UNIVERSITY OF GOTHENBURG

DEPARTMENT OF MARINE SCIENCES

CULTIVATING RED SEAWEED PALMARIA PALMATA

Cultivation method and attitudes in the seaweed industry

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Popular scientific summary

Seaweeds have been cultivated and harvested for human consumption during centuries across the globe. Asian markets dominate seaweed cultivation and trade today and historically, owing to more than 90 percent of global production. The interest in seaweeds in the western world has increased in recent years, perhaps due to the diversification of its cuisine and appreciation for new flavors. Moreover, the need to feed a growing population and to find new foods for a balanced diet is becoming increasingly important in times of global change and strained agricultural systems. Seaweeds are particularly interesting due to their low carbon footprint in the production stage and the relatively few environmental impacts of cultivation. In terms of nutrition, seaweeds contain several beneficial vitamins and minerals, and some have protein levels comparable to soybeans making them a potential addition to plant-based protein alternatives.

One of these high-protein seaweeds is *Palmaria palmata*, commonly known as Dulse. It is a red seaweed growing along the northern coastlines of the Atlantic and Pacific Oceans. Dulse has been consumed as a snack food and used as flavoring for centuries in coastal communities of Ireland, Scotland, and Iceland. It is known for being rich in umami flavor and having a pleasant smokey taste when dried. Today, it can also be found on markets in Europe and North America where it is marketed as a health food, dietary supplement, or seasoning. Dulse is primarily collected by wild harvest while cultivation of the species is limited due to the complexity of its life cycle. It has been identified as one of the most interesting seaweed species for commercial production and previous studies have evaluated different cultivation methods, including both land-based solutions and open-sea farming. This thesis evaluates how light intensity and nutrient levels affect the growth of dulse. It also investigates what the attitudes are towards production of dulse in the seaweed industry in Scandinavia. Hopefully, the results can contribute to the knowledge needed to cultivate dulse and provide an insight to the mindset of the seaweed industry in Scandinavia.

Abstract

The purpose of this thesis is to evaluate the prospects of cultivating *P. palmata* from a technical point of view and to gain knowledge on the industry perspective in Scandinavia. The method was developed based on a pilot study done at Tjärnö Marine Laboratory and proceeded with new trials of cultivation techniques. The experimental cultivation focused on the effects of light intensity level and nutrient level on growth rates and dulse quality. Questionnaires were used during a seaweed conference at the Tjärnö Marine Laboratory to gain knowledge about the attitudes within the industry. The findings show that *P. palmata* growth rates increase when light intensity and nutrient level is increased, but this may result in trade-offs regarding the quality. Furthermore, the findings from the questionnaire show that interest for P. *palmata* is high and people in the industry view the species to be well-established in some areas of use and up-and-coming in new applications.

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1. Introduction

1.1 Ecology and uses of *Palmaria palmata*

The red seaweed *Palmaria palmata,* commonly known as dulse, is found along the northern coastlines of the Atlantic and Pacific Oceans where it grows in intertidal or shallow subtidal areas (Lüning, 1990). It typically thrives in cold and turbulent waters and attaches with disk-like holdfasts to the surface of rocks or macro algae e.g., *Laminaria hyperborea*. The fronds vary in color from deep purple to reddish brown which turns into a brighter red or pink after drying in the sun. The texture is leathery, and the fronds can grow to be around 50 cm long and 3-8 cm wide shaped like the palm of a hand, which is reflected in its Latin name *palmata* (Lüning, 1990). *P. palmata* has a long history of human consumption, especially along the Northern Atlantic coast where it has been used as a food source since the fifth century according to records from Ireland. Dulse was consumed by the Irish and Scottish at this time and they are believed to have brought the tradition of eating dulse to Iceland and North America (Mouritsen et al., 2013). The regularly occurring low tides of these shores enabled the locals to pick fresh dulse which was often used in inland trading. For coastal landowners, most notably in Iceland, dulse was an important source of income (Mouritsen et al., 2013).

While dulse may have been eaten for lack of better food in the past, today, it is considered one of the most flavorful and gastronomically relevant seaweeds. Indeed, in those parts of the western world where seaweeds are part of the traditional cuisine, dulse may be the most popular variety (Mouritsen et al., 2013). Sometimes referred to as the 'bacon of the sea', dulse develops flavors of salty licorice and smoke when dried, and toasted dulse has a pleasant nutty taste (Mouritsen et al., 2013; Mouritsen et al., 2012). Today, dulse is consumed mainly in Ireland and Iceland where it has a long history in the local cuisine. The fresh dulse is usually picked by hand and sun-dried on site before the fronds get sorted and cleaned in small-scale factories. The fronds are then stored to ripen before they are packaged and sold. The dried seaweed is a common snack food in places like the Westman Islands in Iceland. It is used as flavoring in soups, and blends of seaweed salts with dulse can be found in grocery stores (Grote, 2019; Mouritsen et al., 2013; Ocean umami salt flakes, 2022). Dulse can also be found in dietary supplements on markets in Europe and North America. Despite its many appealing qualities as a food, dulse is not commonly used in western household cuisine. Aside from the small-scale traditional uses, dulse has started to find its way into the New Nordic Cuisine where its rich umami flavor is highly sought after (Mouritsen et al., 2012). In Sweden, the interest in wild foraging is increasing and so is the interest for different seafoods, including seaweed. This is reflected in books like "Plocka tång & strandväxter" (Sjögren & Martinson, 2021) that encourage picking and using seaweeds, including dulse, in cooking.

1.2 Nutritional aspects

Other than being a flavorful additive or a tasty snack, dulse has potential to contribute to food security and the green protein shift that is needed to increase global food production and reduce emissions from the livestock and agriculture industries (Bjarnadóttir et al., 2018). The European commission is presently invested in a cross-sectoral EU algae initiative since algae have been identified as an untapped resource in Europe. The EU recognize the algae industry as being an important part in the development towards a green, circular, and carbon-neutral region (European commission, 2021). The nutritional and culinary properties of dulse make it an interesting candidate in this developing industry.

Dulse contains up to 20-25 percent protein by dry weight (Morgan et al., 1980a). This is supported by recent studies of protein extraction that present figures up to 42.1 percent essential amino acids (EAA) (Bjarnadóttir et al., 2018), and 38.6 percent EAA, comparable to the protein content of soybeans (40% EAA) (Mæhre et al., 2014). Protein content is generally high but varies due to variation in season and geographical location, and due to use of different extraction methods (Mæhre et al., 2014). Most importantly, protein from dulse meets the human requirements for EAA and the protein quality of seaweeds may even be superior to most terrestrial plants (Mæhre et al., 2014). Total lipid content also varies between studies, 0.2 – 3.8 percent in Morgan et al. (1980) and 0.4 – 1.8 percent in Mouristen et al. (2013). In either case lipid content is generally low and not sufficient as a sole source of fatty acids in human diets (Mæhre et al., 2014). Carbohydrate content is estimated to 38 – 74 percent on a dry weight basis (Morgan et al., 1980a; Mæhre et al., 2014). Furthermore, dulse contain several important minerals and vitamins that may contribute to the needs of the human diet (Morgan et al., 1980).

1.3 Seaweed production

The Food and Agriculture Organization report that globally, production of aquatic algae more than tripled between 2000 and 2019. From about 10.6 million tons in the year 2000 to 35.8 million tons in 2019. East and Southeast Asia dominate the production of seaweeds contributing with 97.4 percent. Most of the production globally consist of farmed seaweeds (97 percent) and the remaining 3 percent are from wild harvest (Cai et al., 2021). Europe contributes 1.4 percent to the global production and in contrast to the global trend, most of the production here come from wild harvest. In 2019, only 4.7 percent of European production of seaweeds came from cultivation. Norway is currently the biggest producer in Europe with 163 thousand tons of farmed and wild seaweed per year, placing 9th on the list of producers globally. 0.07 percent of the Norwegian production comes from cultivation (Cai et al., 2021). Production of *P. palmata* is dominated by wild harvest primarily in Iceland and Ireland, but small-scale harvest takes place in most regions where the species grow (Grote, 2019).

1.4 Cultivating dulse

Cultivation of dulse has been studied for many years starting in the 1980s including alternative techniques for improving growth, adjusting nutritional contents, and controlling the complicated life cycle (Morgan et al., 1980b; Morgan & Simpson, 1981). Induction of tetrasporangia and cultivating sporelings, or vegetative growth of apical tips or fronds either at sea or tumbling in tanks are possible cultivation methods (Le Gall et al., 2004; Pang & Lüning, 2006; Schmedes et al., 2019; Titlyanov et al., 2006). Nonetheless, commercial cultivation is limited and only a few active producers such as the Maine Sea Farms (2022) are known to have sea-based farming of the shore of Maine, USA. There is currently no commercial farming of *P. palmata* in Europe, but several pilot scale trials of open-sea cultivation have taken place in Spain, Ireland, and Scotland (Martinez et al., 2006; Edwards & Dring, 2011; Sanderson et al., 2012). Werner & Dring (2011) describe cultivation techniques for *P. palmata* at an industrial level including the use of spores in hatchery set-ups transferred to sea-based cultures, and vegetative cultivation in tanks. The authors point out the economic significance of the species in Ireland, both historically and presently. Despite there being a strong incentive to develop commercial cultivation, the study concludes in an economic analysis that this is not economically viable at present. As more high-value products are expected to develop, so is the price for dulse which would support the viability of commercial cultivation (Werner & Dring, 2011).

1.5 Objective and research questions

The aim of the present study is to evaluate the prospects of cultivating *P. palmata* from a technical point of view and to understand the industry perspective in Scandinavia, using the following research questions:

1. How does light intensity and nutrient level affect the growth of *P. palmata*?
2. What are the attitudes within the Scandinavian seaweed industry towards cultivation of *P. palmata?*

2. Methods

This study consisted of two parts: The first was the experimental cultivation of *P. palmata* in different light and nutrient conditions and the second was questionnaires and observations conducted during an algal conference to understand the status and uses of *P. palmata* in Scandinavia from an industry perspective.

2.1.1 Experimental cultivation

Side shoots of *P. palmata* were collected from an existing cultivation at Tjärnö Marine Laboratory (wild harvested from the Koster archipelago) and used in the experiment. The shoots were weighed, and each aquarium was supplied with 2 grams fresh weight per liter (g FW/L). The cultivation experiments were set up in a thermoregulated room where air and water temperature could be manipulated. The first weeks of the project consisted of building and testing the set-up, which included one 14-day test and one final 14-day cultivation. The methods section describes the method used for the final experiment. Both test trial and final trial are presented in the results section but only the final trial was considered viable and is presented in more detail. In the experiments, three light intensity levels and three nutrient levels were tested in all possible combinations resulting in nine separate treatments. Each treatment had eight replicates giving a total number of 72 (9x8) cultivation units. A row of tables was divided into three sections and lamps were hung up at different heights to create three different light intensity levels (L1: 25, L2: 50, and L3: 150 μmol photon m^{-2} s^{-1}). Nets and thin fabric were used to cover the lamps and create the precise light intensity level using a quantum meter model MQ-200. The light regime was set to 16 hours light and 8 hours dark using a timer. The three sections were separated using sheets of black plastic hung from the top of the lamps to the surface of the table. The interior walls of each section were dressed in laminated sheets of white paper to make the light as even as possible. 24 aquaria of 1 L were placed in each section, divided into three nutrient groups with eight replicates in each. The aquaria were randomly rearranged within each section every three days.

To supply the aquaria with water, four cylindrical water tanks were constructed from large drainage pipes, all had an inner circumference of 149 mm and a height of 70 cm. The first tank was used as the main water reservoir, a hole was drilled in the upper part of the tank (57.5 cm above the bottom) to maintain the volume at 10 L. Deep seawater (40 m depth) was supplied to the main reservoir tank via a 1 μm filter through the tap mounted in the thermoregulated room. The other three tanks were used to create the different nutrient levels for the experiment. They were connected to the main reservoir tank by pipes that supplied them with filtrated water in a continuous flow. Aeration was provided in the nutrient tanks using an air pump and airstones at the bottom of the tank. A peristaltic pump (Ismatec IPC) was used to distribute culture medium with nitrogen and phosphorous (N:P μmol/L) in the header tanks. See appendix II for an illustration of the set-up. Each of the header tanks had 24 pipes at the base fitted with small adjustable taps that supplied the aquaria with nutrient enriched water with an exchange rate of once every six hours. The aquaria were made from 1L plastic jars with lids. Two holes were drilled in the bottom of the jars, one for the water pipe and one for the aeration. The holes were slightly bigger than the pipes so that water could overflow and enable a continuous water exchange. During the experiment, jars were closed with the lids and placed upside down with the holes for water and aeration facing upwards. Table 1 summarizes the settings used for the final 14-day cultivation. Water temperature, salinity, and pH were measured using a multimeter from WTW (Multi 3630 IDS SET G). Additional data was collected to monitor light regime and temperature using loggers (HOBO pendant temp/light, 64K) and placing two loggers in random aquaria in each light intensity section. The loggers recorded data every five minutes during the full 14 days of the experiment.

Table 1. Summary of experiment settings

Light intensity (µmol photon m^{-2} s^{-1})	L1: 25 L2: 50 L3: 150
Nutrient level (N:P µmol/L)	N1: 4.9:0.3 N2: 9.8:0.6 N3: 49:3
Stocking density	2g FW/L
Temperature	10°C
Light regime (Light:Dark)	16:8
Salinity	30-34 PSU
pH	<8.0
Water exchange rate	Every six hours

2.1.2 Culture medium

A culture medium was used in the experiment to create three different nutrient levels (N1, N2 and N3) in which the seaweed would grow. To decide which levels to test, data obtained from sharkweb (SMHI, 2022) was used to estimate the ambient seawater N:P levels in the Kosterfjord in May over a ten-year period. Only data from the month of May was used since the experiment would run in May. The first level (N1, ambient seawater) was estimated to contain 4.9 µmol/L of nitrogen and 0.3 µmol/L of phosphorous based on the sharkweb dataset. N1 did not receive added nutrients whilst the two following levels (N2 - ambient times two, and N3 - ambient times ten) received ammonium nitrate (NH_4NO_3) and monosodium phosphate ($NaH_2PO_4 * H_2O$) to double the amount of nutrients in N2 and tenfold the amount of nutrients in N3. See appendix I for culture medium recipe.

2.1.3 Data collection

Data on seaweed growth was collected throughout the experiment by fresh weight measurements (FW) every three days and photographs taken at day 1 and day 14. Seaweed was collected from each aquarium, most of the water was dried off by blotting with paper towels followed by weighing the seaweed. By the end of the trial, tissue samples were directly frozen in -60 Celsius and later dried in a Heto LyoPro 6000 freeze dryer for 4 days. Finally, three water samples from each nutrient tank were collected every three days using a syringe filter (µm45) for analysis of N and P content.

2.1.4 Data analysis

A growth curve over time, based on mean weight of seaweed in each treatment, was plotted with 95 percent confidence intervals (CI) to compare trends in growth. Mean specific growth rate (SGR% Day^{-1}) was calculated for each treatment and plotted with 95 percent CI to compare the overall growth rates of algae in each treatment throughout the full 14 days. The specific growth rate is the percentage increase in fresh weight per day and was calculated using the equation from DeBoer et al. (1978):

$$\mathrm{SGR\%} = \frac{100[\ln(\mathrm{FW_t}/\mathrm{FW_0})]}{\mathrm{t}}$$

In the equation, FW_0 is the initial fresh weight and FW_t is the fresh weight on day *t*. The formula assumes a steady-state exponential growth. A two-way ANOVA was performed in SPSS using the specific growth rates of seaweed from fresh weight data. In addition to the quantitative assessment using fresh weight data, the photographs taken were analyzed qualitatively by studying changes in general appearance, fitness, and colors of the seaweed.

2.2 Conference questionnaire and participant observation

A Scandinavian conference regarding the opportunities and challenges with a Swedish seaweed industry was held at Tjärnö Marine Laboratory between the 21st and 23rd of June 2022 (Gothenburg University, 2022). Attendees were asked to fill out a one-page questionnaire about the status and uses of *Palmaria palmata* based on their respective industry. In addition, a participant observation was conducted throughout the conference to gain further knowledge of the industry perspective.

2.2.1 Self-completion questionnaire

The questionnaire was prepared in Swedish and the aim with the questionnaire was to get a general understanding of the status and uses of dulse according to the conference attendees. It had six closed questions, including both personal factual questions and questions about attitudes (Appendix III). Fixed horizontal answers were used for the factual questions and fixed horizontal answers in the Likert format were used for the attitude questions. Questionnaires were distributed to the conference attendees following a short introduction of my project aim and purpose. 23 responses were collected and could be used in this study.

2.2.2 Participant observation

By participating in the conference I was able to observe and record information about the recent developments in the seaweed industry in Scandinavia. I listened to seminars and discussed with other attendees while taking notes and asking questions. I adopted an informal approach and asked open questions about the general interest and prospects for *P. palmata* in the industry.

3. Results

Results are presented in the following pages including the method development and final settings adopted for the experimental cultivation, the seaweed specific growth rate and growth curves in each treatment used, and the responses attained from the questionnaires.

3.1 Method development

During the test trial in the method development, aeration was not used in the individual aquaria which caused unfavorable conditions for the seaweed. The seaweed did not grow as expected and the different treatments did not show significant difference regardless of the light intensity and nutrient levels.

Moreover, the water exchange rate was initially set to twice daily which further reduced the water movement. All treatments had a 2-3 percent daily growth rate, and there was no apparent trend when looking at the growth rates of the treatments, despite the drastic differences in both light intensity and nutrient level, see figure 1 in appendix IV. This indicates that another factor is interfering with the growth and the settings cannot be regarded as viable for testing growth rate in these different treatments.

Photographs were taken during the test trial and can be seen in table 1-3 in appendix IV. All treatments resulted in seaweed that looks degraded and faded in color. The level of fading increases with level of light intensity but all treatments resulted in faded color with signs of photo-inhibition in some cases. Some samples that were whole and intact at the beginning of the test have broken apart by the end of the 14 days. This is partly due to tissue becoming degraded causing them to break when handled, and partly due to changing texture into rigid and curled tissue that had to be broken apart to enable placing them flat on the light board. After the test trial, some settings were changed to improve the cultivation environment. Firstly, aeration was added to the aquaria and the water exchange rate was increased to six times daily. Secondly, the light intensity levels were adjusted to 25, 50, and 150 μmol photon m^{-2} s^{-1} respectively to reduce the risk of photoinhibition and avoid causing the temperature in the aquaria to rise from the heat of the lamps.

3.2 Experimental cultivation

Results from the final 14-day test is presented in the following pages, including specific growth rate calculations, statistical analysis, growth curves for fresh weight, and photographs for qualitative evaluation. Each treatment resulted in growth of the seaweed at a steady pace throughout the full 14-days.

3.2.1 Specific growth rate

The mean specific growth rates of seaweed in each treatment are summarized in figure 1. The bars indicate the average daily growth rate (%) for each light intensity level and each nutrient level. The figure displays and upwards trend following increasing light intensity level and nutrient level. It appears that both light intensity and nutrients have an impact on seaweed growth as there is a visual difference both within and between the treatments.

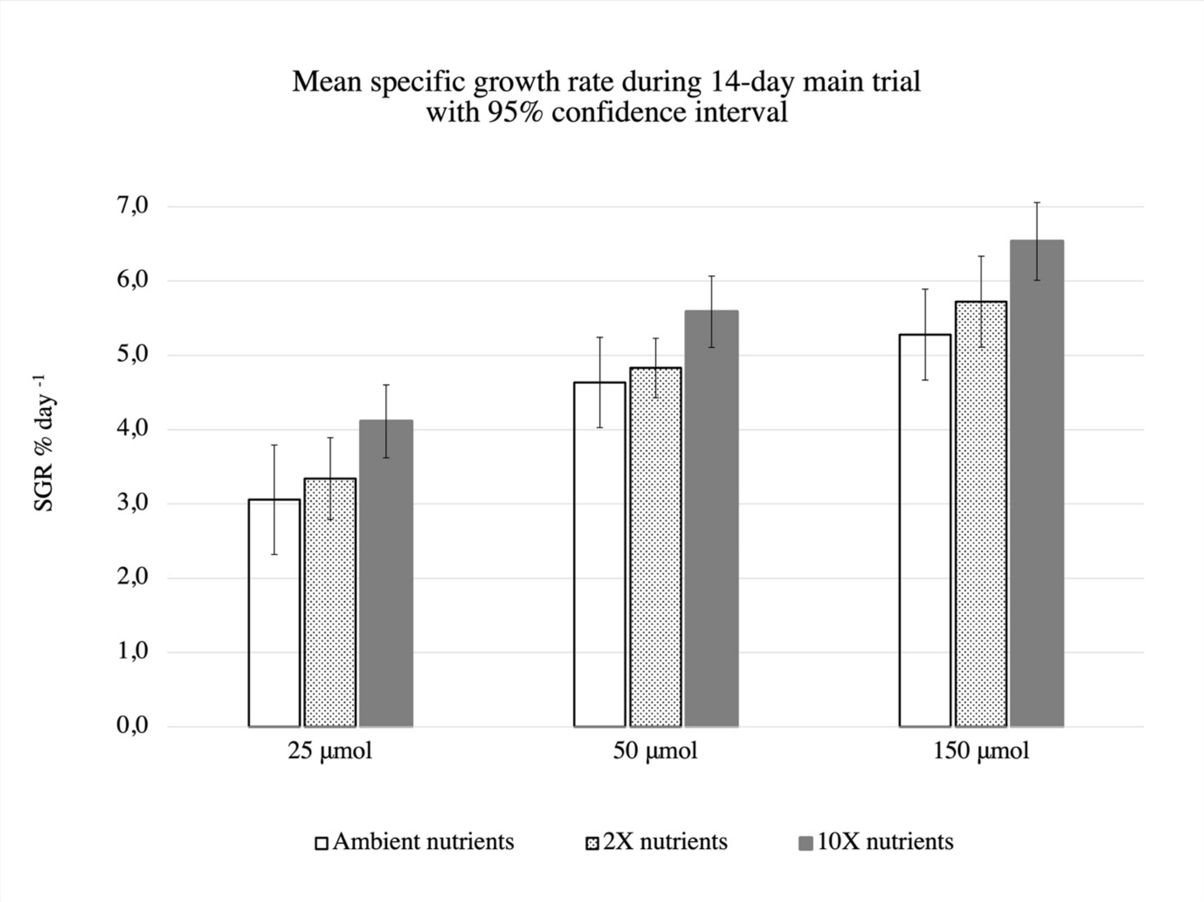

Figure 1. Average specefic growth rates (%) for all treatments during final trial.

A two-way ANOVA was performed to test the variance of the average specific growth rates for the different treatments. The variance of light intensity gave a p-value <0.001 and an F-crit value 3.14 thus rejecting the null hypothesis and proving a relationship, meaning that there is a significant difference in growth rates of seaweed grown in the three different light intensity levels. Secondly, the variance of nutrient levels gave a p-value <0.001 and an F-crit value 3.14 rejecting the null hypothesis and proving a significant difference in growth rates of seaweed grown in the three different nutrient levels.

Lastly, the interaction was tested giving p-value of 0.991 and an F-crit 2.52 thus accepting the null hypothesis and significant difference cannot be proven. This means that growth rates are not dependent on the interaction between light intensity level and nutrient level. A Post Hoc test was performed showing that all three light levels are significantly different while the nutrient levels are divided in two groups where ambient (N1) and two-fold (N2) levels fall into the same group and do not differ from each other, but both differ from the ten-fold nutrient level.

3.2.2 Growth curves

At 25 µmol photon m^{-2} s^{-1} the seaweed fresh weight increased on average between 1.13-1.65 grams in 14 days depending in the nutrient level. The seaweed in aquaria with ambient nutrient level increased the least with 1.13 grams FW which corresponds to a 55 percent increase. The aquaria with two-fold nutrients increased by 1.23 grams FW (61% increase) and the seaweed in ten-fold nutrient treatments grew most at 1.65 grams FW which is a 78 percent increase in 14 days. As seen in figure 2, the ambient nutrient treatment and the 2X treatment run closely throughout the trial whilst the 10X treatment increases more rapidly over time.

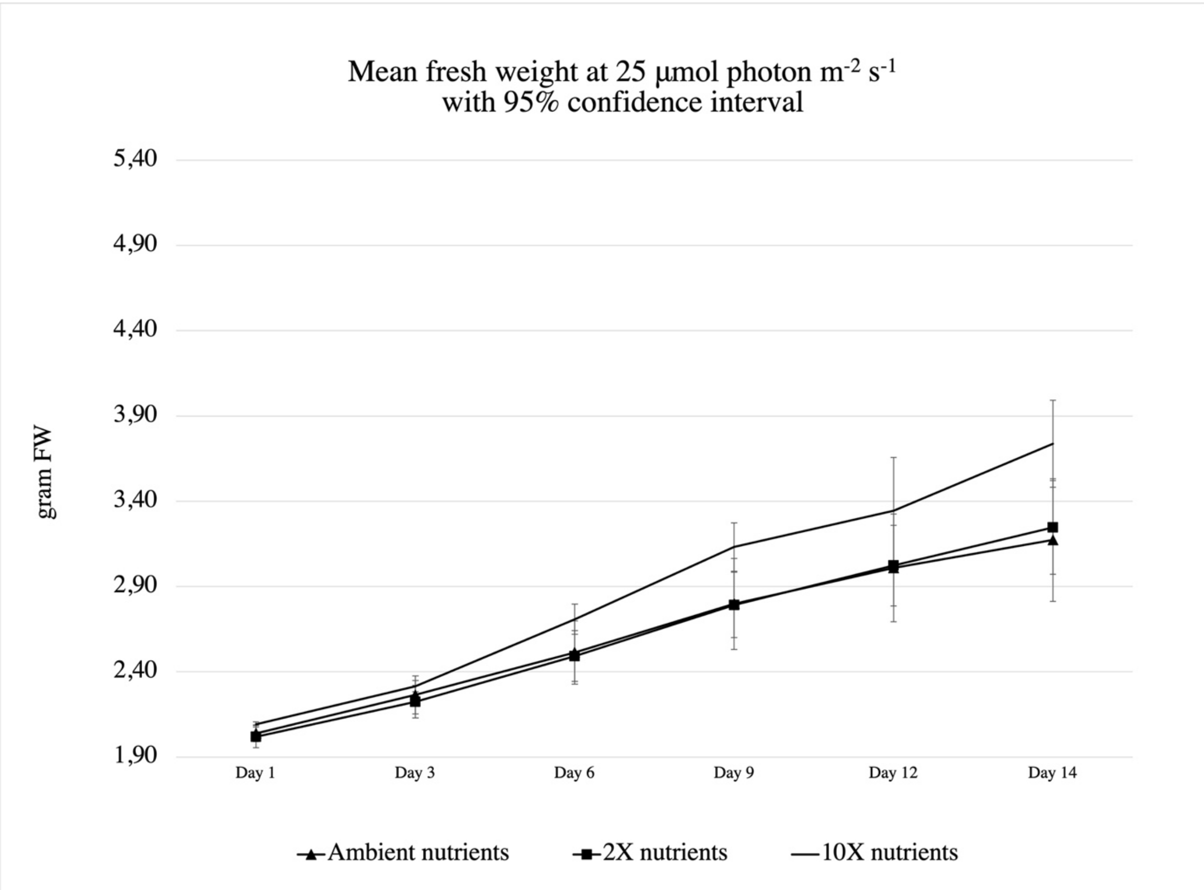

Figure 2. Seaweed growth curve at light intensity level L1 in N1, N2 and N3 nutrient levels during final trial.

Like the previous light intensity level, the results for the 50 µmol photon m^{-2} s^{-1} treatment display a trend following the nutrient level as seen in figure 3. The seaweed fresh weight increased on average between 1.93-2.51 grams in 14 days depending in the nutrient level. The samples in aquaria with ambient nutrient level increased by 1.93 grams FW which corresponds to a 93 percent increase. The aquaria with two-fold nutrients increased by 2.03 grams FW, a 97 percent increase, and the seaweed in ten-fold nutrient treatments grew most at 2.51 grams FW which is a 119 percent increase in 14 days, meaning that the samples more than doubled its fresh weight in the L2N3 treatment.

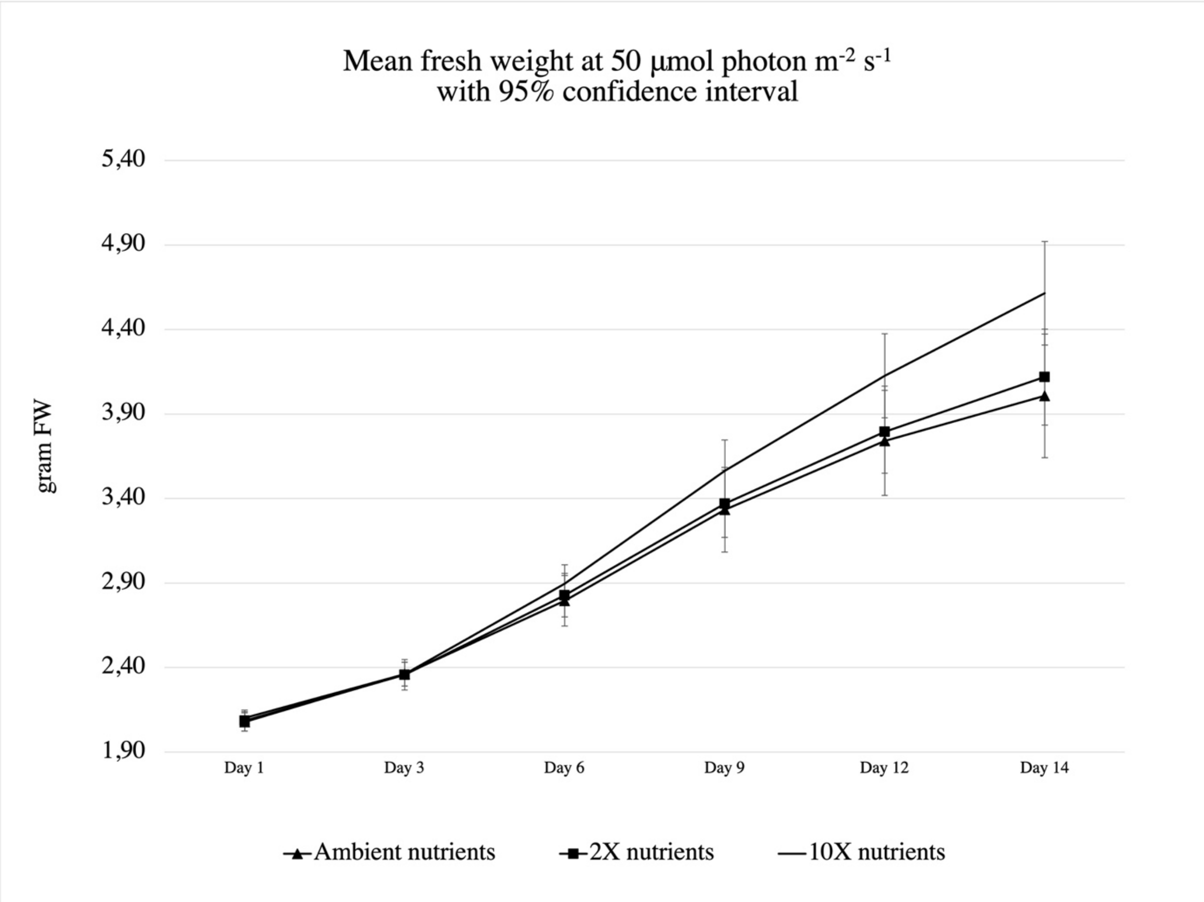

Figure 3. Seaweed growth curve at light intensity level L2 in N1, N2 and N3 nutrient levels during final trial.

The third light intensity level show a steeper growth curve compared to the previous treatments presented, but the trend is similar in that the seaweed in the ten-fold nutrient level has increased most by the end of the 14 days. One difference in this growth curve is that the 10X (N3) curve has a slower growth compared to the other two for the first half of the trial, as seen in figure 4. The seaweed fresh weight increased on average between 2.34-3.07 grams in 14 days depending in the nutrient level. The average fresh weight increase in aquaria with ambient nutrient level was 2.34 grams which corresponds to a 111 percent increase, that is more than double the initial weight. The aquaria with two-fold nutrients increased by 2.58 grams FW, a 125 percent increase in 14 days. Finally, the seaweed in ten-fold nutrient treatments grew most at 3.07 grams FW which is a 151 percent increase in 14 days, that is roughly 1.5 times increase in fresh weight in the L3N3 treatment.

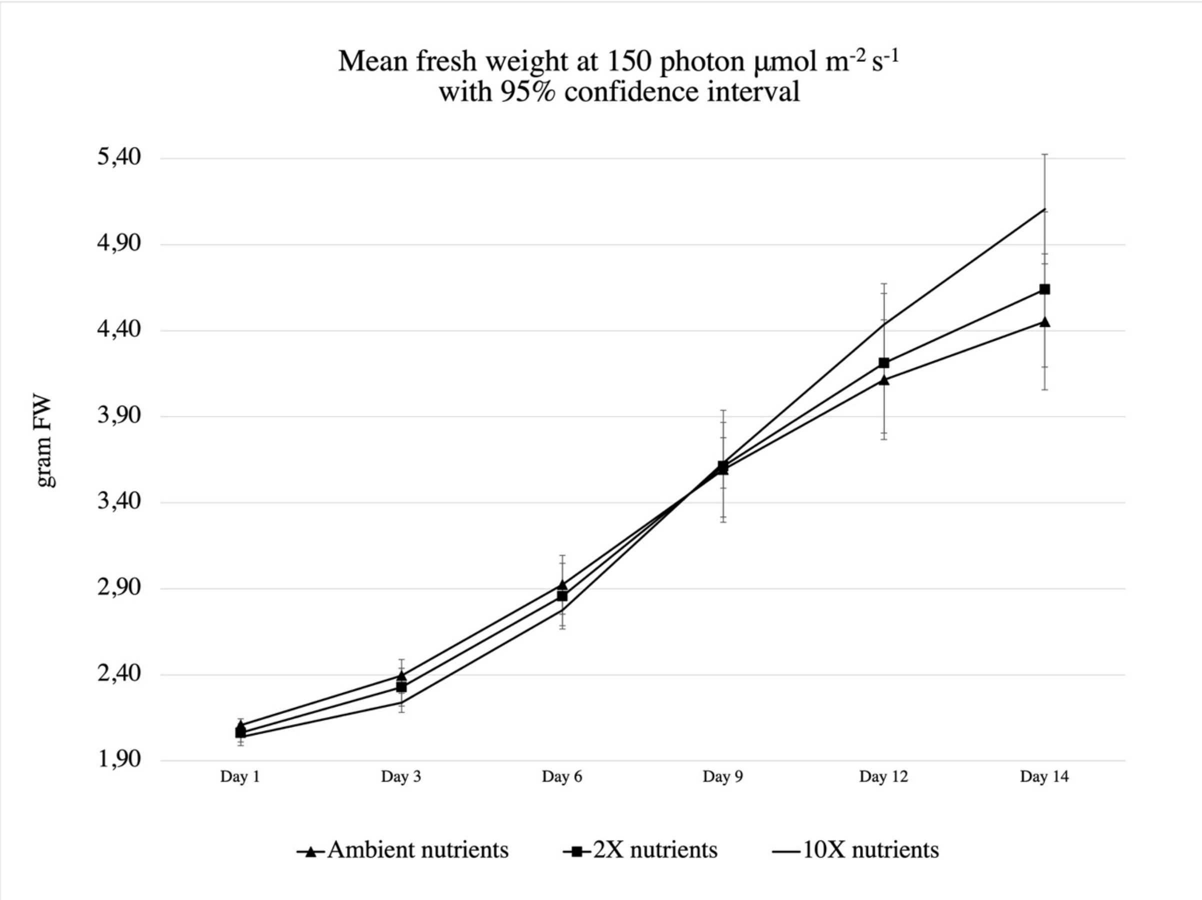

Figure 4. Seaweed growth curve at light intensity level L3 in N1, N2 and N3 nutrient levels during final trial.

3.2.3 Seaweed quality

All samples exposed to the L1 light intensity, irrespective of the nutrient level showed little changes in color or quality of the seaweed tissue. The shade has shifted slightly from purple to reddish/brown and the tips of the leaves are lighter both before and after 14 days. There is no visible photoinhibition and growth is highly visible by the elongation of the leaf tips (figure 5). The aquaria in L1 had no visible fouling in the water or on the seaweed surface.

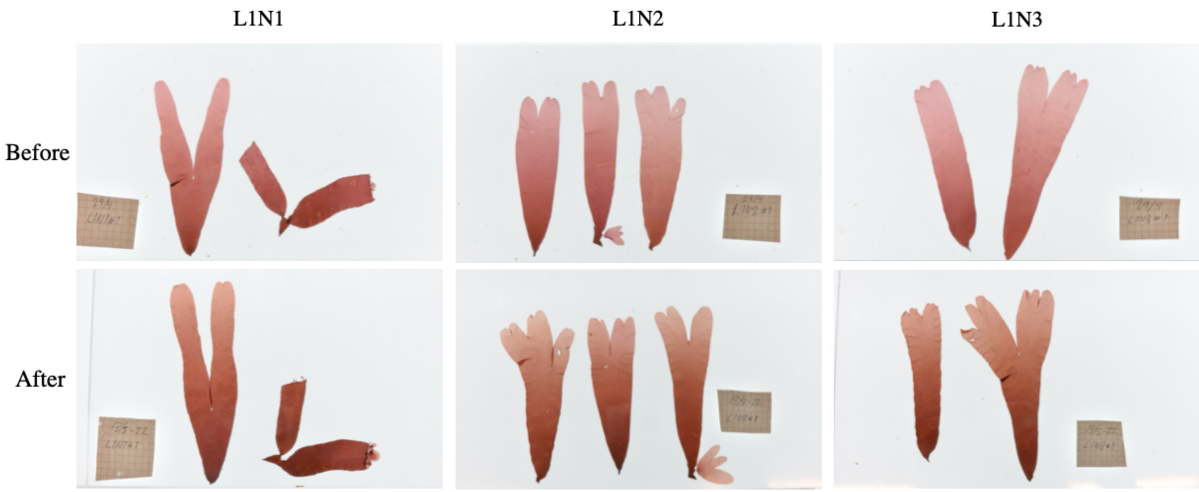

Figure 5. Before and after photos from light intensity level L1 (25 µmol photon m^{-2} s^{-1}) during final trial.

The samples exposed to the L2 light intensity level show a slight gradient of changes in color and degree of fading pigment. As seen in figure 6, they have all shifted from a purple shade to one looking more reddish/brown, that is similar to the L1 treatment. The sample from the L2N1 treatment (ambient nutrient level) show most fading in color, the L2N2 (two-fold nutrient level) show less fading and the sample from the L2N3 (ten-fold nutrient level) show no apparent fading in the pigment. Here too growth is visible through the elongation of the leaf tips, especially in L2N3. The aquaria in L2 had some visible fouling in the water or on the seaweed surface, more so as the nutrient level increased.

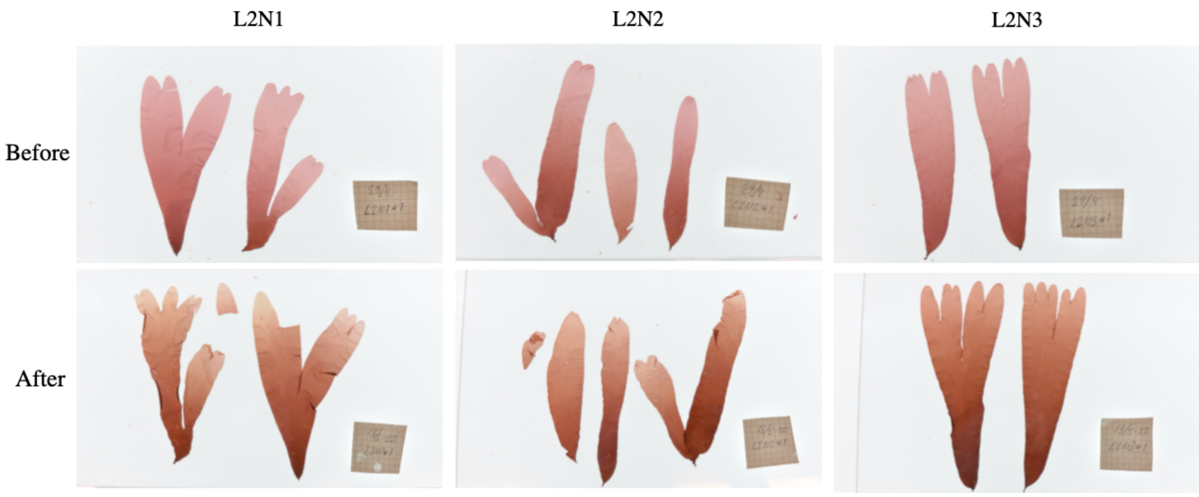

Figure 6. Before and after photos from light intensity level L2 (50 µmol photon m^{-2} s^{-1}) during final trial.

Like the changes in color and faded pigment in the L2 treatment, the before and after photos of the L3 treatment show a gradient of changes from most faded in the treatment with ambient nutrient level and least faded in the ten-fold nutrients treatment (figure 7). The two-fold nutrient level (N2) show significant fading on the tips of the leaves. Also in this light intensity level the shade has gone from purple to reddish/brown in all treatments.

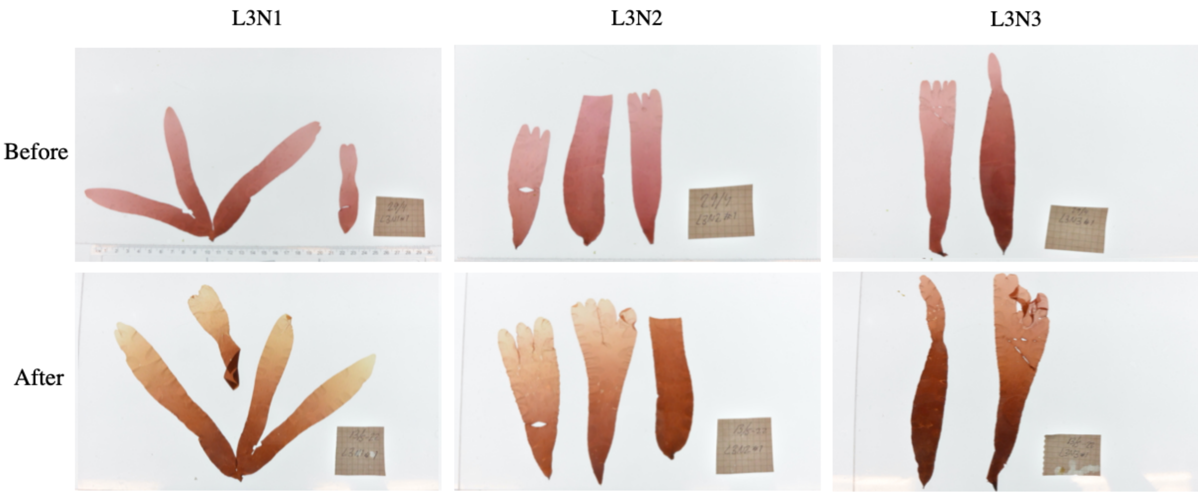

Figure 7. Before and after photos from light intensity level L3 (150 µmol photon m^{-2} s^{-1}) during the final trial.

The aquaria in all three nutrient levels had visible fouling in the water, on the seaweed surface and on the surface of the aquaria walls. The fouling was more extensive than in both L1 and L2 treatments. Most fouling had the L3N3 treatment with long strands of filamentous seaweed growing on the inside of the aquaria walls and at the base of the sample seaweed.

3.3 Conference questionnaire

The distribution of questionnaires during the conference resulted in 23 responses collected and analyzed in the present study. 20 out of 23 answered that their work takes place in Sweden, the remaining three answered Norway. Most participants were representatives of the seaweed cultivation industry, and the second biggest group of participants represented the research and education sector. Many filled in more than one of the choices for what industry they belonged to, suggesting that the conference attendees and perhaps the industry consist of people working broadly with seaweed. The participant industry categories are summarized in figure 8. Out of the nine (28%) participants that filled in seaweed cultivation as their industry, four indicated it as their main work. Three indicated cultivation activities combined with scientific research or education and the remaining two indicated seaweed cultivation in combination with seaweed harvest. All participants in this questionnaire that are directly engaged in seaweed cultivation are based in Sweden.

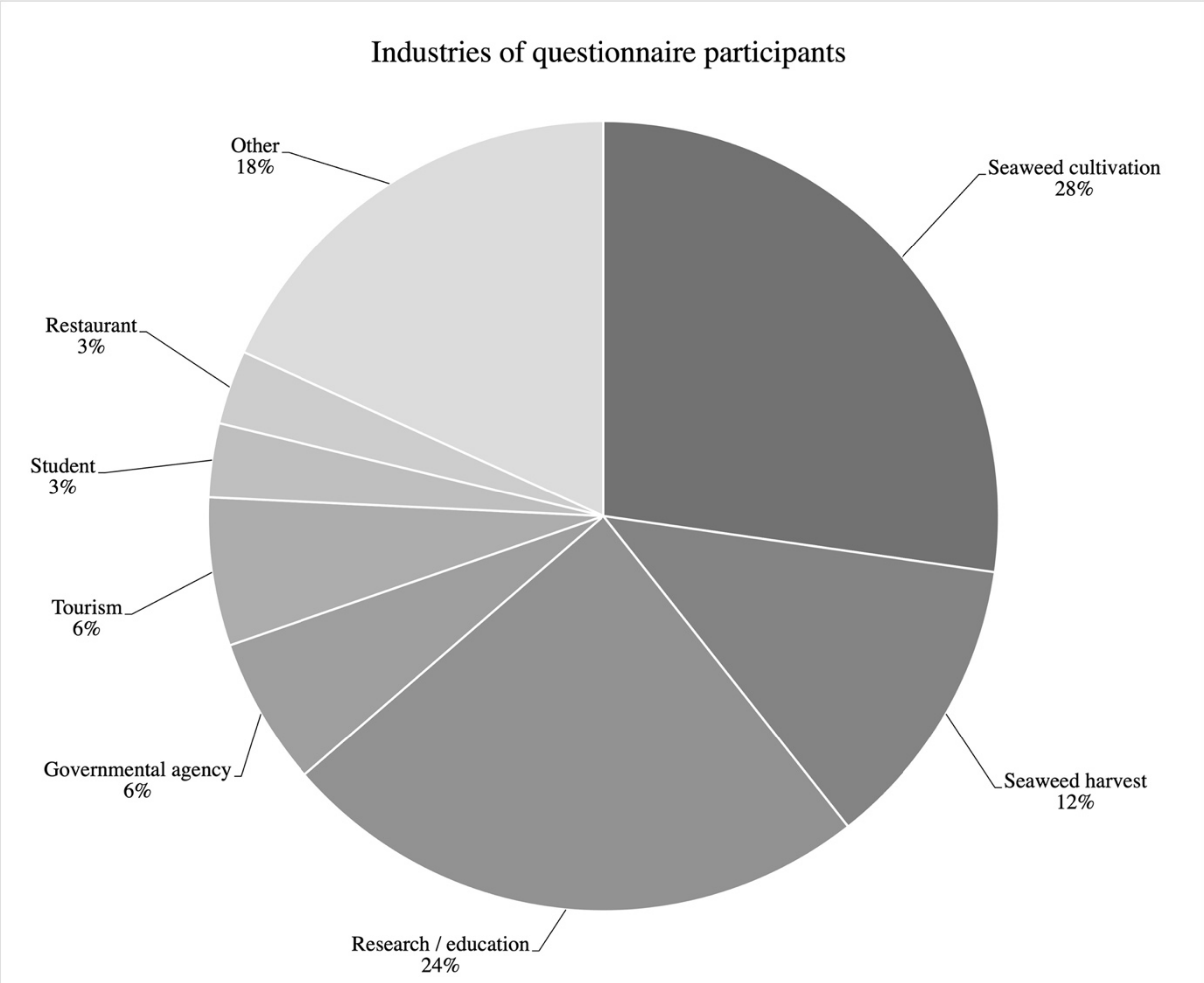

Figure 8. Summary of the industries that questionnaire participants belong to.

The category marked other (16%) include innovation support, counselling, non-governmental organizations, consultancy, and fish farming. On the question if *Palmaria palmata* is currently included in their work, 9 of 23 (39%) answered yes, nine (23%) answered no, and five (22%) answered N/A. Those who answered yes belonged to the following categories of industries: Research/education; seaweed farming; seaweed harvest; governmental agency; counselling; tourism. Table 2-4 summarizes the results of the questionnaire, and it shall be noted that some questionnaire participants have indicated being involved in more than one industry category. In those cases, the selected alternative applies multiple times (once per industry category). For example, one participant has indicated being involved in both seaweed cultivation and seaweed harvest, and then answered *very true* to the claim that the interest is increasing within his/her industry. Then the answer *very true* applies one time in the category *seaweed cultivation* and one time in the category *seaweed harvest*.

Table 2. Number of replies in each alternative by industry category.

The interest for *P. palmata* is increasing within my industry								
	Seaweed cultivation	Seaweed harvest	Research / Education	Governmental agency	Tourism	Student	Restaurant	Other
Very true	5	2	6	-	1	-	1	2
Partly true	1	1	1	-	1	-	-	2
Neither	2	1	-	-	-	1	-	-
Not really true	-	-	-	-	-	-	-	-
Not true	-	-	-	-	-	-	-	-
Don't know	1	-	1	1	-	-	-	1
N/A	-	-	-	1	-	-	-	1

Roughly 50 percent indicated that it is *very true* that the interest in *P. palmata* is increasing within their industry. Given that the survey only included 23 participants it is not a large enough dataset to draw any general conclusion. However, since the seaweed industry (in Sweden) is relatively small and the conference was attended by many of those active in research and commercial production of seaweed in Sweden, the results can be interpreted as indications of general trends. Note that some categories have very few respondents, in some cases only one, and is therefore not viable as such but I have chosen to include them to show the full extent of questionnaire responses. None of the responses to the question above has indicated that there is not increasing interest however some have indicated that *neither* applies which could be interpreted as the interest is neither growing nor declining.

Table 3. Number of replies in each alternative by industry category.

The interest for *P. palmata* is increasing from my customers								
	Seaweed cultivation	Seaweed harvest	Research / Education	Governmental agency	Tourism	Student	Restaurant	Other
Very true	1	1	-	-	-	-	-	2
Partly true	2	1	2	-	-	-	-	2
Neither	1	-	1	-	-	-	-	-
Not really true	1	-	-	-	-	-	-	-
Not true	-	-	-	-	-	-	-	-
Don't know	4	2	2	1	1	1	1	1
N/A	-	-	1	1	1	-	-	1

The next question did not apply to all participant, as some do not work on a customer basis. However, this is sometimes a question of interpretation as most industries operate within a system that reports to either an authority, public interest, or other organization.

In those cases, the authority or public interests can be considered customers. Most (39%) answered *Don't know* on the question regarding the increase of interest from customers. In general, answers are more diverse for this question and the categories that selected the answers *very true* were seaweed cultivation, seaweed harvest, innovation support, and counselling services.

Table 4. Number of replies in each alternative by industry category.

There is potential for developing *P. palmata* in my work								
	Seaweed cultivation	Seaweed harvest	Research / Education	Governmental agency	Tourism	Student	Restaurant	Other
Very true	7	4	7	-	2	1	1	5
Partly true	-	-	-	-	-	-	-	-
Neither	1	-	-	-	-	-	-	-
Not really true	-	-	-	-	-	-	-	-
Not true	1	-	-	-	-	-	-	-
Don't know	-	-	1	1	-	-	-	-
N/A	-	-	-	1	-	-	-	1

The final question in the questionnaire generated results that indicate a very positive outlook for the future of *P. palmata* in the industry. Roughly 82 percent answered *very true* on the claim that there is potential for developing *P. palmata* in their work. One replied that it is *not true* and the remaining either did not know or it did not apply to their work. Despite being a small sample, that cannot be counted towards any general conclusions, it can be stated that within this group the interest for developing *P. palmata* appears strong.

4. Discussion

The following pages include an evaluation of the results from the experimental cultivation and the questionnaire with regards to the research questions. Furthermore, the discussion will relate to previous research and consider the strengths and weaknesses of the data as well as ideas for future research.

Considering the first research question, 'How does light intensity and nutrient level affect the growth of *P. palmata*?', the test trial shows that despite big differences in provision of light and nutrients supply, some conditions must be in place for the seaweed to thrive. These conditions include sufficient aeration and water exchange rate, and the present study show that unless these are provided, *P. palmata* will grow slowly and degrade. This is supported by

Werner & Dring (2011) who recommend a steady exchange of water and tumbling of the seaweed. It is only after the baseline conditions are established that the effects of light intensity and nutrient level can be properly tested. The method development also establishes the importance of maintaining pH-level below eight and this is controlled by sufficient aeration.

The two-way ANOVA and subsequent post-hoc test showed that both light intensity and nutrient level affected the growth rate respectively. However, an interaction between the two parameters could not be proven. This raises some interesting questions; firstly, which parameter affects growth more, and secondly, how can this be implemented to optimize the cultivation method? On the other hand, the images of the seaweed provide more nuanced results which suggest that growth rate is not the sole important factor when evaluating the cultivation method.

In addition to growth rates, quality is important when cultivating seaweed for human consumption. Dulse should be deep purple or red in color, leaf structure should be intact and fouling organisms minimized. Evaluating the change in pigmentation of the seaweed by comparing the photographs taken should be viewed as a qualitative analysis, due to the difficulty in seeing very slight changes. Nevertheless, it is a valuable addition to the results and brings some nuance to the growth rate and growth curve data. The images indicate that availability of more nutrients may prevent photoinhibition when light intensity level is increased, suggesting that increasing light intensity should be combined with an addition of nutrients to avoid unwanted outcomes in terms of dulse quality. On the other hand, treatments with the highest light intensity (L3: 150 μmol) experienced fouling in all aquaria which also increased with the level of nutrients, the L3N3 treatment had the highest seaweed growth rate and seemingly good quality dulse, but also the most fouling. The treatments with light intensity level L2 (50 μmol) had no fouling in the ambient nutrient level (N1), but visible fouling in the N2 and N3 nutrient level. This means that added light and nutrients indeed may increase growth rate and produce high quality dulse, but the risk of fouling increases which could become a major problem in terms of product quality and technical aspects like set-up maintenance.

Taken together, it appears that *P. palmata* cultivation has potential to be optimized and adjusted to fit a range of preconditions and desired outcomes of individual seaweed farmers. This must also be viewed from the technical-economical perspective to establish a realistic trade-off when choosing the set-up. Providing light, either by placing tanks outdoors in natural light or installing lamps is relatively easy and can be done cost efficiently, but care must be taken when choosing light intensity and light regime. Adding nutrients may present challenges in terms of environmental impacts of nutrient rich wastewater and regulations connected to this.

The economical perspective is not further developed in the present study but would be an interesting continuation for future research. Furthermore, nutrition and pigment analysis are not included in the scope of this study due to lack of time. This is a key part of product development and finding potential uses of dulse, this should be further researched.

The test trial provided several valuable insights to which factors are important when cultivating dulse and the credibility of the data from the final trial could be improved. Nevertheless, there are some weaknesses in the method that must be considered. Firstly, the nutrient tanks used to create the different nutrient levels were not replicated. This could potentially cause errors in the data if a tank was contaminated or otherwise different from the others. To reduce the risk of errors in this case, measurements were taken regularly of water temperature and pH. Secondly, the culture medium recipe was prepared using existing data on total nitrogen and total phosphorous in the Kosterfjord over a ten-year period for the month of May. The actual concentration of nitrogen and phosphorous in each treatment is therefore unknown, and analysis of the enriched seawater was not possible within the timeframe of the study. Water samples were collected and saved as described in the method, which would enable future analysis.

The second research question: 'What are the attitudes within the Scandinavian seaweed industry towards cultivation of *P. palmata?*', is a question with room for much discussion with regards to the results obtained from the questionnaire. Overall, one can say that interest in dulse is very high within the industry. For many of the conference attendees, dulse is seen as the interesting new species for cultivation. Although not being new in terms of its culinary relevance and among seaweed harvesters, the prospect of successful cultivation of the species sparked much interest when discussed during the conference.

The main weakness of the questionnaire data is the low number of responses. This is partly due to the size of the conference that was attended by around 35 people all together, furthermore, not all attendees were present when the questionnaire was handed out. Because of this, one cannot make any general conclusions from the responses. Nevertheless, the responses may give an indication to what the attitudes are in the industry. 39 percent answered that *P. palmata* is part of their work today, which is very promising and suggest that the species is already somewhat established in the Scandinavian industry. However, we cannot know exactly how it is worked with aside from the knowledge we have that it is not yet being cultivated commercially. This is also considered one of the main challenges according to the discussions during the conference: How to achieve successful cultivation? The complex life cycle of red seaweeds, including dulse, was pointed out by several attendees. Moreover, health and safety regarding food products was extensively discussed, including potentially harmful substances in dulse that must be monitored. Taken together, the seaweed industry in Scandinavia sees the potential in dulse for future cultivation and as a product on the Scandinavian market as it is today (imported from Iceland and Ireland), and in new forms. The main traits of dulse that are highlighted by attendees are the flavor and the high protein content, vitamins, and minerals.

5. Conclusion

The present study shows that increasing the light intensity and nutrient level in tank cultures of *P. palmata* will increase the growth rate of the seaweed. Different growth rates can be achieved by adjusting the amount of light and nutrients added. The study also shows that increased light intensity can cause photoinhibition, while adding nutrients to such treatments may reduce the photoinhibition. Moreover, the occurrence of fouling organisms increases as light intensity level and nutrient level increase, which may lower the commercial value of dulse due to on-growth. Dulse quality depend mainly on its size (growth rate), pigmentation, fouling, and nutritional value. The quality of dulse in this study was evaluated based on all factors above except the nutritional values which is a key aspect, and the most significant element lacking in this study.

The seaweed industry in Scandinavia shows great interest in *P. palmata* as a future species for cultivation. Its culinary traits and nutritional content as described in the literature and historical sources makes it a highly relevant seaweed for commercialized production. Both the flavorful palette and high protein content are regarded as the species main traits. In conclusion, product development plays an important role for the development of the whole seaweed industry in Scandinavia and was a recurring topic throughout the conference. This applies to dulse as much as any seaweed and cultivation must be combined with development of new products to success in reaching the bigger markets and household cuisine.

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7. Appendix

APPENDIX I – CULTURE MEDIUM RECIPE

Culture medium

Ammonium nitrate & Monosodium phosphate

Mean value from May during 10 yrs & 30m depth	
Ammonium	0,922
Nitrate	3,764
Nitrite	0,17
Phosphate	0,327 (rounded to 0,3)
tot-N	4,856 (rounded to 4,9)

Data obtained from Sharkweb to determine reference value for nutrients

X2 N:P

Compound	Stock solution (mg L^{-1} dH2O)	Concentration N & P in stock solution (umol/l)	Concentration in ambient seawater (umol/l)	Concentration in final medium (umol/l)
NH_4NO_3	((4,9/2)*80,04)/1000 = **0,196098**	4,9	4,9	9,8
$NaH_2PO_4 * H_20$	(0,3*137,99)/1000 = **0,041397**	0,3	0,3	0,6

X10 N:P

Compound	Stock solution (mg L^{-1} dH2O)	Concentration N & P in stock solution (umol/l)	Concentration in ambient seawater (umol/l)	Concentration in final medium (umol/l)
NH_4NO_3	((44,1/2)*80,04)/1000 = **1,764882**	44,1	4,9	49
$NaH_2PO_4 * H_20$	(2,7*137,99)/1000 = **0,372573**	2,7	0,3	3

Recipe X2 nutrients

1. 4 L MilliQ water
2. NH_4NO_3 301,21 mg + 100,40 mg = **401,61 mg**
3. $NaH_2PO_4 * H_2O$ 63,59 mg + 21,2 mg = **84,79 mg**

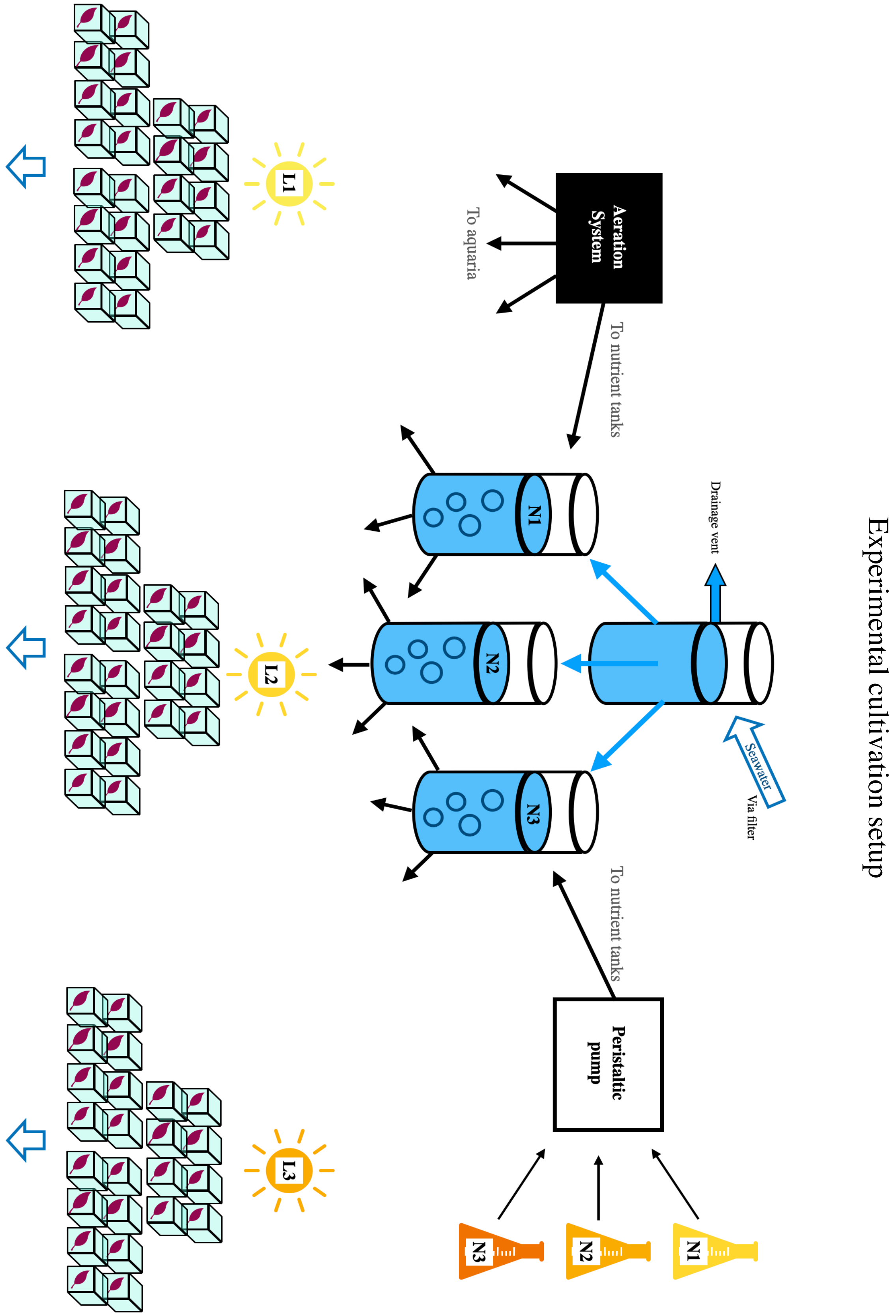
Recipe X10 nutrients

1. 4 L MilliQ water
2. NH_4NO_3 2 710,86 mg + 903,62 mg = **3 614,48 mg**
3. $NaH_2PO_4 * H_2O$ 572,27 mg + 190,76 mg = **763,03 mg**

Method

1. Autoclave four 1 L bottles and one 5 L bottle
2. Fill the 5 L bottle with a little milliQ water
3. Weigh salts and add to the 5 L bottle
4. Swirl the bottle or use magnetic mixer to dissolve
5. Fill bottle to 4 L and make sure the salts are properly dissolved
6. Fill the 1 L bottles with the culture medium, label and store in fridge until use

APPENDIX II – EXPERIMENTAL CULTIVATION SETUP



APPENDIX III – QUESTIONNAIRE

ENKÄTUNDERSÖKNING

Status & användning av *Palmaria palmata* i Skandinavien

1. Vilket land är er verksamhet baserad i?

____

2. Vilken bransch tillhör ni? Flera alternativ möjliga

☐ Algodling
☐ Algskörd
☐ Restaurang
☐ Turism
☐ Forskning & utbildning
☐ Myndighet
☐ Annat: ___________________________________

3. Ingår *Palmaria palmata* i er verksamhet idag?

☐ Ja ☐ Nej ☐ Vet ej ☐ Ej tillämpligt

4. Välj det alternativ som du tycker stämmer bäst för följande påståenden:

a. Intresset för *Palmaria palmata* ökar internt i min bransch

Stämmer inte	Stämmer inte helt	Varken eller	Stämmer delvis	Stämmer mycket
☐	☐	☐	☐	☐

☐ Vet ej ☐ Ej tillämpligt

b. Intresset för *Palmaria palmata* ökar från våra kunder

Stämmer inte	Stämmer inte helt	Varken eller	Stämmer delvis	Stämmer mycket
☐	☐	☐	☐	☐

☐ Vet ej ☐ Ej tillämpligt

c. Det finns utvecklingspotential för *Palmaria palmata* inom vår verksamhet

Stämmer inte	Stämmer inte helt	Varken eller	Stämmer delvis	Stämmer mycket
☐	☐	☐	☐	☐

☐ Vet ej ☐ Ej tillämpligt

Övriga reflektioner och kommentarer:

Kontaktinformation:

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APPENDIX IV – TEST TRIAL RESULTS

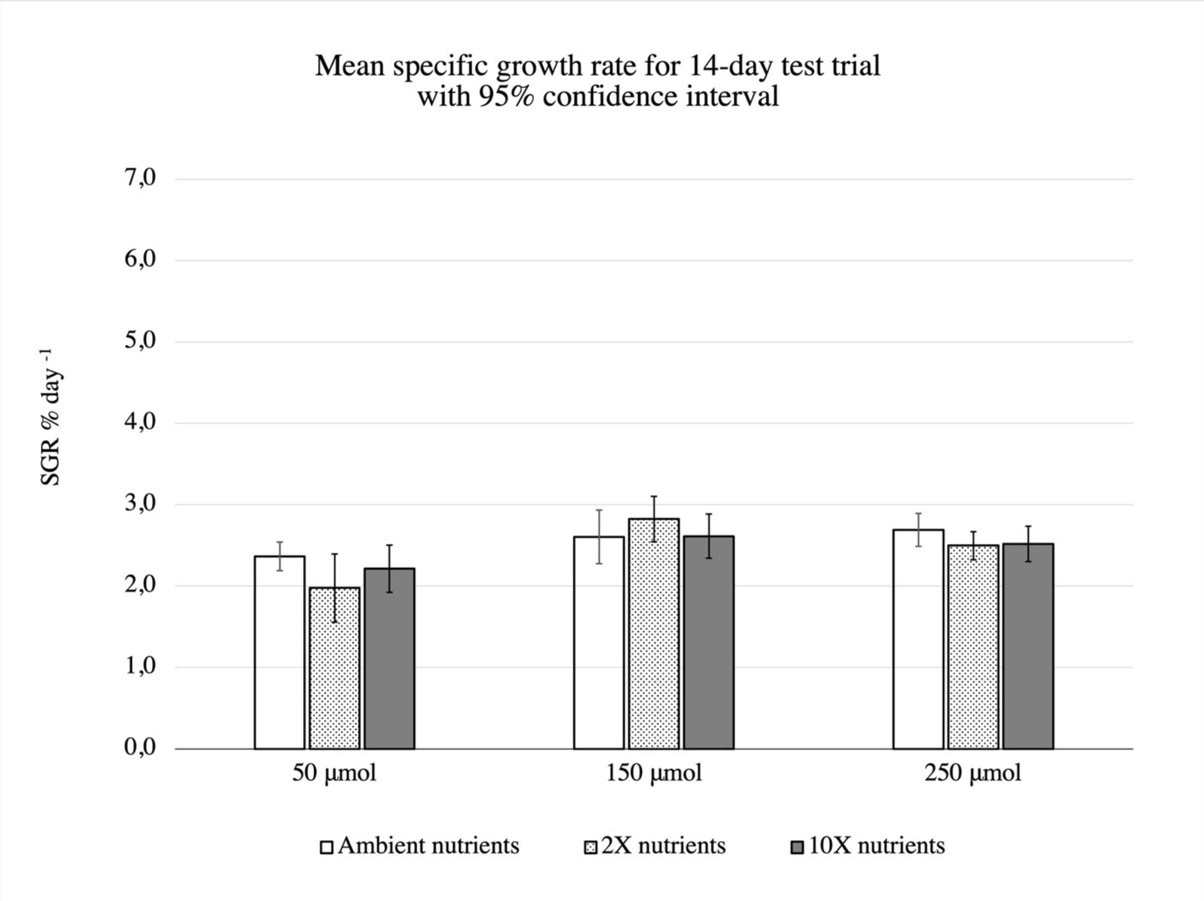


Figure 1. Average specific growth rates (%) for all treatments during test trial.

Table 1. Before and after photos from light intensity level L1 (25 µmol photon m^{-2} s^{-1}) during test trial.

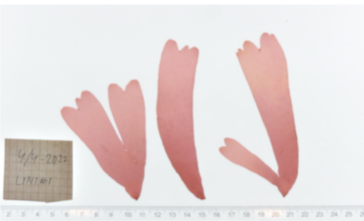
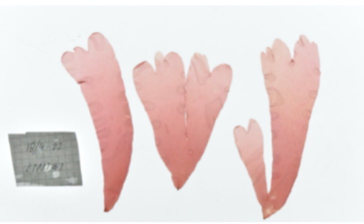
	L1N1	L1N2	L1N3
Before			
After			

Table 2. Before and after photos from light intensity level L2 (150 µmol photon m^{-2} s^{-1}) during test trial.

	L2N1	L2N2	L2N3
Before			
After			

Table 3. Before and after photos from light intensity level L3 (250 µmol photon m^{-2} s^{-1}) during test trial.

	L3N1	L3N2	L3N3
Before			
After