFETY

The seaweed samples underwent a detailed chemical hazard assessment to establish benchmarks and support proper risk assessment. Inorganic arsenic is the major food safety concern, and all samples (94/94) were well below the federal limits of 3 mg/kg DW (highest measured value: 0.5 mg/kg DW). Inorganic arsenic was consistently <1% of total arsenic. Cadmium was observed in 15/94 samples meeting or exceeding the EU recommendation for a food supplement (3 mg/kg DW). This does not preclude their use in many other applications, but this heavy metal should be monitored and discussed in a food safety plan. Mercury and lead were considerably less prevalent but remain chemicals of concern. Iodine is both a nutrient and a potential hazard at incorrect dosage. Kelps were shown to be comparably lower than European counterparts, and only 5/94 samples contained >1 mg/kg DW iodine.

CARBOHYDRATES

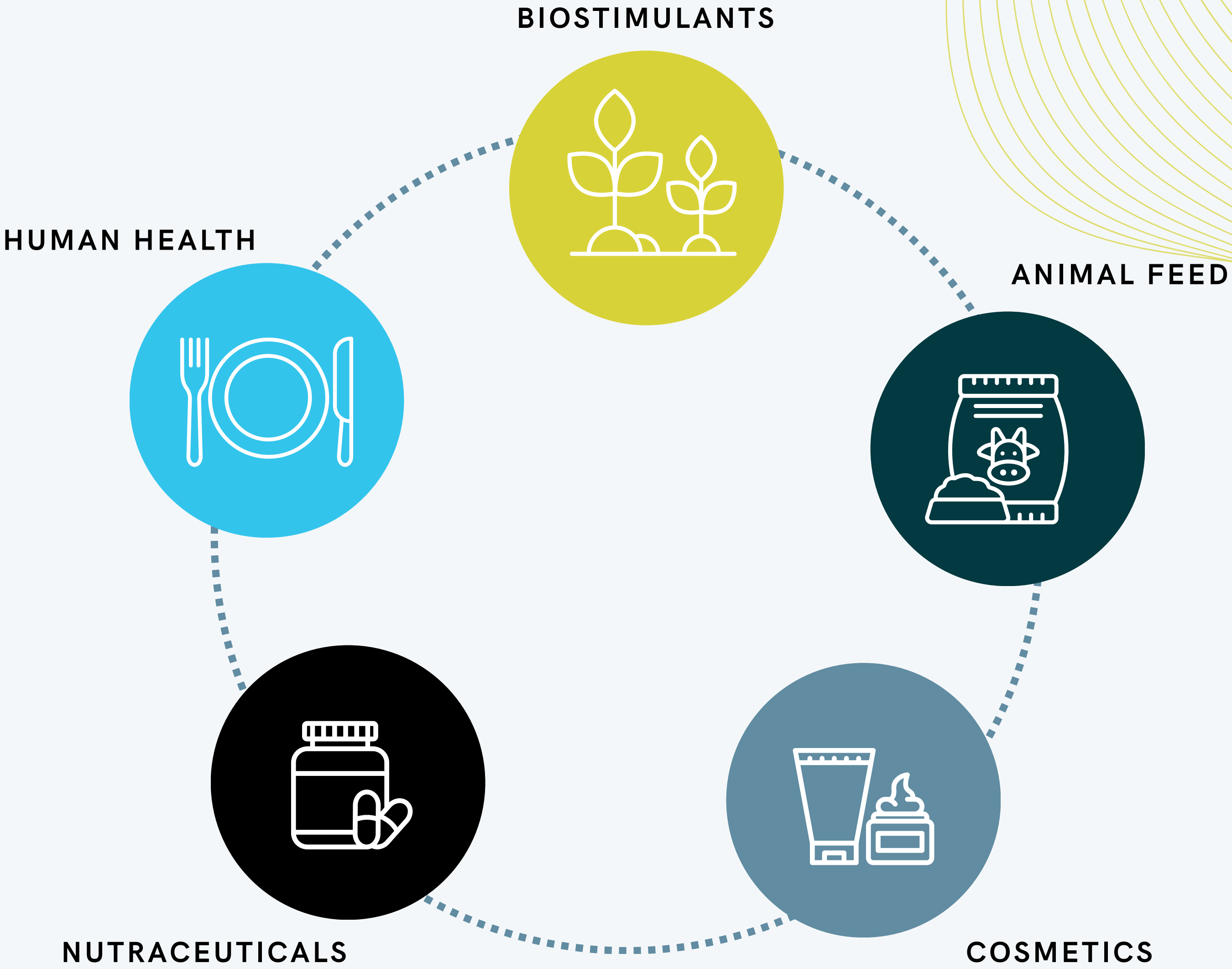
The seaweed samples underwent detailed analysis to establish their carbohydrate profile. Alginic acid levels up to 32% were observed for samples of *A. marginata* (Winged kelp) and *C. costata* (Five-ribbed kelp). Fucoidan was up to 6-6.5% DW in samples of *M. pyrifera* (Giant kelp), *S. latissima*, and *A. marginata*. Higher galactose (surrogate for carrageenan) values (up to 22% DW) were measured for red seaweeds *C. exasperates* (Turkish towel) and *O. californica* (Prickly pear). Glucose testing did not permit differentiation of cellulose and laminarin, but up to 30% DW glucose was observed in samples of *H. nigripes* and *S. latissima*. Mannitol levels of up to 30% DW were found for samples of *H. nigripes* and *A. clathratum*.

BIOACTIVES

Detailed bioactive assessment requires many rounds of testing, especially if intending a human, plant, or animal application, but an initial general evaluation was performed with targeted assaying. Pigment analysis revealed a profile rich in chlorophylls and moderate levels of fucoxanthin. Higher total phenolic content was found in *S. latissima* and *Ulva*, higher total phlorotannin content was found in *M. pyrifera* and *F. distichus*, and higher total flavonoid content was found in *Ulva* and *F. distichus*. Both *Ulva* and *C. fragile* were found to have higher levels of the polyphenol chlorogenic acid (0.5 mg/g DW) that greatly exceeded other samples.

APPLICATIONS

It is clear from the above summary that the diversity of seaweed composition is vast in Alaska. Certainly, humans, plants, and animals can benefit from many of the nutrients and bioactives (e.g., carbohydrates and polyphenols) shown to be in these seaweeds. Food/feed industries benefit from a low-sodium mineral source (K, Ca, Mg), especially with beneficial amounts of iodine. The fiber content of seaweed is quite high, and it may be a good source of both soluble and insoluble fiber. Plant health products will continue to benefit from the minerals and bioactives present in seaweed. Seaweed bioactives remain highly sought-after cosmetic and wellness ingredients. Seaweed carbohydrates possess desirable features for food (alginate, carrageenan) and biological (fucoidan, laminarin) applications. The challenge continues to be creating suitable processing infrastructure and building towards external markets. Ideally, this report supports that necessary growth.



SECTION 2 - INTRODUCTION

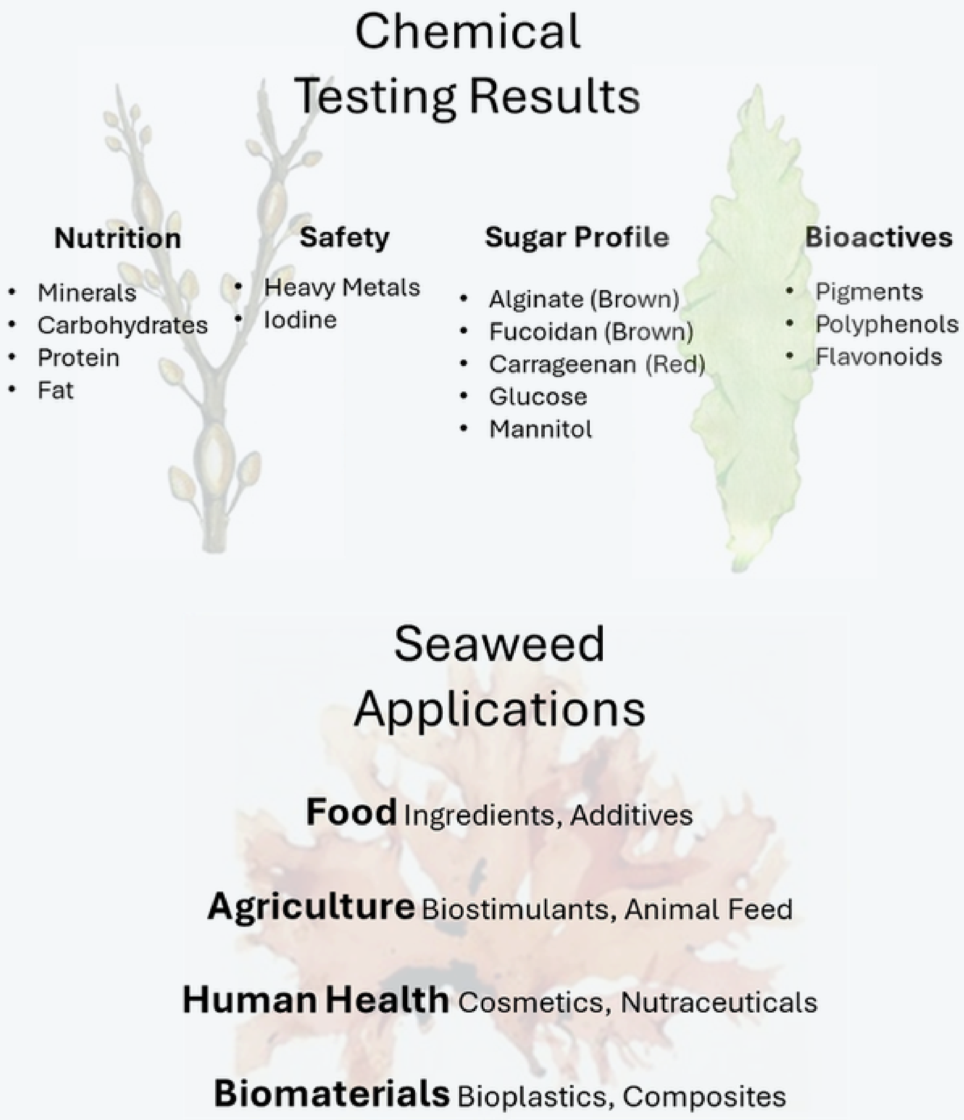
The range of inherent chemical complexity and variability of Alaskan seaweeds places great importance on establishing industry benchmarks that document the constitution of this industrial feedstock. Variations in seaweed chemical profiles have been observed due to the farming location, seasonality, and species (Jardell, 2024). Seaweeds, specifically kelp, stockpile different compounds depending on the season (Schiener et al., 2014). For example, higher alginate contents occur in summer months, mannitol/laminarin accumulates during summer/autumn to be utilized during winter, and protein and mineral contents are highest in winter and lowest during summer. Certainly, a keen understanding of seaweed chemistry serves to support quality, health, and safety claims related to composition as well as its role in the greater market.

Saccharina latissima (Sugar kelp), the most broadly cultivated seaweed in Alaska, has been extensively surveyed for variation across a range of major chemical markers (Zhang et al., 2019). One limitation of current research is the primary focus on European biomass – Denmark, Sweden, Norway, Great Britain – with little information on North American, particularly Alaskan, seaweed. Information on the chemical composition of Alaskan seaweed is generally limited with respect to literature or commercial product specification sheets, the latter being a typical requirement for raw material sale into higher-value markets. Alaskan seaweed compositions have been largely determined by comparisons to analogous species grown in largely different environments – an approach fraught with potential error. This project – the 2024 Alaska Seaweed Tissue Analysis Project - was designed to address this literature limitation.

In early 2024, a large species seaweed sampling plan was created, and work began to collect material from locations around Kodiak and Sitka, Alaska. In total, this collection effort yielded 94 samples from 17 different species. Most of the samples were collected from wild stocks, and whenever possible, the same sampling site was visited monthly at three distinct times (April, May, June). Samples were stored frozen before shipping to a third-party laboratory for an intensive set of chemical analyses (Celignis Biomass Analysis Laboratory, Ireland). This data was released in 2025 and used to create "Seaweed Species Profiles," which summarized the information for each species by chemical type into a mix of visual and tabular formats (Seaweed Tissue Analysis 2024 Dashboard). Once the profiles were compiled, a series of stakeholder interviews were performed to gather industry feedback on the data. Ten key stakeholders from seven companies/organizations across food, feed, cosmetics, biostimulants, and R&D sectors were interviewed, including buyers, users, and advisors. Key insights from this activity are shared in a separate report.

This document is prepared as the final installment of the 2024 Seaweed Tissue Analysis project and aims to describe the insights provided by the data in alignment with current industry uses of seaweed (particularly those underway in Alaska - food, agriculture, human health, and biomaterials). Where possible, differences in key chemical groups are highlighted across species, classes, or related to environmental factors. To place the information in a global context, data sets are correlated to existing information provided by industry and academic sources. Test methods are discussed and possible complementary approaches noted. The project intent was to identify promising species for future cultivation efforts or highlight specific features of Alaskan seaweed that can create competitive advantages in emerging global markets. To our knowledge, a comparison of this nature has never been completed in North America.

Figure 1: Summary of Alaska Seaweed Tissue Analysis Project 2024 report focus areas.



LIST OF ABBREVIATIONS

Abbreviation	Meaning	Common name	Classification
Research Samples			
AC	*Agarum clathratum*	Sieve kelp	Brown
AM	*Alaria marginata*	Winged kelp	Brown
CC	*Costaria costata*	Five-ribbed kelp	Brown
CE	*Chondracantus exasperatus*	Turkish towel	Red
CF	*Codium fragile*	Dead man's fingers	Green
CT	*Cymathaere triplicata*	Three-ribbed kelp	Brown
DM	*Devaleraea mollis*	Pacific dulse	Red
DV	*Desmarestia viridis*	Stringy acid kelp	Brown
EF	*Eualaria fistulosa*	Dragon kelp	Brown
FD	*Fucus distichus*	Rockweed	Brown
GP	*Graciliaria pacifica*	Red spaghetti	Red
HN	*Hedophyllum nigripes*	Split kelp	Brown
MP	*Macrocystis pyrifera*	Giant kelp	Brown
NL	*Nereocystis luetkeana*	Bull kelp	Brown
OC	*Opuntiella californica*	Prickly pear seaweed	Red
SL	*Saccharina latissima*	Sugar kelp	Brown
US	*Ulva* spp.	Sea lettuce	Green
KOD	Kodiak, Alaska	Sample location	KOD
SIT	Sitka, Alaska	Sample location	SIT
General Abbreviations			
AAFCO	Association of American Feed Control Officials		Organization
AOAC	Association of Official Analytical Collaboration		Organization
CFR	Code of Federal Regulation		Regulation
DW	Dry weight		Unit
EU	European Union		Organization
FDA	Food and Drug Administration		Organization
ICP-OES	Inductively Coupled Plasma Optical Emission Spectroscopy		Test method
ISO	Internation Standards Organization		Organization
ND	Not detected		Unit
NM	Not measured		Unit
NIH	National Institute of Health		Organization
WHO	World Health Organization		Organization

SECTION 3 - NUTRITIONAL PROFILE

Seaweed is truly a global industry with widespread production and use. Most marine-based macroalgae (AKA seaweed) are consumed directly as food, where, in 2017 it accounted for 70% of the 12 billion USD global market share (Poblete-Castro et al., 2020). Its use in food has spanned millennia as it contains a wide range of bioactive compounds, flavor, and nutritional benefits (McHugh 2003). Seaweed use as a substantive food ingredient is most common in the Asian Pacific, where it is found in soups, salads, and most meals, but adoption is increasing within North America. In the United States, the brown and red algae food definitions (21 CFR § 184.1120 and 21 CFR § 184.1121, respectively) apply to dried compounds exclusively for use as flavor enhancers or adjuvants - i.e., spice - per the 21 CFR § 101.22(a)(2). This is a tremendous simplification of seaweed, which hosts numerous nutritional components: macronutrients.

3.1 *MACRONUTRIENTS*

In general, fresh seaweed is primarily water with moisture content ranging from 85-90% - naturally, it is the remaining dry fraction that is of commercial interest. The samples collected for this study had moisture content ranging from 77-98%, with an average of 88%. Regardless of species, seaweeds have a typical macronutrient profile: largely minerals + carbohydrates (~80%) with <25% protein and only small amounts of fat (Table 1). A large range for macronutrients was observed, and some highlights will be discussed below. The highest mineral contents were observed in red and brown species, although these were greatly variable. Brown seaweeds were the richest in carbohydrates, but again display great variance. Certain green and red seaweed samples were found to have the highest protein content (~25%), but in general, most samples had protein levels <20%. This variance is consistent with reports that examined proximate compositions of brown, red, and green seaweed (Hrstich-Manning et al., 2023; Healy et al., 2023; Hentati et al., 2020).

Table 1: Range in proximate composition of seaweed samples in study (% DW).

	Minerals	Carbohydrates	Protein	Fat
Brown	16 - 57	33 - 77	4 – 26	0.2 - 7
Red	19 - 59	23 - 65	6 – 26	0.4 - 1
Green	25 - 51	37 - 58	6 – 26	1 – 3

3.2 MINERALS

Ash, or total minerals, can account for over 50% DW in seaweed and is largely composed of the marine cations: sodium, potassium, calcium, and magnesium, with chloride and sulfate as the main counterions. Cl, K, and Na are by far the most abundant ions and represent ~90% of the total ions measured in the samples. The highest and lowest mineral-containing samples are provided in Table 2 along with their relative amounts of Cl, K, and Na.

Table 2: Highest and lowest mineral values (% DW).

	Sample ID	Cl	K	Na	Ash, 550 °C	Ash, 815 °C
Highest 5 Values	KOD-DM-04-003	17.4	14.7	2.3	58.8	44.6
	SIT-NL-06-037	23.1	15.7	3.5	56.8	46.6
	SIT-GP-05-029	18.7	9.5	1.7	53.1	32.5
	SIT-GP-04-012	14.7	16	2.4	51.5	31.4
	KOD-CF-06-045	24.3	0.9	6.9	51	48.3
Lowest 5 Values	KOD-SL-06-036	5.3	4.2	2	20.5	17.4
	SIT-HN-05-022	5.8	3.3	0.7	19.5	13.3
	KOD-OC-04-012	3.2	3.9	1.4	19.1	17.5
	SIT-SL-06-038	5.4	4.6	1.4	19	15.8
	SIT-HN-06-035	4.2	3.1	1.4	16	12

Sample naming key: [location]-[species]-[month]-[sampleID]
Example: SIT-NL-06-037 refers to Sitka, *N. luetkeana*, June, sampleID 037

Ash is estimated via combustion, which can be achieved under different thermal conditions. For this work, both 550 °C and 815 °C were explored and ash result for each sample reported as the 550 °C value. For comparison, 815 °C values were 60-100% of the 550 °C values (Table 3). An alternative method to estimate mineral content is to take the sum of the major ions determined by ICP-OES (ISO 16967:2015 and ISO 16968:2015). This analysis revealed a discrepancy between calculated ash values and sum of total ions. Ash is a rapid tool to estimate the mineral content of samples, but quantitative mineral analysis using ICP is the more accurate method. 13 samples were observed to have >30% total minerals by analysis with ICP-OES - of this group five samples were Bull kelp.

Table 3: Highest mineral samples by different methods (% DW).

Sample ID	Sum (total* ions)	Ash (550 °C)	Ash (815 °C)
KOD-SL-05-044	39.1	46.7	28.8
KOD-CC-04-011	37.9	35.7	31.7
KOD-NL-06-040	37.8	43.9	38.4
SIT-DM-06-039	37.3	33.6	27.3
KOD-NL-05-028	35.4	39.9	23.3
SIT-GP-04-012	34.5	51.5	31.4
KOD-NL-04-013	34.1	48	44.6
SIT-MP-05-018	33	36.4	23.2
SIT-DM-04-008	32.8	38.1	21.8
KOD-NL-06-047	32.7	43.3	27
*: Cl, K, Na, Ca, Mg, Fe, P, Al, Ca, Si, Ti			

A main mineral of interest in seaweed is potassium, which has immediate application as a crop nutrient source. It was the presence of potassium that led to a drastic increase in the refining of kelp during WW1 in California to support U.S. agriculture while potash imports were embargoed (Neushul, 1989). Potassium levels in the samples ranged from 0.5-16% DW, the highest value was observed in *G. pacifica* (SIT-GP-04-012: 16% DW), but two Bull kelp samples displayed similar elevated levels (SIT-NL-06-037: 16% DW; KOD-NL-04-013: 15% DW). Three samples of *D. mollis* were also shown to contain larger amounts of potassium (KOD-DM-04-003: 15% DW; SIT-DM-04-008: 12% DW; KOD-DM-06-031: 12% DW). Conversely, *C. fragile* was found to be consistently low in potassium, with all six samples <1% DW.

Sodium levels ranged from 0.6-9% DW, with *C. fragile* representing 6 of the top 10 samples (Na = 5-9% DW). Seaweed shows promise as a low-sodium seasoning due to its elevated potassium levels compared to sodium. Use of salt substitutes containing potassium is a potential strategy to reduce sodium intake, increase potassium intake, and thereby lower blood pressure and prevent the adverse consequences of high blood pressure (Greer et al., 2019). According to guidelines issued by the WHO, adults should consume less than 2,000 mg of sodium, or 5 grams of salt, and at least 3,510 mg of potassium per day – equating to a K:Na ratio of at least 1.8 (WHO, 2013). These intake targets are not without some contention (Liu et al., 2024), but it does indicate a potential value for natural sources of potassium. The ratio of K to Na was calculated for all samples and revealed a clear species effect: all green samples were <1.5 K:Na, with most samples <1 (Table 4). This aligns with the relatively low potassium content in green seaweeds (<3% DW). Conversely, most brown and red seaweeds displayed greater potassium than sodium (>3 K:Na). Still, there was substantial variation across all samples with respect to K and Na composition.

Table 4: Potassium and sodium levels of seaweed samples in study (% DW).

	K	Na	Average K:Na
Brown	**2.0-16**	**0.7-5.1**	**3.4**
Red	**3.8-16**	**1.2-4.3**	**3.9**
Green	**0.5-3.1**	**1.8-9.2**	**0.5**

Calcium and magnesium are other minerals of interest in seaweeds and display considerable variance across samples: Ca = 0.2-3.7% DW; Mg = 0.3-3.7% DW. Within these analyses, some clear trends were observed. The highest calcium was observed for *A. clathratum,* which was 2 - 4% DW calcium and represented 4 of top 5 samples (all other samples were <2%). Calcium levels of 3% DW have been observed previously for *A. clathratum* (Kreissig et al., 2021), suggesting that this may be a typical species effect and not directly tied to the unique growing environment - further supported by the similarity between both Kodiak and Sitka sample calcium levels. Red seaweeds were generally low in calcium, with most samples calculated at <0.5% DW. The green seaweeds of the measured set are the most magnesium-rich, representing the top 13 samples for Mg concentration with *Ulva* spp. dominating the list (Table 5). Further, *Ulva* appeared to have a potential environment-dependency, with the samples collected in Sitka appearing to be greater in magnesium than their corresponding Kodiak samples.

Table 5: Highest magnesium values (% DW).

Sample ID	Magnesium
SIT-US-05-020	**3.7**
SIT-US-04-002	**2.5**
SIT-US-04-013	**2**
SIT-US-06-040	**1.9**
SIT-US-04-009	**1.9**

Additional minor elements analyzed include phosphorus (<0.7% DW for all samples), iron (<0.1% DW for all samples except KOD-AM-04-010: 0.4% DW), silicon (<0.5 % DW for all samples), aluminum (<500 ppm DW for all samples except KOD-AM-04-010: 2500 ppm DW).

3.3 CARBOHYDRATES

Total carbohydrates are typically estimated during proximate analysis, i.e., total carbohydrates (%) = 100 - %(moisture + ash + protein + fat). This is because there are several different carbohydrates present in food products, and specific analysis is complicated. Nevertheless, in this study, a more detailed sugar analysis was performed that looked at the individual sugar molecules (monosaccharides) and reported total sugars as the sum. The monosaccharides measured include mannitol, glucose, fucose, galactose, mannose, rhamnose, xylose, arabinose, glucuronic acid, mannuronic acid, guluronic acid, and iduronic acid. The top six samples, in terms of total sugars, are shown in Table 6 - *H. nigripes* and *S. latissima* were clear outliers.

Table 6: Highest sugar and fiber values (% DW unless stated).

		Fiber		
Sample ID	**Total Sugars**	**Soluble**	**Insoluble**	**% of total Sugars**
SIT-HN-06-035	67.9	35.6	10.6	68
SIT-HN-05-022	66.4	26.8	8.3	53
SIT-SL-06-038	65.8	25.6	17.4	65
KOD-SL-06-036	56.2	21.7	16.2	67
SIT-SL-05-026	54.5	19.5	11	56
SIT-HN-05-021	52.3	17.1	12.1	56

Nutritional interest in seaweed often stems from their potential to act as prebiotics which is largely dependent on their carbohydrate profile. Prebiotics are a group of nutrients that are degraded by gut microbiota (Davani-Davari et al., 2019) - they were first defined in 1995 as "nondigestible food ingredients that beneficially affect the host by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the colon, thus improving host health" (Gibson et al., 1995). They can feed the intestinal microbiota, and their degradation products are released into blood circulation to support not only the gastrointestinal tracts but also other distant organs. For this reason, indigestible dietary polysaccharides (i.e., fiber) attract attention as functional food ingredients with health benefits (Lopez-Santamarina et al., 2020).

Although all prebiotics are fiber, not all fiber is prebiotic (Slavin, 2013) - simple chemical testing may not fully reveal the health benefits. The current practice is to measure total dietary fiber and further quantify 'soluble' and 'insoluble' components - which was performed in this study per AOAC method 2011.25. Dietary fiber is known to alleviate constipation, lower cholesterol, reduce cancer metastasis, and improve overall mortality rates. Total fiber content ranges from 16-46% DW, with brown seaweeds generally higher. In the data set, fiber was shown to represent 24-67% of the total sugars measured, some examples are shown in Table 5.

The FDA recognizes the relationship between diets low in fat and high in fruits, vegetables, and grain products that contain fiber and risk of cancer (21 CFR § 101.76) and coronary heart disease (21 CFR § 101.77). Coronary heart disease health claims focus more on the presence of soluble fiber (21 CFR § 101.81). In general, soluble fibers are more completely fermented and have a higher viscosity than insoluble fibers. Soluble fiber was typically >50% of total fiber in the seaweed samples (55% average). The highest values for soluble fiber were found in *H. nigripes* (>30% DW), but closer analysis of soluble fiber revealed *F. distichus* contained the largest percentage of soluble fiber (77-83% total fiber, total fiber = ~27% DW). In fact, 5 of the top 10 soluble fiber values were observed for *F. distichus*. Conversely, *A. marginata* appeared highest in insoluble fiber values with three samples (SIT-AM-04-001: 22% DW; SIT-AM-05-025: 21% DW; KOD-04-010: 19% DW).

Seaweeds will stockpile different nutrients depending on their life stage (Schiener et al., 2014). The storage carbohydrates mannitol and laminarin have also been found to accumulate during summer and autumn. This way, these polysaccharides can be utilized during winter as an energy source for new tissue growth. This effect can be clearly observed in the two large carbohydrate species: *H. nigripes* and *S. latissima* (Table 7). Samples were collected from the same locations over three months. The data reveals that carbohydrates are stockpiled later in the season, with June samples consistently exceeding their April counterparts. Additionally, there appears to be a location effect, with carbohydrate values higher in samples collected in Sitka compared with Kodiak. This could be attributed to a range of environmental factors (light intensity, nutrient availability, water motion, etc.), but does indicate the value of site selection when targeting specific chemical components from seaweed biomass. The limited sample space cannot be discounted in making meaningful comparisons, but the trend is compelling. Notable outliers (SIT-SL-05-031, KOD-SL-05-044, KOD-SL-06-046) refer to samples collected from commercial farm operations. In this case, the life stage of the seaweed is expected to be much different from its wild counterparts due to cultivation practices.

Table 7: Variation in total sugars in *H. nigripes* and *S. latissima* (% DW).

	Sitka		Kodiak	
Month	**Sample ID**	**Total Sugars**	**Sample ID**	**Total Sugars**
Hedophyllum nigripes				
April	SIT-HN-04-007	29.12	KOD-HN-04-009	39.51
May	SIT-HN-05-021	52.33	KOD-HN-05-017	41.39
	SIT-HN-05-022	66.35		
June	SIT-HN-06-035	67.87	KOD-HN-06-041	46.44
Saccharina latissima				
April	SIT-SL-04-004	35.03	KOD-SL-04-006	36.18
May	SIT-SL-05-026	54.45	KOD-SL-05-019	48.17
	SIT-SL-05-031*	42.19	KOD-SL-05-044*	28.25
June	SIT-SL-06-038	65.75	KOD-SL-06-036	56.17
			KOD-SL-06-046*	29.22
* indicates farmed sample				

Beyond nutrition, it is a source of chemicals (hydrocolloids such as alginate, carrageenan, and agar) that provide desirable food structural properties such as gelling and texturizing. These specific seaweed polysaccharides are discussed in Section 5.

3.4 PROTEIN

Protein, which is made of individual building blocks called amino acids, is a key nutritional component of any animal's diet. It is commonly estimated in seaweed as 'crude protein,' which is determined after measuring the total nitrogen and multiplying by 5 (Angell et al., 2015). This value is intended as a rough estimate. A more detailed protein measurement can be performed by measuring the individual amino acids in the material after hydrolysis. From here, the total amino acids (AKA total protein) can be further divided into essential (cannot be synthesized by the human body) and non-essential (synthesized in the body) categories. Crude protein and amino acid breakdown are provided for select high and low samples in Table 8. Crude protein ranged from 4-26% DW (or 0.8-5.2% DW nitrogen). Protein contents are found to be highest in winter and lowest during summer, where it has been suggested these nitrogen reserves sustain the growth of seaweeds into summer carbohydrate accumulation. The highest crude protein samples were all collected in April, the earliest month surveyed. 9 samples have >4% DW nitrogen. Of these, only one sample was a brown seaweed (KOD-EF-05-026: 4.1% DW). The remainder were red (SIT-DM-04-008: 5.2% DM; SIT-DM-04-003: 4.3% DM; KOD-OC-04-012: 4.2% DM; KOD-OC-05-029: 4.0% DM) or green (*Ulva*: 3 samples ≥5.0% DM).

Table 8: Highest and lowest protein values, including amino acid (AA) breakdown (% DW).

	Sample ID	Crude Protein	Total AAs	Essential AAs	AA:Crude Protein
Highest 5 Values	SIT-US-04-013	26.2	23.4	7.9	0.89
	SIT-DM-04-008	26	21.6	7.2	0.83
	SIT-US-04-009	25.1	18.4	5.4	0.73
	KOD-US-04-008	25	17.6	5.8	0.7
	SIT-DM-04-003	21.6	13.8	4.9	0.64
Lowest 5 Values	SIT-SL-05-031	5.4	4.7	1.5	0.87
	SIT-AC-06-046	5.1	5	1.4	0.98
	SIT-SL-05-026	4.9	4.5	1.4	0.92
	SIT-MP-06-47	4.4	4.2	1.4	0.95
	SIT-SL-06-038	4	4.1	1.5	1.03

In general, the relative number of amino acids aligned with the crude protein. However, the estimation of crude protein by nitrogen conversion seems to overestimate the total protein if compared to total amino acids. The ratio of total amino acids to crude protein (AA:crude protein, Table 8) points to a discrepancy between these values for higher nitrogen-containing seaweeds. This could indicate the presence of more nitrogen-containing salts (e.g., metal nitrates). A general conversion factor of 5 may not be appropriate, and species-specific factors should be considered (Lourenço et al., 2006). The project samples were 30-40% essential amino acids, which aligns with other reports (Černá 2011). Considerable crude protein variance was observed in *Ulva* (6-26% DW), but this is not uncommon for this genus (Soufi et al., 2024).

3.5 FATS

For this project, fat content was measured as the sum of fatty acid (FA) methyl esters produced after standard saponification/methylation treatment (for an analogous method see Kendel et al., 2015). This is meant to minimize overestimation of total lipids that result from conventional crude fat measurements, namely Soxhlet extraction with petroleum ether (USDA, 2009). Other nonpolar components (e.g., phlorotannins) may also be separated during apolar solvent extraction and complicate this traditional gravimetric approach.

Total lipids ranged from 0.2 - 6.5% DW. The seaweed that appeared to contain the most lipids was *F. distichus*. Previous work has observed lipid concentrations up to 6% DW for other *Fucus* spp. (Catarino et al., 2018). Although they are low in fat, many authors have focused their studies on the lipid fraction of *Fucus* spp. due to the high content in polyunsaturated fatty acids (PUFAs), which are essential fatty acids of the utmost importance for human metabolism. Seaweed blends that can leverage these nutritional components are being studied in considerable detail (Marques et al., 2021; Pereira et al., 2012). Caterino et al. report the total content of PUFAs and C18:1n9C (oleic acid) in *F. distichus* is 48.5% and 16.7%, respectively, of total fatty acids. The ratio of PUFAs to total fat for select samples ranges 32-46%, while oleic acid ranges between 14-26% of total fat, showing good correlation with literature values (Table 9). *D. mollis* was consistently low in lipids, with average values of 0.4 - 0.7% DW.

Table 9: Highest fatty acid (FA) values (% DW).

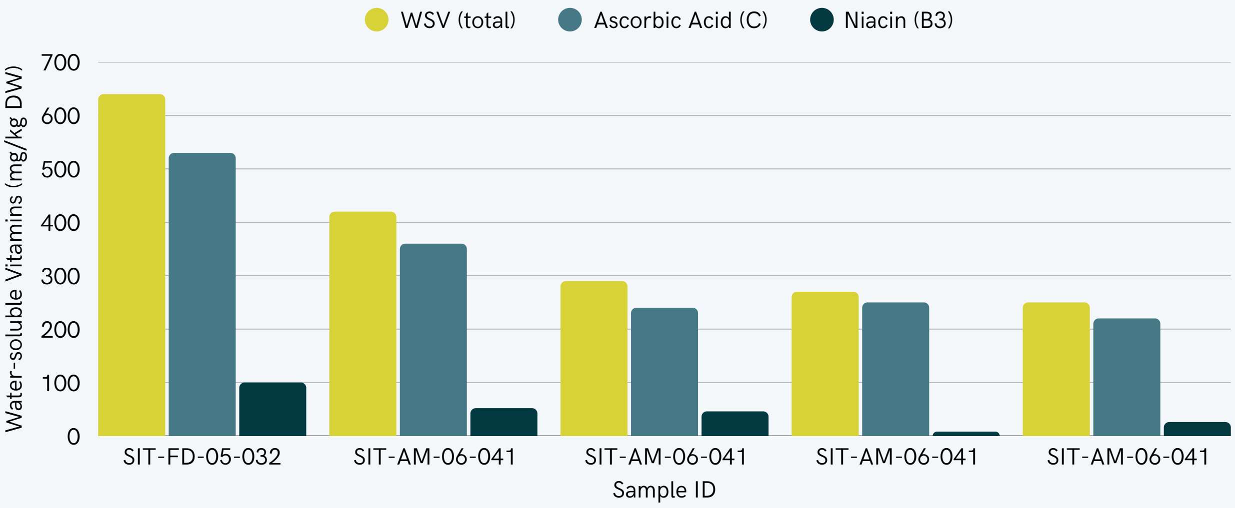
Sample ID	Total FAs	SFAs	MUFAs	PUFAs	C18:1n9C (oleic acid)	C18:2n6c (linoleic acid)
SIT-FD-05-032	6.5	2	2.1	2.4	1.5	0.8
SIT-FD-06-048	4.3	1.5	1.4	1.4	1.1	0.5
KOD-DV-05-021	3.9	1.2	0.9	1.9	0.3	0.3
KOD-FD-04-014	3.5	1.1	0.9	1.6	0.5	0.4
SIT-FD-04-016	3.5	1.2	1.1	1.3	0.8	0.4

3.6 VITAMINS

One reason seaweed has attracted great interest as a component of human or animal feed is the claim that algae, particularly seaweeds, represent an exceptional source of vitamins. The literature abounds with studies on the vitamin content in different seaweeds (Hagan et al., 2023). There appears to be some agreement the most abundant seaweed vitamins, which can sufficiently contribute to daily vitamin requirements, are water-soluble vitamins (WSV) B1, B2, B12, and C, and fat-soluble vitamins (FSV) A and E (Škrovánková, 2011). Only select brown seaweeds were analyzed for vitamin content in this study.

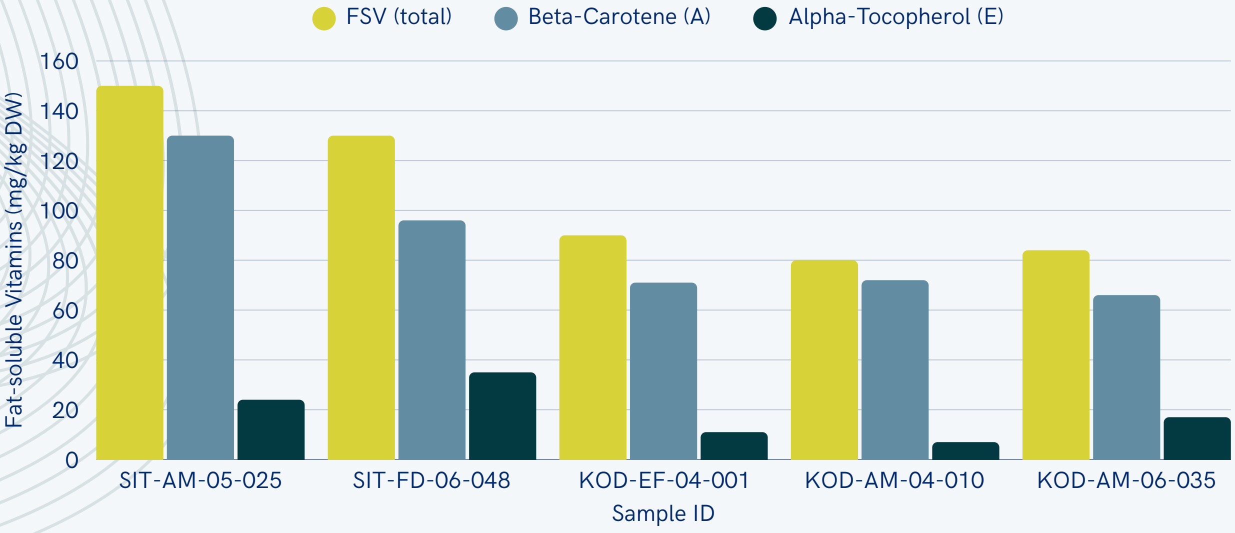
WSV were shown to range from 2 - 640 mg/kg DW in the measured samples (Figure 2). The major WSVs were Ascorbic acid (C) and Niacin (B3). These represent >90% of most WSV profiles. Ascorbic acid is widely available in fruits and vegetables; while its appearance is of some interest, it is unlikely seaweed will supplant existing sources of the vitamin. The recommended daily intake (RDI) of Niacin is 14-18 mg. A daily serving of dried seaweed above 10 g would deliver 1 mg of Niacin (based on SIT-FD-05-032). This just meets the threshold to "contain Niacin" (5-10% DV). Vitamin B12 (cobalamin) presence in seaweed has attracted much interest as a potential non-animal source of the essential vitamin. It was not detected in any of the project samples, but it has been reported only in small values in brown seaweeds and at considerably higher levels in Rhodophyta such as *Porphyra* spp. (Yamada et al., 1996)

Figure 2: Highest water-soluble vitamin (WSV) values.



FSV were shown to range from 1 - 150 mg/kg DW in the measured samples (Figure 3). Of these, provitamin A (beta-carotene) and vitamin E (alpha tocopherol) were most abundant. The RDI of vitamin A is 0.7-1.3 mg retinol activity equivalents (RAE) per day. 1 mg RAE is equivalent to 12 mg dietary beta-carotene - i.e., SIT-AM-05-025 contains 11 mg RAE/kg. Therefore, 10 g DW of this seaweed would deliver 0.1 mg RAE and be considered a source of vitamin A. It is worth noting that carrots, the ostensible vitamin A delivery source du jour, contains 60-200 mg/kg beta-carotene (by fresh weight) (Saeed et al., 2022). Of course, a typical carrot serving is greater than most seaweeds, but there are clearly vitamins of note present. For comparison, C. fragile and G. chilensis beta-carotene levels were found to be 197.9 and 113.7 mg/kg DW, respectively. The largest vitamin E levels were observed in KOD-DV-04-004 (48 mg/kg DW) and this vitamin concentration dropped precipitously later in the season: KOD-DV-05-021: 15 mg/kg DW; KOD-DV-06-033: 6 mg/kg DW. Previous work has reported the alpha-tocopherol level in *M. pyrifera* in Chile as 17.4 mg/kg DW (Ortiz et al., 2009). In this study, alpha-tocopherol in *M. pyrifera* samples were shown to range from 3-11 mg/kg DW.

Figure 3: Highest fat-soluble vitamin (FSV) values.



SECTION 4 - SAFETY

Food safety considerations in seaweed have been covered in detail elsewhere (Serin, 2025; Good et al. 2023; FAO, 2021; Concepcion et al., 2020). Food safety hazards are classified as biological, chemical, or physical; the data collected in this project is exclusively chemical. The chemical hazards most commonly associated with seaweed products are heavy metals (arsenic, cadmium, mercury, lead) and iodine. This is a biological feature: seaweeds uptake minerals from the environment and this feature lends to their use as an organic source of micronutrients important for human, animal, and plant health (Circuncisão et al., 2018). However, this same trait places seaweed at risk for accumulating potentially toxic amounts of heavy metals or specific minerals (iodine) at rates that preclude their use in certain applications.

4.1 HEAVY METALS

Arsenic is the most common heavy metal contaminant, followed by cadmium (Shaugnessy et al., 2023). Arsenic, in oxidation states 3+ and 5+, is incredibly common in marine environments and exists in two major forms, inorganic and organic. Inorganic arsenic (IAs) is generally more hazardous than organic arsenic, and higher oxidation states further increase the toxicity (Kuivenhoven et al., 2023). Arsenic can be found at high levels (>50 ppm) in dried seaweed, but previous work demonstrated only a small percentage is inorganic in the species cultivated in the US (Yu et al., 2024).

Brown and red seaweed intended for use as food are described in 21 CFR § 184.1120 and 21 CFR § 184.1121, respectively. As an ingredient, these seaweeds must meet chemical standards established in Food Chemicals Codex summarized in Table 10 (National Research Council, 1981). Arsenic levels were very variable across the seaweed samples (2-118 mg/kg DW). 19/94 samples were found to contain ≥50 mg/kg DW arsenic. Brown seaweed appears to accumulate arsenic at a higher level; no red or green seaweeds (28/94) were found to exceed 25 mg/kg DW arsenic. The samples were broadly collected from wild sources that may have had a longer lifespan to accumulate heavy metals.

Table 10: Specified chemical requirements for brown and red algae according to CFR (Serin, 2025).

Analysis	Brown Algae	Red Algae
Arsenic (as As, inorganic)	3 mg/kg	3 mg/kg
Ash (Total)	45%	45%
Iodine	1-5 mg/g	50 mg/g
Lead	10 mg/kg	10 mg/kg
Moisture content	13%	20%

It is important to note that, currently, there is no total arsenic limit for dried brown seaweed as a food product in the United States: CFR only states a limit for inorganic arsenic. Most arsenic in the seaweed is present in less harmful organic forms such as arsenosugars (Yu et al., 2024). All seaweeds meet the threshold established by the FDA, even those highest in total arsenic (Table 11). Cadmium was the second most abundant heavy metal (1-5 mg/kg DW in 27/94 samples). Still, it was below detection (<1 mg/kg DW) in the remaining 67/94 samples. These slightly elevated levels of cadmium may be a cause for concern depending on the market or application of the product. Despite no formal levels existing in US regulations, the European standard for cadmium in "food supplements consisting exclusively or mainly of dried seaweed, products derived from seaweed, or of dried bivalve molluscs" is 3.0 mg/kg (EU 2023/915). Mercury was only detected (10 mg/kg) in one sample (CC-04-005), while lead was below the limit (<1 mg/kg DW) in all samples.

Table 11: Highest arsenic values (mg/kg DW).

Sample ID	Total Arsenic	Inorganic Arsenic
KOD-MP-06-039	118	0.45
SIT-MP-04-014	72	0.25
SIT-MP-05-018	68	0.31
SIT-MP-06-47	68	0.3
KOD-AM-06-035	66	<0.1

4.2 IODINE

Acute iodine toxicity, typically caused by overconsumption of supplements containing iodine, represents a considerable issue for food and feed manufacturers using seaweed, particularly kelp. The recommended dietary allowance varies: 150 µg/d for adults, 220 to 250 µg/d for pregnant women, and 250 to 290 µg/d for breastfeeding women (NIH, 2024). In general, 1 mg/d is considered safe for most individuals. For kelp intended as a dietary supplement, daily ingestion of the additive must be limited to an amount of iodine of 225 µg (21 CFR § 172.365). The iodine level of dried kelps can exceed 4 mg/g DW (Stévant et al., 2025), with the exception of *Alaria* spp. (Rolenda 2018). In this project, only 5/94 samples were found to contain >1 mg/g DW iodine (Table 12).

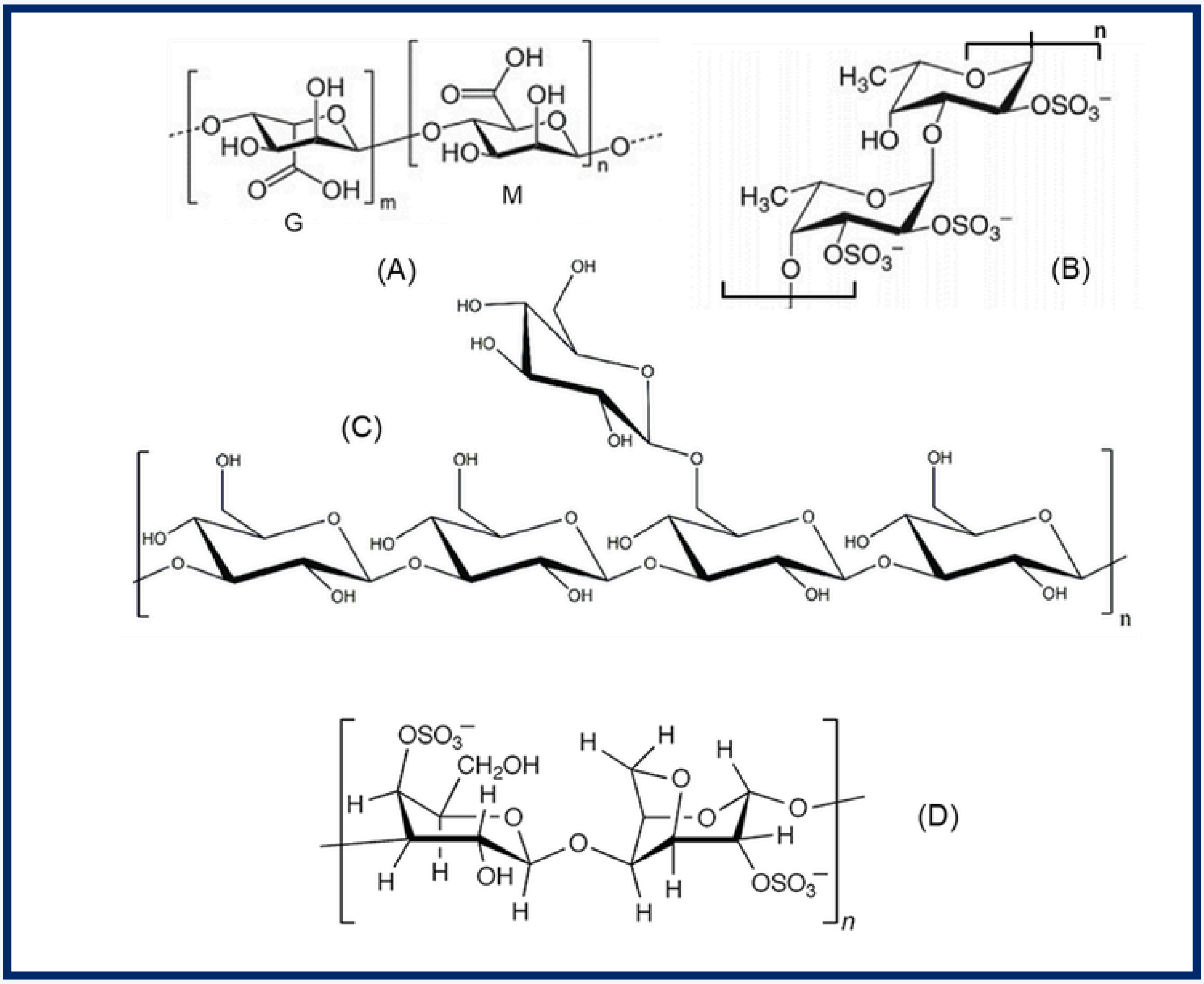
Table 12: Highest iodine values (mg/g DW).

Sample ID	Iodine
SIT-HN-05-022	**1.6**
SIT-SL-05-031	**1.4**
KOD-SL-06-046	**1.3**
SIT-HN-05-021	**1.2**
KOD-SL-05-044	**1.1**

SECTION 5 - CARBOHYDRATES

Carbohydrates represent the major commodity chemical class present in seaweed. Alginate (brown) and carrageenan (red) are industrially relevant hydrocolloids - (A) and (D), respectively (Figure 4), which find widespread applications in the food industry (Saha et al., 2010). Beyond that, other carbohydrate components of seaweed are attractive for their functional or therapeutic properties - fucoidan (B), laminarin (C), and mannitol. Seaweed will stockpile different nutrients, specifically carbohydrates, depending on their life stage, season, and environmental conditions (Schiener et al., 2014). The highest alginate contents are reported to occur in summer months. The storage carbohydrates mannitol and laminarin have also been found to accumulate during summer and autumn. This way, these polysaccharides can be utilized during winter as an energy source for new tissue growth. Seaweed carbohydrates are estimated by monosaccharide analysis – i.e., measuring the individual amounts of each carbohydrate building block. More details on seaweed carbohydrates can be found in the literature (Stiger et al., 2016).

Figure 4: Seaweed carbohydrates. Alginic acid (A), Fucoidan (B), Laminarin (C), Carrageenan (D).



5.1 ALGINATE

Total alginate is calculated as the sum of L-guluronic acid (G) and D-mannuronic acid (M). Across the brown seaweeds, samples ranged from 9-32 % DW total alginate: 17 samples contained >20 % DW. Alginate function in certain product applications, such as gelling, is dictated by the ratio of M:G monosaccharides (Abka-khajouei et al., 2022; Jiao et al., 2019). M:G ratio varied from 1.5-7.8, with the lower alginate-containing samples having a greater relative amount of L-guluronic acid (Table 13). *A. marginata* and *C. costata* samples were the richest in alginate. Previous work has reported the quantity of alginate in *A. marginata* (16.8 % DW, Bajwa et al., 2024) and C. costata (22-29 % DW, Wu et al., 2014).

Table 13: Highest and lowest alginate values across brown seaweed samples

	Sample ID	Alginate, % DW	M:G
Highest 5 Values	SIT-AM-04-001	32	7.8
	SIT-AM-05-025	30	6.4
	KOD-CC-04-011	23	4.1
	SIT-CC-04-005	23	4
	SIT-AM-06-041	22	5.4
Lowest 5 Values	SIT-MP-06-47	12	3.2
	SIT-SL-06-038	12	2.4
	KOD-DV-05-021	11	1.6
	KOD-DV-04-004	9	1.5
	KOD-DV-06-033	8.7	1.6

5.2 FUCOIDAN

Fucoidans are sulfated polysaccharides present in the cell walls of the brown seaweeds, composed usually of fucose as the main monosaccharide, but accompanied by very variable amounts of other monosaccharides like galactose, xylose, mannose, rhamnose, and/or glucuronic acid (Ponce et al., 2020). For this study, a fucoidan-rich fraction was isolated from kelp samples (Order: Laminariales) using acidic aqueous extraction followed by precipitation with ethanol. The putative fucoidan was analyzed for carbohydrate profile. The fucoidan levels in the kelp samples were found to range from 1-6.6% (Table 14).

Table 14: Highest and lowest fucoidan values across kelp samples (% DW unless stated).

			Fucoidan composition *(% of total fucoidan)*			
		Fucoidan	**Fucose**	**Xylose**	**Mannose**	**Glucuronic Acid**
Highest 5 Values	SIT-MP-06-47	6.6	36.5	29.2	9.6	17.8
	KOD-SL-05-019	6.4	35.3	11.7	6.1	8.8
	KOD-MP-06-039	6.4	25.3	41.7	18.7	9.9
	KOD-AM-05-022	6.2	38	31.7	17.5	ND
	KOD-DV-06-033	6.1	17.6	23.1	9.4	29.2
Lowest 5 Values	SIT-NL-04-010	1.8	35.8	15.3	22.9	14.7
	KOD-NL-06-047	1.5	60.9	2.9	5.6	5.4
	KOD-CC-04-011	1.5	33.6	23.6	5.3	16.1
	KOD-CC-05-027	1.3	33.5	20.6	12.7	13.6
	SIT-NL-06-037	1.2	36	15.6	16.7	20.8

Previous work (Ponce et al., 2020) has extensively summarized the diversity of monosaccharides present in fucoidan isolated from different brown seaweeds. Fucose contents have been shown to vary considerably in seaweed fucoidan; interestingly, there appears to be considerable amounts of xylose in the samples from this study. Previous reports of fucoidan isolated from *S. latissima* have shown xylose levels of 2-14% of the monosaccharides present. In this work, xylose levels of up to 27% were observed. Still, fucoidan is incredibly variable, and it is difficult to draw many conclusions from the small sample set.

Table 15 shows how fucoidan isolated from the *M. pyrifera* and *N. luetkeana* samples fluctuates during April-June. Fucoidan levels in *M. pyrifera* samples collected in Sitka and Kodiak both appear to rise over the sampling period. Conversely, *N. luetkeana* samples appear to reach maximum fucoidan levels in April before decreasing. The fucoidan composition remains quite variable. The exact biological reasons for this variation may be complicated to fully elucidate, but the data suggest that if fucoidan is intended for specialty applications, it may not be sufficient to focus on a unique seaweed species: detailed chemical testing should be a quality control stage gate.

Table 15: Fucoidan quantity/composition in *M. pyrifera* and *N. luetkeana* (% DW unless stated).

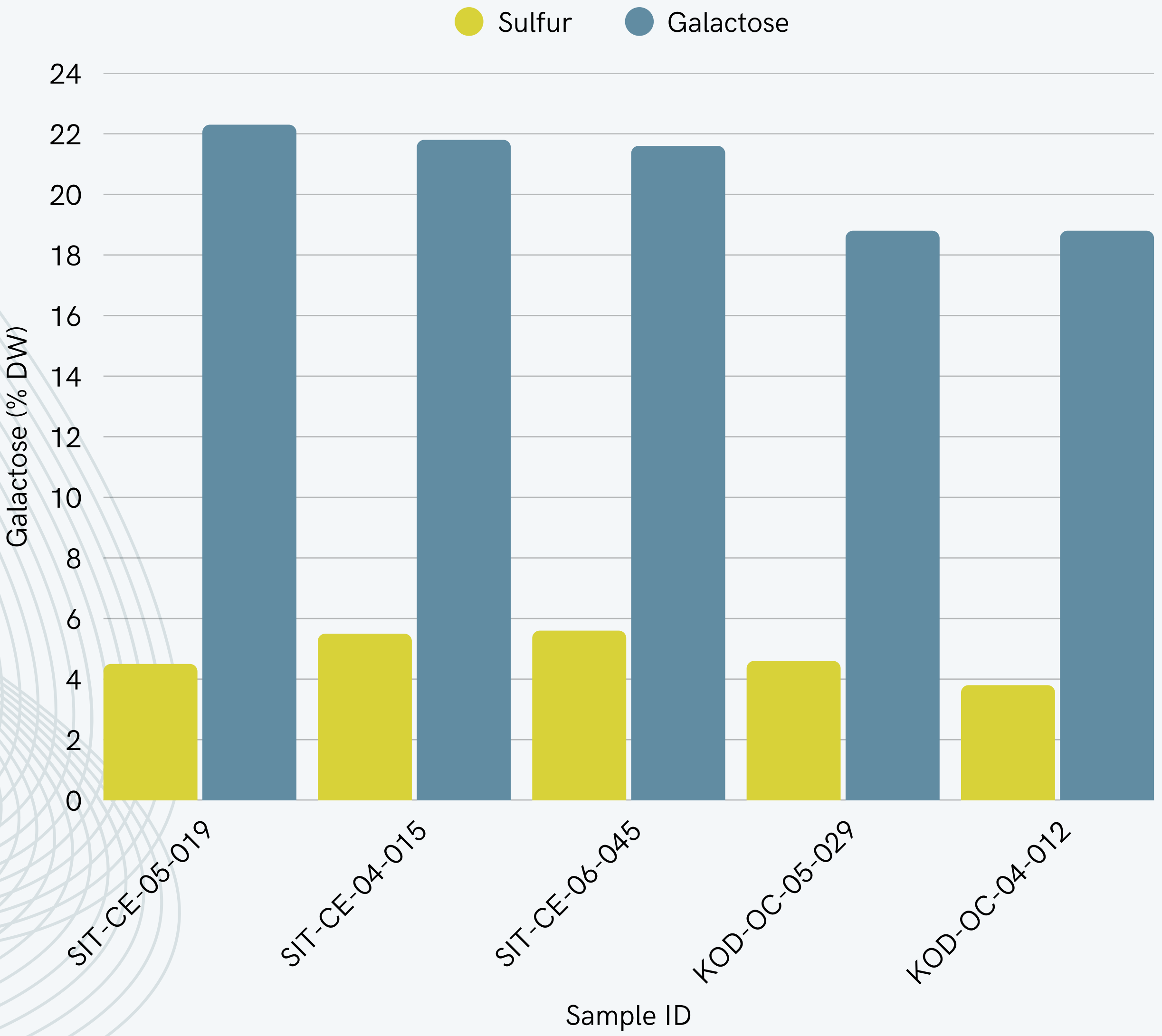
		Fucoidan composition (*% of total fucoidan*)			
	Fucoidan	**Fucose**	**Xylose**	**Mannose**	**Glucuronic Acid**
Macrocystis pyrifera					
SIT-MP-04-014	4.4	50.4	25.3	8.5	9
KOD-MP-04-002	4.4	29.3	29.4	16	20.7
SIT-MP-05-018	6	34.9	33.4	10.8	15.5
KOD-MP-05-025	5.7	33	23.7	14.6	16.4
SIT-MP-06-47	6.6	36.5	29.2	9.6	17.8
KOD-MP-06-039	6.4	25.3	41.7	18.7	9.9
Nereocystis luetkeana					
KOD-NL-04-013	3.2	26.3	20.4	22.5	23.9
KOD-NL-05-028	3.9	33.9	20.5	24.6	13.4
KOD-NL-06-040	2.6	41	23.4	27.4	ND
KOD-NL-06-047	1.5	60.7	2.9	5.6	5.4

Beyond the monosaccharide composition, researchers suggest the degree of sulfation plays a considerable role in fucoidan bioactivity (Wang et al., 2019). Degree of sulfation has been calculated as the molar ratio of sulfate:fucose (Rhein-Knudsen et al., 2023). Sulfate contents were not directly measured in this work, but sulfur content may be used to estimate sulfation (converting to S to SO3 to estimate a sulfated hydroxyl group). This approach is complicated by the xylose and galactose which may also be sulfated in fucoidan. No comments can be made on the sulfation pattern of the fucoidan identified in this project.

5.3 CARRAGEENAN

Carrageenan consists of a non-regular pattern of galactose derivatives - various combinations of sulfation patterns and anhydro-bridges - beyond description for this document. More info on carrageenan classes and structure can be found elsewhere (Mendes et al., 2024). Galactose and sulfur, a potential surrogate for carrageenan content, can be measured with relative ease in seaweeds, and was performed for this work. Red seaweeds, a known source of carrageenan, were shown to contain the most galactose and sulfur of all measurements (Figure 5). A total of 10/94 seaweed samples, all red, had >10% DW galactose content while total of 8/94 seaweed samples, had >3.5 %DW sulfur. *C. exasperates* and *O. californica* samples collected all had high galactose and sulfur content, perhaps indicative of high carrageenan levels. Carrageenan can exceed 50% DW of some red seaweeds (Asni et al., 2021).

Figure 5: Highest galactose values in red seaweeds.



5.4 GLUCOSE

Glucose is found in two major seaweed polysaccharides: laminarin (β-1,3-glucose) and cellulose (β-1,4-glucose). Total glucose was measured in all sample and only 6/94 samples contained >15 % DW (Table 16). A subset of brown seaweed samples (38/94) was analyzed further by carbohydrate class to estimate total laminarin and cellulose. Only SIT-SL-06-038 and KOD-SL-06-036 were shown to contain >10% DW laminarin.

Laminarin is a water-soluble oligomer and cellulose is water insoluble. Therefore, specific sample preparation is used to support quantification of each carbohydrate type. Methanolysis using methanol at low pH only allows for the detection of soluble sugars present in the samples. The insoluble fibers fraction, found in seaweed within the cell walls in the form of cellulose, cannot be quantified by this method (Stévant et al., 2018). More aggressive hydrolysis conditions must be used to measure cellulose (Becker et al., 2021). FDA includes cellulose as a recognized source of dietary fiber (21 CFR § 101.9(c)(6)(i)) and should be captured with insoluble fiber measurement (Section 3.3).

Table 16: Highest glucose values and associated carbohydrates (% DW).

	Glucose	Laminarin	Cellulose
SIT-HN-06-035	32	NM	NM
SIT-SL-06-038	27.5	19.3	5.9
SIT-HN-05-022	19.2	NM	NM
KOD-SL-06-036	16.3	14.7	1.1

5.5 MANNITOL

Mannitol is a sugar alcohol of commercial relevance in a range of industries. Mannitol has a distinct sweet taste and unique physical properties that lead to its use as a food additive (E421) in anti-caking agents, low-calorie sweetener, and bulking agent. Found in brown algae, it is accumulated especially in *Laminaria* spp. and *Saccharina* spp. where it can make up 20-30% DW of the algae (Holdt et al., 2011). Mannitol was found to be >20% DW in 9/94 samples (Table 17). An interesting trend appeared when comparing species collected at separate sites during similar time windows: Sitka samples consistently contained more mannitol than their Kodiak counterparts.

There are many variables that may contribute to this observation, including experimental ones. However, it may indicate potential in strategic site selection for stockpiling specific carbohydrates in seaweeds. Mannitol is known to rise in the summer months (Adams et al., 2011), which may explain why no sample from April contained >20% DW.

Table 17: Highest mannitol values and comparison across regions (% DW).

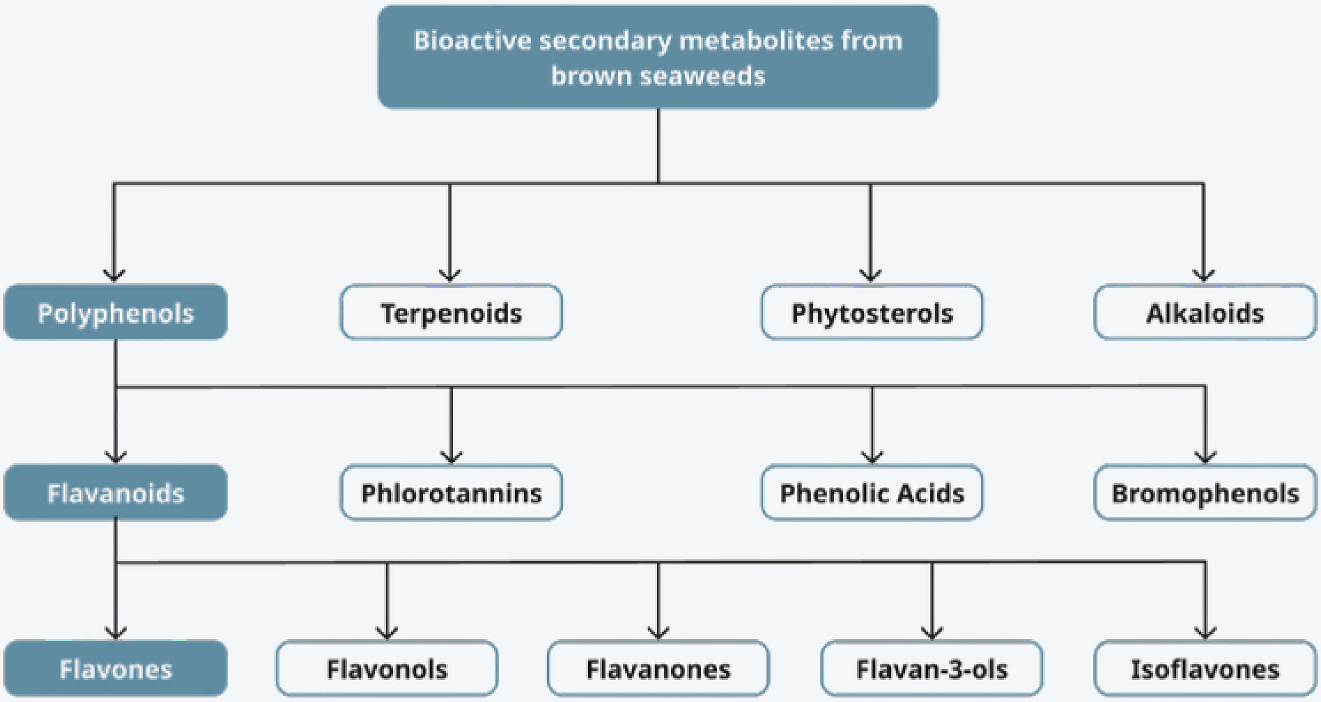
Sitka Samples		Kodiak Samples	
Species ID	**Mannitol**	**Species ID**	**Mannitol**
SIT-HN-05-022	30.6	**KOD-HN-05-017**	12
SIT-AC-06-046	28.1	**KOD-AC-06-034**	11.4
SIT-MP-06-47	26	**KOD-MP-06-039**	2
SIT-SL-05-026	23.6	**KOD-SL-05-019**	15.3
SIT-SL-06-038	22.6	**KOD-SL-06-036**	17.8
SIT-HN-05-021	22.5	**KOD-HN-05-017**	12

SECTION 6 - BIOACTIVES

Seaweed is widely sought as a source of unique bioactive molecules, specifically natural chemicals that can elicit beneficial health outcomes that are desirable in the food and personal care industries. Products that leverage these properties are readily identifiable by their use of the "-ceutical" suffix – e.g., nutraceuticals: food products that provide additional health benefits beyond basic nutrition (Matos et al., 2024); cosmeceuticals: cosmetic products that have medicinal or drug-like benefits (López-Hortas et al., 2021). Many of the carbohydrates discussed earlier – specifically fucoidan and laminarin - can be considered bioactives as they have been linked to distinct properties such as antimicrobial, antioxidant, or broad immunostimulatory effects (Lomartire et al., 2022).

Beyond carbohydrates, seaweed is also host to other bioactive molecules (Figure 6). For this study, pigments (Yordi et al., 2024) and polyphenols (Cotas et al., 2020) – including phlorotannins (Khan et al., 2022) and flavonoids (Vinodkumar et al., 2023) – were identified using either direct quantification or estimation using assays. The goal is to better understand how Alaskan seaweed compares in bioactive content to analogous species found globally.

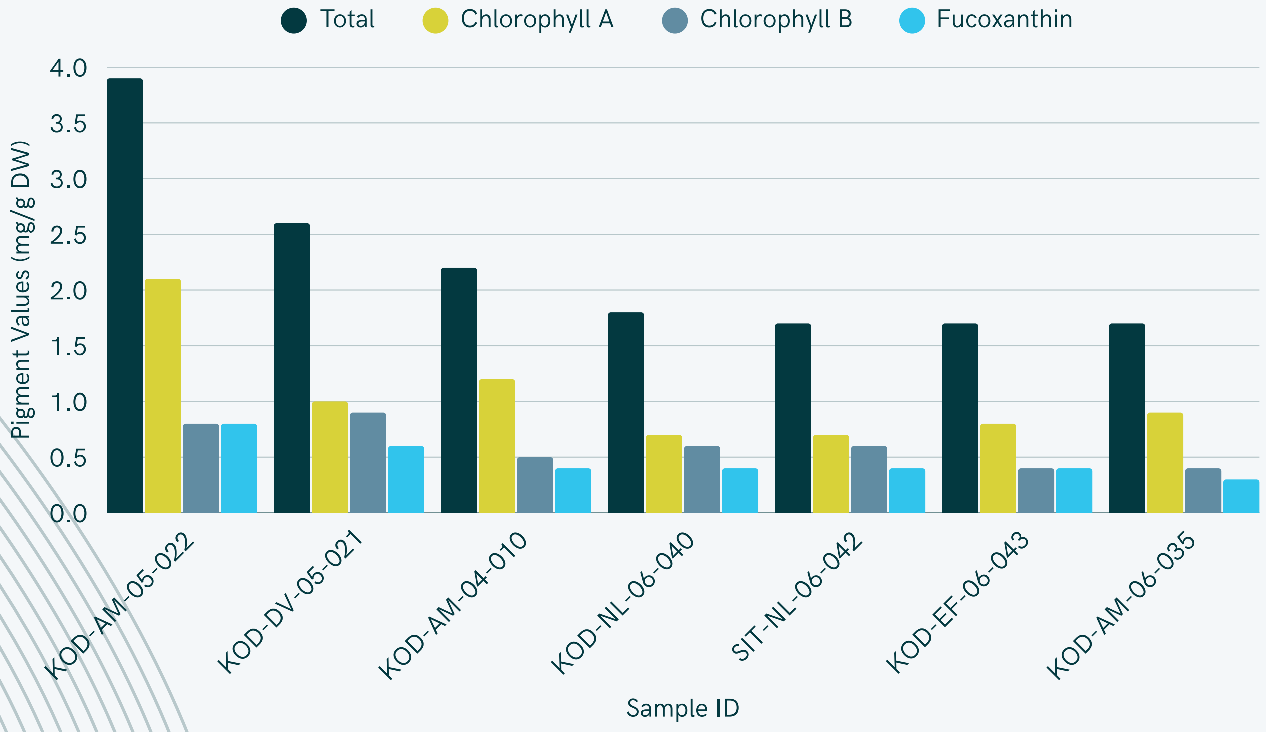
Figure 6: Select examples of bioactive chemicals in brown seaweed (Vinodkumar et al., 2023).



6.1 PIGMENTS

All brown and red seaweeds (81/94) collected in this project were tested for pigments (chlorophylls: Chlorophyll A, Chlorophyll B, Chlorophyll C; carotenoids: Violaxanthin, Antheraxanthin, Lutein, Zeaxanthin, Beta-Carotene, and Fucoxanthin). The total pigment content ranged from 0.02-3.9 mg/g DW, with brown seaweeds generally higher than reds (Figure 7). The greenish-brown color of brown seaweed is attributed to fucoxanthin, together with chlorophylls A and C (Yordi et al., 2024). Previous work with *N. luetkeana* has noted these pigments show highest levels in fall-winter with decreasing values at other times in the year (Wheeler et al., 1983) - so the values may be lower as a result of the harvest season targeted in this study.

Figure 7: Highest total pigment values and select pigments.



Fucoxanthin has attracted considerable attention as a seaweed refinery target due to observations of remarkable biological properties (Peng et al., 2011). The fucoxanthin content of brown seaweed has been studied in Asia, Europe, and Australasia (Din et al., 2022), but considerably less is known about the North American counterparts. Considerably more Fucoxanthin (2-4 mg/g DW) has been observed in brown seaweeds collected from the Atlantic Ocean (Rubino et al., 2022). Wheeler et al. describe the pigment content of N. luetkeana in detail but report the amount as µmol pigment·m-2; a value not readily converted to mg/g DW. The presence of these compounds is of considerable importance for manufacturers of functional food, however more research is required to accurately assess the potential of Alaska seaweeds for pigment extraction.

6.2 POLYPHENOLS, PHLOROTANNINS, FLAVINOIDS

Polyphenols are a class of molecules that feature phenol (hydroxybenzene) units throughout a complicated hodgepodge of organic derivatizations. The main polyphenols of commercial interest in seaweed are phlorotannins (phloroglucinol derivatives) and flavonoids (benzopyrone derivatives). Laboratories typically utilize specialized assays prior to costly (and difficult) quantification of the individual polyphenol types. These tests compare the activity – typically as an antioxidant – of a sample against a known standard (Table 18).

Table 18: Chemical assays used to estimate polyphenol content in seaweed.

Assay	Unit
Total Phenolic Content	mg gallic acid equivalent (GAE)/g DW
Total Phlorotannin Content	mg phloroglucinol equivalent (PGE)/g DW
Total Flavonoid Content	mg quercetin equivalent (QE)/g DW

Total phenolic content was found to range from 1-32 mg GAE per g DW (Table 19). Previous research on Canadian seaweeds of the Atlantic measured the total phenolic content of genera from this study (Tibbetts et al., 2016) – namely *Saccharina* spp., *Fucus* spp., and *Alaria* spp. – as well as commercial seaweed blends. The values observed in this study align with these results. It is hard to identify outliers, but multiple *Fucus* and *Ulva* samples rank in the top 6 samples for total phenolic content.

Table 19: Highest total phenolic content (mg GAE/g DW).

This Study		Tibbetts et al., 2016	
Sample ID	**Total Phenolic Content**	**Reference ID**	**Total Phenolic Content**
SIT-SL-05-026	32	*S. latissima*	11
KOD-US-04-008	20	*A. esculenta*	18
KOD-US-05-023	20	*F. vesiculosus*	47
SIT-FD-06-048	16	Kelp/Dulse Blend	21
KOD-FD-06-037	16	Kelp Blend	44
SIT-FD-05-032	16	*A. nodosum*	59

Total phlorotannin content was found to range from 0.1-7.3 mg PGE per g DW (Table 20) and was only measured in the brown seaweed samples (64/94). Both Macrocystis and Fucus appear multiple times in the top 5 samples for total phlorotannin content. Further, F. distichus (KOD-FD-06-037 and SIT-FD-06-048) rank in the top five for total phenolic and phlorotannin content. Phlorotannins have been suggested to possess a plurality of beneficial bioactivities (Venkatesan et al., 2018).

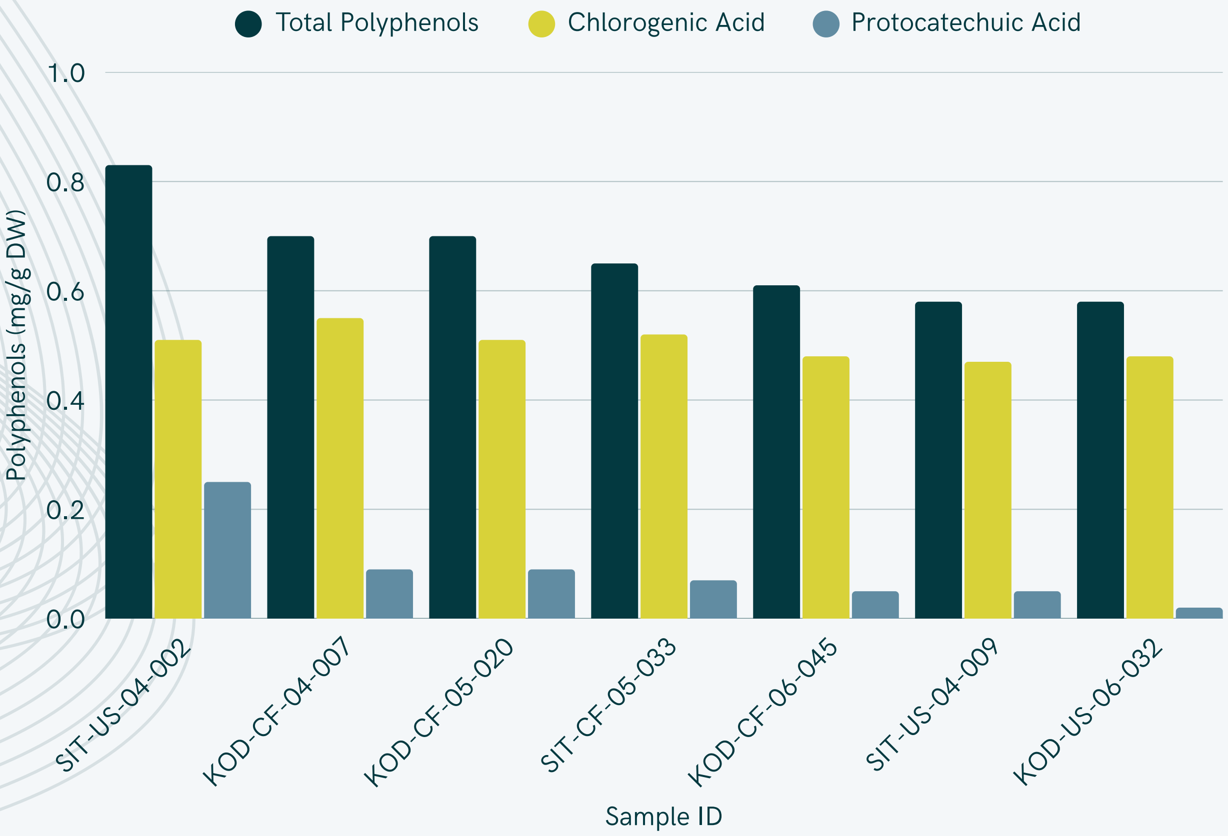
Table 20: Highest total phlorotannin content (mg PGE/g DW).

Sample ID	Total Phlorotannin Content
SIT-MP-05-018	7.3
KOD-FD-06-037	5.9
SIT-FD-06-048	4.8
KOD-MP-06-039	4.5
KOD-AM-06-035	4.4

The general approach for phlorotannin measurement is to utilize the Folin-Ciocalteu assay or reaction with 2,4-dimethoxybenzaldehyde – both approaches creating specific complexes with phenolic compounds that can be identified spectrophotometrically (Najibi et al., 2025). Some research has suggested use of the Folin-Ciocalteu assay is not indicative of the actual phlorotannin content in seaweeds due to side reactions (Sardari et al., 2020). Still, it remains the most common method to rapidly assess the phlorotannin content of a range of samples. It may be a better 'relative' measurement that can help guide future evaluations of seaweeds intended as phlorotannin feedstock.

Seaweed samples were measured for the presence of distinct polyphenols (e.g., Chlorogenic Acid, Syringic Acid, Gallic Acid, p-Coumaric Acid, Ferulic Acid, Vanillic Acid, Vanillin, Caffeic Acid, Salicylic Acid, Protocatechuic Acid, Catechin, Quercetin). The total polyphenol content ranged from 0.03 – 0.83 mg/g DW. The highest individual polyphenol values were found in the green seaweeds *Ulva* and *C. fragile* samples (Figure 8). These samples are particularly high in chlorogenic and protocatechuic acid. Green coffee bean extracts are rich in chlorogenic acid, and it has potentially beneficial anti-inflammatory and antioxidant properties (Nguyen et al., 2024). Similarly, protocatechuic acid is found in plants that are high in phenolics – Queen Anne's Thistle: 12-14 mg protocatechuic acid/g DW - and has shown anti-inflammatory, antimicrobial, and antioxidant effects (Mahfuz et al., 2022). Protocatechuic acid has been observed in extracts of red seaweed (*M. japonica*: Hossain et al., 2025) and green seaweed (*U. fasciata*: Mahfuz et al., 2022).

Figure 8: Highest total polyphenols values and select phenols.



Total flavonoid content was found to range from 0.1-16.5 mg QE/g DW. The highest flavonoid-containing samples (Table 21) often showed high total phenolic content (Table 19) – e.g., *Ulva* and *Fucus* samples. There is little information on the flavonoid content of the seaweeds in this study, but a range of levels has been observed in seaweed (Verma et al., 2025; Zhong et al., 2020). Like phlorotannins, flavonoids are a difficult class of molecule to accurately quantify. A detailed speciation would require a level of phytochemical profiling (Nicolescu et al., 2025) beyond the scope of this project.

Table 21: Highest total flavonoid content (mg QE/g DW).

Species ID	Total Flavonoid
KOD-US-05-023	16.5
SIT-FD-05-032	12.7
SIT-FD-04-016	11.6
KOD-FD-06-037	9.5
KOD-US-06-032	8.5

SECTION 7 - SEAWEED APPLICATIONS

This study was intended to identify potential species of interest for future cultivation efforts. In particular, the study designers hoped the chemical data would point towards use cases where Alaskan seaweed could excel. This section aims at highlighting some of the application requirements and certain seaweed data that may indicate potential within these fields. Wherever possible, analogies to existing products or regulations will be made.

7.1 ***FOOD***

Seaweed use as a substantive food ingredient is most common in the Asian Pacific, where it is found in soups, salads, and most meals, but adoption is increasing within North America. Its ubiquitous use in food processing is due to its versatility as an additive - providing beneficial gelling and thickening properties that are vital for commercial meat, dairy, confectionery, bakery, and consumer products. This section will focus on seaweed use as a nutrient or supplement and avoid the more qualitative evaluation of applications as a flavorant - despite the strict CFR definitions for brown and red algae (21 CFR § 184.1120 and 21 CFR § 184.1121, respectively).

Flavour can be difficult to quantify; seaweeds have specific sensory properties described as marine, crustacean, or green, and tastes of both salt and umami (Jönsson et al., 2023). The umami flavors may be attributed to the presence of specific amino acids: aspartic acid and glutamic acid. Amino acid profiling (Section 3.4) revealed that these "umami" compounds dominate the protein composition. Some samples were observed to contain 2-3% DW aspartic acid and >3% DW glutamic acid - but in general, all seaweed samples contained these amino acids.

The traditional nutrients of greatest interest are minerals and fiber. Vitamins, as discussed in Section 3.6, are below the threshold to assume a realistic daily intake will amount in a suitable dosage. Protein values, while inspiring on a dry matter basis, are not likely to be a major driver for adoption of seaweed food ingredients. Reports highlighting seaweeds as the new animal-free protein source (Celente et al., 2023) rarely explore the different economics associated with drying compared to terrestrial crops - e.g., soy, legumes, wheat - that can be cut and left in a field. Such low-cost processing is not possible for seaweed except in warm, dry climates.

An adequate daily intake of minerals is essential for the prevention of chronic nutrition-related and degenerative diseases, including cancer, cardiovascular disease, and obesity (Muñoz et al., 2020). Seaweeds contain 10 to 20 times the amount of minerals when compared to land plants due to bio-accumulation from seawater (Holdt et al., 2011). The most deficient minerals in humans are Cr, Mg, Zn, and Ca (Campbell 2001).

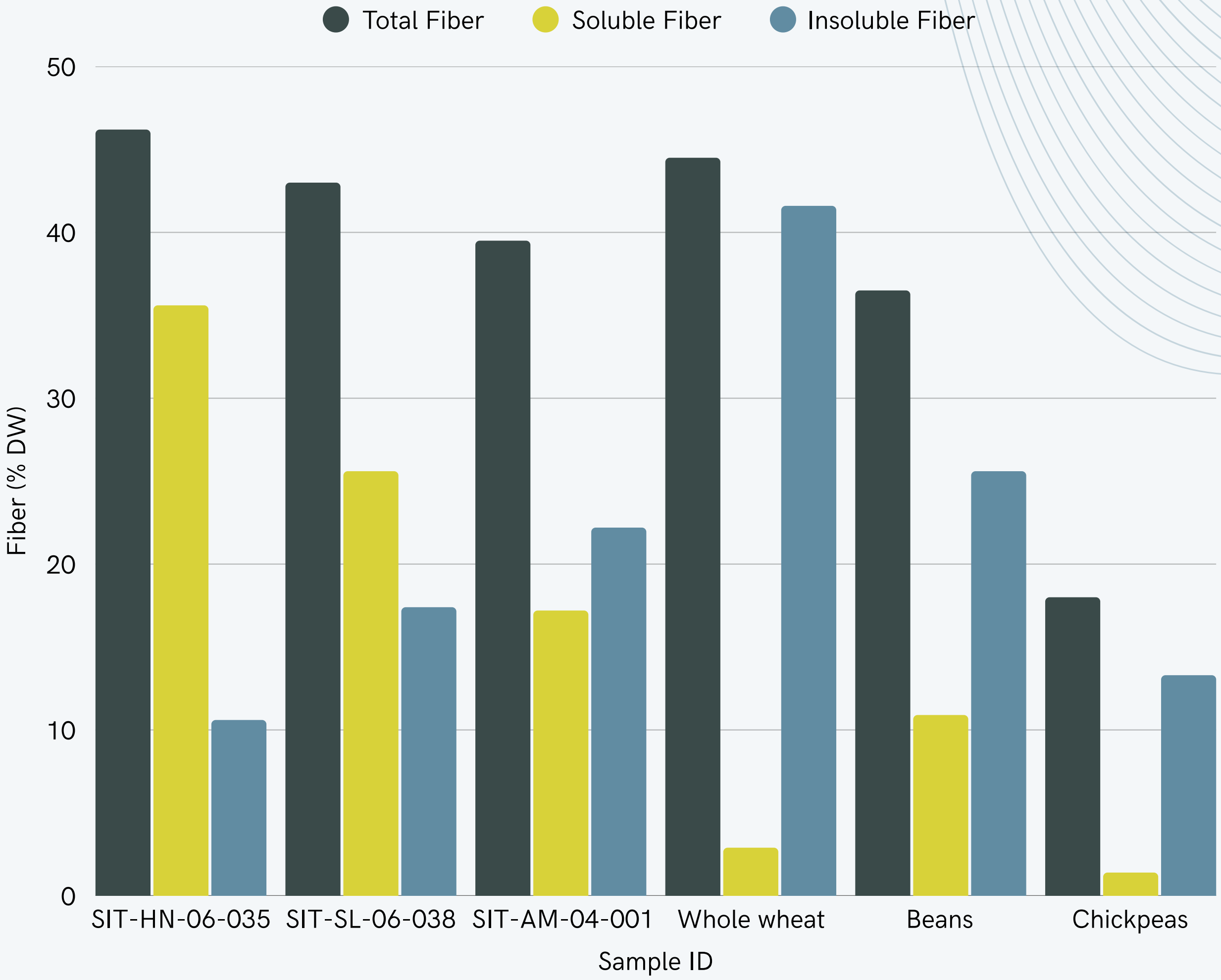
Calcium and Magnesium appear most associated with seaweed: levels of up to 3.7% DW were observed. In fact, seaweed samples collected during this project were shown to greatly exceed essential mineral levels of other common foods (Table 22).

Table 22: Minerals in common food sources and comparison to select seaweed samples, adapted from Muñoz et al., 2020 (all values mg/g DW).

Essential Mineral	Food Source (USDA)		Seaweed ID	
Calcium	*Collard Greens*	23	KOD-AC-05-018	37
	Kale	25	SIT-AC-04-017	34
Magnesium	*Rice Bran*	8	SIT-US-05-020	37
	Basil dried	7	SIT-US-04-002	25
Potassium	*Parsley, freeze-dried*	63	SIT-GP-04-012	160
	Tomatoes sun-dried	34	SIT-NL-06-037	157

In Asia, seaweeds have been used in human nutrition since ancient times and the role they play in mitigating high blood lipid and lipoprotein levels and the risk of coronary heart disease has been studied (Jiménez-Escrig et al., 2000). Nowadays, dietary fiber from different sources is known to decrease the risk of coronary heart disease. Dietary fiber from brown algae is essentially composed of four families of polysaccharides: laminarins, alginates, fucoidans, and cellulose. Seaweed is rich in carbohydrates and, as many of these sugars are indigestible, fiber. Where it appears to outperform other foods is the comparably large percentage of soluble fiber (Figure 9). Alginate has been specifically reviewed by US food authorities in the document "Science Review of Isolated and Synthetic Non-Digestible Carbohydrates" (FDA, 2016), ostensibly paving the way for its inclusion in fiber claims (21 CFR § 101.9(c)(6)(i)). Beyond alginate, laminarin is also an excellent source of soluble dietary fiber and studied to support intestinal metabolism (Karuppsamy et al., 2022).

Figure 9: Fiber in common food sources and comparison to select seaweed samples, adapted from Jiménez-Escrig et al., 2000.



There is concern over chemical hazards in the adoption of seaweed ingredients, specifically heavy metals (Section 4.1) and iodine (Section 4.2). The results of this study indicate that heavy metal levels are generally in alignment or lower than other seaweed products (CFIA, 2020). Still, any product quality control protocol should include periodic monitoring of heavy metals. Iodine is more application-specific: depending on the seaweed source and dose, it is possible to exceed the maximum daily recommendations of FDA (225 µg/day) or NIH (1 mg/day). There is tremendous focus in the food chemistry community to identify processing methods that reduce iodine levels in seaweed. Success has been observed for warm water treatment, boiling, and fermentation shown to remove up to 90% of iodine (LibergKrook et al., 2024). This is accompanied by a drastic reduction in other minerals – many of which are potentially beneficial as discussed above. Documented adherence to iodine limits is, and will continue to be, a major component of a company's Quality Control protocol.

7.2 AGRICULTURE

Plant Health: Fertilizers and Biostimulants

Seaweed is found in a range of plant health products – in liquid extract or solid meal format. It can be considered a fertilizer – material of natural origin which is added to soil to provide nutrients necessary to sustain plant growth (USDA, 2012) – when it is used to provide key micronutrients such as potassium, calcium, or magnesium. It is also used as a plant biostimulant – a material that stimulates natural processes to enhance or benefit nutrient uptake, nutrient efficiency, tolerance to abiotic stress, or crop quality and yield (USDA, 2019). In the US, a seaweed product intended to be used with crops must adhere to fertilizer regulatory programs established at the state level. In most cases, these agencies are strictly concerned with contaminants (heavy metals) in fertilizer products at unsuitable levels (Fertilizer Tonnage Reporting, 2025). The seaweed samples analyzed in the project adhered to the heavy metal standards for food-grade seaweed and should be well-suited to the production of agricultural products.

Potassium will continue to be a major plant nutrient that is common to seaweed. Potassium levels up to 16% DW were observed, and many seaweed samples showed elevated potassium levels (Section 3.2). Other minerals, especially calcium and magnesium, should be monitored. Laminarin is also relevant to plants. It has been shown to stimulate the natural defense reactions of a wide variety of agricultural crops, including vegetables and fruits, against plant pathogens such as bacteria and fungi (Aziz et al., 2003). The EPA published regulations related to laminarin use as a biopesticide (40 CFR § 180.1295). Unfortunately, the data was not complete to make interpretations of laminarin content in the samples. In general, biostimulant activity is difficult to predict by composition alone. Carbohydrates represent the largest organic component of seaweed and are reported to contribute largely to observed bioactivity in plant health applications (EBIC, 2023).

Animal Health

Seaweeds for animal feed are single or mixed species seaweed blends commonly prepared by drying and milling. They are often marketed as mineral supplements but are increasingly being considered as a natural source of functional health chemicals that can substitute antibiotic usage in certain animals, increase performance, and/or improve general animal health (Morias et al., 2020). The similar mineral considerations of humans (Section 7.1) and plants (Section 7.2.1) apply to animals. Potassium will continue to be the mineral of note. According to AAFCO, the product shall be labelled with guarantees for maximum percentage of salt (NaCl) and the minimum percentage of potassium (K). A minimum or maximum guarantee for iodine must also be stated. Fiber and total carbohydrates may be important for gut health and should be documented.

The mineral of most frequent concern is iodine. Seaweed is rarely expected to be a major component of an animal's diet (<10%, as fed) and therefore makes up only a small portion of the complete feed. AAFCO set the maximum daily inclusion of iodine is much lower for horses (5 mg/kg complete feed) as compared with swine (400 mg/kg complete feed) or cattle (50 mg/kg complete feed). The highest iodine level measured in the study (1600 mg/kg) would permit up to 3% inclusion in cattle diet without any iodine-reduction treatment.

Methane Reduction

Seaweed has attracted recent interest as a food additive to reduce methane production in ruminants. This is largely due to emerging research on the red seaweed Asparagopsis spp. (reviewed in Wasson et al., 2022; Camer-Pesci et al., 2023). This seaweed, when appropriately dried or processed, has been shown to reduce enteric methane emissions >80% when fed at surprisingly low concentrations (<1% DM). This is not a seaweed native to the US or recognized in food or animal feed regulations. The use of other seaweeds to reduce methane emissions in cattle continues to be explored - although evidence is comparably lacking to Asparagopsis-based strategies. Both bromoform (Asparagopsis) and phlorotannins (brown seaweeds) have been reported as the methane-reducing compounds from seaweed (Min et al., 2021). Red seaweeds from this project were analyzed for bromoform, and none was detected. The methane reduction effects of phlorotannins are much less understood, so the project data is not comparable.

7.3 ***HUMAN HEALTH***

Section 6 discussed different bioactive molecule classes that are being explored in nutraceutical and cosmeceutical applications, among other human health applications. Seaweed use is certainly more ubiquitous in cosmetics than any other health segments. The interest in these products is based on increased demand for natural ingredients, the versatility of the bioactive compounds, and technical features imparted by their inclusion in formulations (López-Hortas et al., 2021). Seaweed polysaccharides have many cosmetic functions. For example, they act as rheology modifiers, suspending agents, hair conditioners, and wound-healing agents, and can also moisturize, hydrate, emulsify, and emolliate (Goddard et al., 1999).

Skin naturally possesses antioxidant agents able to block reactive oxygen species (ROS) and avoid cell destabilization (Wang et al., 2015). However, these defenses can be overrun when the amount of ROS is increased by UV exposure, which can lead to cell damage, DNA breakdown, and cell death - all contributors to skin dryness. ROS accumulation may thus be responsible for photoaging complications, such as inflammation, melanoma, and skin cancer. Seaweed rich in antioxidants, which will react with ROS, may be applied to prevent skin aging and cutaneous disorders. Antioxidant activity was not specifically measured in this projec,t but has been associated with polyphenol content (Section 6.2): high total phenolic and flavonoid content extracts display high antioxidant capacities (Kim et al., 2024; Castejón et al., 2021; Zhong et al., 2020).

Seaweed for gut and body health (nutraceutical) applications is an emerging field (Matos et al., 2024). There is recent increase of interest in using seaweeds to reduce diseases like hyperglycemia, hypercholesterolemia, and hyperlipidemia (Charoensiddhi et al., 2017). The major focus in these cases is application as a prebiotic (Section 3.3) or specific nutrient source. Still, researchers and companies continue to explore processing methods and chemical assaying to unlock consistent bioactivity from seaweed to support more targeted (and stringent) nutraceutical applications.

7.4 BIOMATERIALS

Seaweed is finding increasing application as a biomaterial, specifically in packaging (Manikandan et al., 2025), building materials (Mendili et al., 2025), and even tissue engineering (Farshidfar et al., 2023). Most interest is focused on using seaweed to replace plastic in common applications. The slow degradation of plastics, combined with their widespread use in single-use products, has resulted in a significant accumulation of plastic waste (Torrejon et al., 2024). Seaweed’s biochemical composition, high in hydrocolloids like alginate and carrageenan, makes it suitable for bioplastics production due to its gelling and film-forming properties. In addition to these hydrocolloids, seaweed also contains cellulose, which also has the potential as a raw material for bioplastic production. Recently, biotechnology companies have secured patents where alginate/seaweed is explicitly used in the production of bioplastics (Notpla: US20230080039A1; US20250144864A1 and Sway: US20230147656A1).

Alginate was found to range from 9-32% DW in brown seaweeds analyzed in this project. Two samples of *A. marginata* were found to have alginate levels that greatly exceeded all other samples (AM-04-001: 32% DW; AM-05-025: 30% DW) and had elevated mannuronic acid levels (AM-04-001: 28% DW; AM-05-025: 26% DW). All seaweeds were found to have greater mannuronic acid than guluronic acid. The M/G content of the alginate is related to its physical properties, and this may impact applications as a bioplastic component. Alginate bioplastic films are reported to offer desirable attributes such as low oxygen permeability, biodegradability, and compatibility with functional additives. In food packaging, these films can be tailored as active packaging systems by incorporating antimicrobial agents, antioxidants, and UV-barrier compounds to improve food preservation and safety (Grau, 2024). Alginate and its hydrogels have been widely employed in tissue engineering due to its outstanding properties in terms of hygroscopicity, biocompatibility, biodegradability, non-toxicity, flexibility, and chelating ability. However, alginate alone has some drawbacks which hinder its potential for further biomedical applications without crosslinking or other additives. More research is needed to determine the ideal alginate quantity and composition for seaweeds intended as a biomaterial. Still, beyond medical, biomaterial applications will continue to be lower-value opportunities for cultivated seaweeds compared to nutrition and health.

SECTION 8 - ALASKA SEAWEED TISSUE ANALYSIS 2025

This project produced an exceptional amount of quality data to support the benchmarking of seaweeds across Alaska. These results demonstrate the safety, biodiversity, and rich industrial applicability of these seaweeds. This report was intended to highlight initial findings across the broad range of test types but may be incomplete. The public is encouraged to consider deeper assessment of the public Alaska Seaweed Tissue Analysis Project data available online. The major goal of this project was assessing product safety and establishing species standards to guide future innovations within the Alaska seaweed industry. A secondary goal was to highlight unique species worth exploring for new innovative applications. A diverse collection of seaweed samples of different species, locations, and season were collected and analyzed. Using this data, nutrition and biological traits were identified and safety/standards established. This is certain to guide product development and research endeavors across Alaska with an eye towards global markets.

The samples in this project were largely wild-sourced. To expand the scope, the follow-up Alaska Seaweed Tissue Analysis Project 2025 focused on sampling at commercial operations, including kelp farms and commercial-scale wild harvests, to build a complementary data set to this initial 2024 work. A detailed chemical profiling akin to this project is beyond the scope of a standard farmer panel. A simplified profile was adopted for 2025, focusing on nutrients, hazards, carbohydrate profile, and allergens. Laboratory testing is being performed at ISO 17025:2017 certified third-party locations to align with food industry standards. Contributing farmers receive a complete chemical data package and draft product specification for each sample they contributed. This work will increase industry awareness, document product safety, inform marketing efforts, and allow regions to better serve specific markets.

APPENDIX

Data tables assosciated with corresponding figures.

TABLE A1 - FIGURE 2 (PAGE 20). HIGHEST WATER-SOLUBLE VITAMIN VALUES (MG/KG DW).

Sample ID	WSV (total)	Ascorbic Acid (C)	Niacin (B3)
SIT-FD-05-032	640	530	100
SIT-AM-06-041	420	360	52
SIT-AM-06-041	290	240	46
SIT-AM-06-041	270	250	8
SIT-AM-06-041	250	220	26

TABLE A2 - FIGURE 3 (PAGE 20). HIGHEST FAT-SOLUBLE VITAMIN VALUES (MG/KG DW).

Sample ID	FSV	Beta-Carotene (A)	Alpha-Tocopherol (E)
SIT-AM-05-025	150	130	24
SIT-FD-06-048	130	96	35
KOD-EF-04-001	90	71	11
KOD-AM-04-010	80	72	7
KOD-AM-06-035	84	66	17

TABLE A3 - FIGURE 5 (PAGE 28). HIGHEST GALACTOSE VALUES IN RED SEAWEEDS (% DW).

Sample ID	Galactose	Sulfur
SIT-CE-05-019	22.3	4.5
SIT-CE-04-015	21.8	5.5
SIT-CE-06-045	21.6	5.6
KOD-OC-05-029	18.8	4.6
KOD-OC-04-012	18.8	3.8

TABLE A4 - FIGURE 7 (PAGE 32). HIGHEST TOTAL PIGMENT VALUES AND SELECT PIGMENTS (MG/G DW).

Sample ID	Total	Chlorophyll A	Chlorophyll B	Fucoxanthin
KOD-AM-05-022	3.9	2.1	0.8	0.8
KOD-DV-05-021	2.6	1	0.9	0.6
KOD-AM-04-010	2.2	1.2	0.5	0.4
KOD-NL-06-040	1.8	0.7	0.6	0.4
SIT-NL-06-042	1.7	0.7	0.6	0.4
KOD-EF-06-043	1.7	0.8	0.4	0.4
KOD-AM-06-035	1.7	0.9	0.4	0.3

TABLE A5 - FIGURE 8 (PAGE 35). HIGHEST TOTAL POLYPHENOLS VALUES AND SELECT PHENOLS (MG/G DW).

Species ID	Total Polyphenols	Chlorogenic Acid	Protocatechuic Acid
SIT-US-04-002	0.83	0.51	0.25
KOD-CF-04-007	0.7	0.55	0.09
KOD-CF-05-020	0.7	0.51	0.09
SIT-CF-05-033	0.65	0.52	0.07
KOD-CF-06-045	0.61	0.48	0.05
SIT-US-04-009	0.58	0.47	0.05
KOD-US-06-032	0.58	0.48	0.02

TABLE A6 - FIGURE 9 (PAGE 39). FIBER IN COMMON FOOD SOURCES AND COMPARISON TO SELECT SEAWEED SAMPLES (ADAPTED FROM JIMÉNEZ-ESCRIG ET AL., 2000, ALL VALUES % DW).

Source	Insoluble Fiber	Soluble Fiber	Total Fiber
SIT-HN-06-035	10.6	35.6	46.2
SIT-SL-06-038	17.4	25.6	43
SIT-AM-04-001	22.2	17.2	39.5
Whole wheat	41.6	2.9	44.5
Beans	25.6	10.9	36.5
Chickpeas	13.3	1.4	18