A site suitability framework for small-scale cultivation of *Saccharina latissima* in Nova Scotia using multi-criteria decision analysis

by

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Dalhousie University is located in Mi'kma'ki, the ancestral and unceded territory of the Mi'kmaq. We are all Treaty people.

Honours Thesis

Dedication

To my family, friends, partner and younger self, your perseverance and support during my final undergraduate years have gotten me where I am today. I could have never planned to have gotten through the mental and physical injuries suffered during this time.

Thank you for your listening ears, your words and your love. This work reflects the mark you have left on me.

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Abstract

Nova Scotia has a nascent kelp aquaculture industry. An economic study showed that kelp farming could become a 38-million-dollar industry in the future. Additionally, kelp is relatively environmentally benign compared to other mariculture industries making it an industry with low environmental impact for growth in Nova Scotia. However, there are only a handful of farmers that are operating today. There are many challenges barring development of a robust kelp industry. These have been outlined as lack of processing plants, market access, educational and awareness aids for farmers and stringent regulations. Site suitability analysis has been used previously to help create effective policy surrounding mariculture while mitigating both environmental and socio-economic adversities. Using a Multi-Criteria Decision Analysis method, this research aims to construct a site suitability framework that will aid farmers and policy makers in choosing location and updating regulations for kelp farms cultivating *Saccharina latissima* in Nova Scotia. Furthermore, this research applied the MCDA framework to an operational farm in Mahone Bay as a case study to check the efficacy of the research. It was found that the Indian Point Marine Farms site was suitable for Sugar Kelp cultivation which aligns with previous years of successful Sugar Kelp yield. However, further research is required to test the efficacy of economic criteria of the MCDA since this farm operates through non-profit funding for educational purposes. Apparent limitations to this research lays in the scarcity of data and previous research specific to Nova Scotia Sugar Kelp cultivation. Further research should focus on gathering nutrient data, ecotype differences in regional populations of Nova Scotian Sugar Kelp, and the formulation of a survey to provide more accurate weighted comparison analysis. Ultimately this could all inform a larger GIS mapping study for industry and policy use.

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1. Introduction

Seaweed has been a food source for coastal communities for centuries mainly in Eastern civilizations (Fatima et al., 2018). Today, seaweed is used as food, fertilizer, pharmaceutical and cosmetic product, and animal feed (Fatima et al., 2018). There are three main types of seaweed, green, red, and brown (Titlyanov & Titlyanova, 2010). Green Seaweeds are rich in cosmetically and pharmaceutically useful compounds (Fatima et al, 2018). Red seaweed is the most common and widely used for its binding constituents like agar and carrageenan (Fatima et al, 2018). Though not as widely consumed as red seaweeds, brown seaweed like *Saccharina latissimi,* known as Sugar Kelp, contributes to the food industry as a complete ingredient ready for consumption, rather than an extract. Brown seaweeds are commonly eaten raw, dried, or boiled (Fatima et al., 2018). They are abundantly present in Asian cuisine but are not a commonality among Western diets (Palmeiri & Forleo, 2020). However, the strength of the market in the east has caught the eye of Northwestern countries. Seaweed trade has a total annual value of over $14 billion (USD) as of 2019 (Haworth et al., 2023). East and Southeast Asian countries dominate this industry with China, Indonesia, Japan, South Korea, and the Philippines contributing 99% of the total value of global production (Nayar & Bott, 2014).

Seaweed has been gaining interest in the west as part of a new development area called the Blue Economy (Lee et al., 2020). This industry was first coined by the United Nations Conference on Sustainable Development (Lee et al., 2020). The blue economy's goal is to tap into the underutilized ocean space which works towards achievement of several SDGs (Lee et al.,2020). However, there are caveats to this industry's goals as many of the industries within the blue economy can have adverse effects on the ocean ecosystem if applied too heavily (Lee et al., 2020). Seaweed cultivation is seen as a hopeful industry to bridge the gap between sustainability and economic development as it has been shown to tread lightly on the environment, is easily cultivated with little investment cost, and has abundant market uses (Choudhary et al., 2021; Hossain et al., 2021).

The publicity seaweed farming has been gathering has instilled interest in a Nova Scotian industry (Howarth et al., 2023). Government grants have been awarded to NGOs such as Aquaculture Association of Nova Scotia for research surrounding the cultivation of kelp and to spark interest in growing a local seaweed economy (Kraly, 2019). They have collaborated with teams from Merinov, Centre for Marine Applied Research, and Ecology Action Centre over the last several years to focus more resources on the industry.

Nova Scotia is seen as a hub for aquaculture. It has more than 7500 km of coastline that are regarded as biophysically suitable for various aquaculture projects, seaweed aquaculture being among them (Bradford et al., 2020). The shallow and rigid nature of the Nova Scotia coast simplifies farm logistics and nutrient rich waters create a perfect environment for seaweed to thrive. Furthermore, recent socio-economic hardships make the seaweed industry more enticing for locals. Nova Scotia has a declining rural population due to job opportunities and poverty leading to cityward migration (Bradford et al., 2020). There is hope that seaweed farming could increase economic development in rural communities directly and indirectly (Bradford et al., 2020).

Like most sustainable industries, there is a limit to the scale of their application before they become destructive to the environment. Seaweed cultivation is not exempt from this fact. Large-scale monoculture cultivation of seaweed in Asian countries has shown that overloading coastal ecosystems with abundant seaweed aquaculture can result in environmental degradation. Large seaweed farms can have an adverse effect on benthic ecosystems changing the nutrient availability, genetic contamination, increasing particulate organic matter, current flow, and light availability (Titlyanov & Titlyanova, 2010; Howarth et al., 2023). Changes in light availability is especially worrisome noting Nova Scotia's critical eel grass ecosystem. It is crucial that all farms, large or small do not affect these species or other crucial benthic habitats. Furthermore, large-scale farming occupies large areas which could have socio-economic effects on local communities impacting recreational potential, community interests and fishing operations (Titlyanov & Titlyanova, 2010). Both socio-economic and environmental impacts could be detrimental to Nova Scotian coastal environments. This is an especially challenging subject as there is not much data on large scale seaweed farming in North America due to the nascence of the industry. Currently, environmental monitoring has guidelines for kelp aquaculture under the Aquaculture Management Act (1996). It is important that the province moves quickly in creating healthy guidelines for the kelp industry before it becomes too large to make sure effective and proactive conservation is upheld. However, this is a difficult task as farmers already find policy regulations a barrier to success (Haworth et al., 2023)

Smaller scale farming is much less likely to have negative environmental impact. Ecosystems have a much higher likelihood of mitigating stress (i.e. change to environment) when stress happens in small doses. By limiting the size of seaweed farms many of the harms noted above are less likely to have severe impacts on the surrounding ecosystem (Titlyanov & Titlyanova, 2010). Instead, the positive effects outweigh the negative effects. Among the positive effects of seaweed industry are eutrophication mitigation, ocean acidification buffering, low input agriculture, habitat provision, sustainable economic development, and diversification of livelihood income (Haworth et al., 2023; Bradford et al., 2023; UN Environmental Program, 2023).

Nova Scotia has many endemic species of seaweed worthy of cultivation (Haworth et al., 2023). *Saccharina latissima* is the first species of seaweed being cultivated in the province, likely because of the public resources available from research institutions and other organizations such as, GreenWave (in Maine), AANS, Centre for Marine Applied Research (CMAR) and the EAC who are making seaweed cultivation information available (Haworth et al., 2023). In their work, these organizations show how kelp aquaculture logistics are not overly difficult. They identify that kelp aquaculture is especially ideal for fisherman looking to diversify their livelihoods as they already have the equipment and many of the skills needed (Haworth et al., 2023). By setting up several moorings attached with longline grids held in place by buoys, communities or individual farmers can create a kelp aquaculture site with little upfront investment in comparison to other aquaculture industries (St-Gelais et al., 2022). The investment is significantly reduced if operational equipment is already available, i.e. boats, trucks and trailers (St-Gelais et al., 2022). Once a farm’s infrastructure is in place, the largest expenditures over the year are labour, seed and fuel and are only a fraction of the initial cost for setting up the farm infrastructure (St-Gelais et al., 2022). The simplicity of operations and low investment costs of kelp aquaculture make kelp aquaculture attractive to Nova Scotians especially given the need for rural economic development.

1.1 Knowledge Gaps & Learning Objectives

While investment costs for kelp farming are low, effort is not. There is much work to be done prior to constructing a farm. Many factors must be identified as suitable to determine if a potential farm site will be social, economically, and environmentally feasible. Environmental and socioeconomic parameters must all be analysed to make sure the kelp has the correct physical conditions to thrive, there is access to market infrastructure and there are no conflicting uses of the area. Interested farmers need to confirm that their potential farm sites are satisfactory in these areas before they begin to apply for licensing and before constructing their farm. Failure to choose a site that is suitable in these conditions could result in an unsuccessful business due to insignificant crop yield, high equipment expense, or conflict between stakeholders.

While access to educational platforms like GreenWave's Regenerative Ocean Farming Hub and the EACs Sustainable Aquaculture initiative are available to interested farmers, there is little research on site suitability that consolidates and synthesizes environmental and socioeconomic site selection parameters. This leaves farmers to make guesses based on piecemeal information. This paper aims to fill the knowledge gap in academic site analysis by examining environmental and socioeconomic factors at two different Nova Scotian kelp farms through a sustainability lens. This will help reduce the guesswork for farmers when choosing a location for their kelp aquaculture project. The paper will answer the question, what environmental and socio-economic factors contribute to a thriving small-scale Sugar Kelp farm in Nova Scotia? To answer this question the paper will focus on these learning objectives:

- Create a suitability decision framework for small scale Sugar Kelp aquaculture in Nova Scotia.
- Analyze a Mahone Bay Sugar Kelp farm site using the framework and gathered data.
- Discuss benefits, shortcomings and future research of the site suitability framework.

2. Literature Review

Kelp aquaculture has been gaining interest in western countries over the past several years. Kelp's low impact, low input nature places it ahead of high emissions terrestrial agriculture and fin-fish mariculture making it a more sustainable food product (Forbes et al., 2022). This is especially enticing for Nova Scotia as it is an exemplary region for all types of aquaculture (Bradford et al, 2020). Interest in kelp farming has led to a budding industry in Nova Scotia. However, policy and research in Nova Scotia is equally as nascent which is concerning for sustainability reasons. Small-scale cultivation has been acknowledged as a strategy to reduce the likelihood of environmental damage (Bradford et al., 2020). Employing this type of scale will help maintain growth in the industry while allowing adequate policy and research to catch up. Moreover, research methods in kelp aquaculture lack a framework for site suitability, especially pertaining to Nova Scotia's regional nuances. Multi-criteria decision frameworks have been proven useful in site suitability analysis in other aquaculture industries and will be useful for new farmers and policy makers in Nova Scotia. This literature review aims to explore key themes like the building interest in seaweed aquaculture, cultivation scale as a tool for sustainability, and site suitability methodology.

2.1 Global Interest in Seaweed Aquaculture

The United Nations (UN) have been an important driver of information in the seaweed farming space. In 1976, the Food and Agriculture Organization of the United Nations (FAO) released a report on seaweed cultivation outlining different species and the possible agricultural uses for them, the different techniques of cultivation, and the regions that currently employed them (Naylor, 1976). This report set the stage for much of the research and interest in seaweed as a sustainable industry. The report documented various important uses of seaweed and acknowledged the potential for environmentally friendly cultivation. Many of the products like agar, fertilizer, pharmaceuticals, edible seaweed, and animal feed mentioned in the report are still being referenced today (Howarth et al., 2023; UN Environmental Program, 2023).

In recent years, the UN has developed rhetoric surrounding sustainability with their Sustainable Development Goals. These have set the stage for nations, research institutions and businesses alike steering them towards different pillars of sustainability. New research is looking to understand seaweed aquaculture's place within the SDGs where the industry shows promise in a plethora of goals including health and hunger, goals two and three; environmental sustainability and responsible production, goals six, 12, 13, 14 and 15; and reducing inequalities, goals 1, 5, 8 and 10 (Troell et al., 2023). The UN has reinstated their stance on the sustainability of seaweed aquaculture this summer with a comprehensive report titled, Seaweed Farming: Assessment on the Potential of Sustainable Upscaling for Climate, Communities, and the Planet (UN Environment Programe, 2023). They discuss the benefits and adversities of seaweed farming synthesized through scientific literature and report their findings in terms of Strengths, Weaknesses, Opportunities and Threats (SWOT Analysis). The overall findings conclude that scaled seaweed farming has many benefits but also adversities. To mitigate these adversities scientific coordination, innovation and regulation need to operate in unison to achieve the positive effects of seaweed farming while diminishing the negatives (UN Environment Programe, 2023).

The 2023 UN report on seaweed farming is a significant congregation of sustainable seaweed agriculture knowledge. The benefits and adversities found within the report will inform much of the considerations for sustainability concerns as Nova Scotia's kelp industry grows. The environmental benefits of seaweed farming are carbon sequestration and carbon energy displacement, biodiversity support, water quality enhancement, coastal protection (UN Environment Programe, 2023). The environmental adversities of seaweed farming are identified as habitat competition, disease procurement, invasive species introduction, increased organic matter export, mega-fauna entanglement, marine pollution, and halocarbon emissions. Thanks to the groundwork the UN has done, the benefits and adversities of seaweed farming have been collated in a concise and useful way for analysis by those interested in bringing this industry to Nova Scotian shores.

2.2 Kelp Aquaculture in Nova Scotia

Nova Scotia has a historical connection to the ocean industry due to its extensive coastline and proximity to the sea. With a shallow meandering nutrient sufficient coast, Nova Scotia has shown its capacity to support several different types of mariculture (Bradford et al., 2020). Additionally, there are many individuals in coastal communities who possess beneficial assets like access to boats and rigging knowledge that would reduce the barriers to building a kelp aquaculture project (Bradford et al., 2020). Kelp aquaculture could aid in curbing the recent emigration of rural youth to urban centers in search of employment (Bradford et al., 2020). Kelp aquaculture's applicability for both the region and the people who live there make it an excellent industry to provide diversified streams of income for coastal families while building new economic opportunity throughout the province.

The potential for Nova Scotian kelp aquaculture has helped secure funding for non-governmental organizations (NGOs) interested in research and development (Howarth et al., 2023). This has helped lay the groundwork for experts like Howarth et al. (2023) and Bradford et al. (2020) to conduct extensive research on the opportunities and barriers to the inception of a socially, economically, and environmentally sustainable kelp aquaculture industry in Nova Scotia. Furthermore, only a few NGOs have begun to fill key knowledge gaps in educational aids for farmers and policy makers alike. Research in opportunities and barriers as well as the nascence of educational aids are evidence for the usefulness of a site suitability framework that would help further develop kelp aquaculture industry in Nova Scotia.

Howarth et al. have created an extensive review of opportunities and barriers for seaweed aquaculture in Nova Scotia. This paper reviews several different types of seaweed with cultivation potential in Nova Scotia (NS). They concentrate the paper on kelp aquaculture for many reasons: (1) well understood life cycle; (2) simple, low-cost hatcheries; (3) current kelp hatchery projects in NS; (4) low operational cost; (5) Similar equipment to shellfish farming for ease of transition or use. These opportunities outline the potential for kelp aquaculture in NS adding to the local interest: They show how Sugar Kelp (*Saccharina Latissima*) specifically is a practical raw product for Nova Scotian shores. Howarth et al. help inform the intent behind focusing on kelp within this research.

Howarth et al. (2023) note that there are several important barriers to kelp aquaculture in NS. They found that capable processing facilities have yet to be created and market access are the largest inhibitors of progress for the local industry (Howarth et al., 2023). Additionally, they found that local opinions voiced a need for more educational and awareness supports for prospective farmers and others described kelp farming regulations as overly stringent (Howarth et al., 2023). Local NGOs like the EAC have begun to fill educational gaps with projects like their Farmer Training, Seaweed Nursery and Education Centre (EAC, 2024). Yet, there is still a need for research effort in all the aforementioned barriers to kelp aquaculture. Site suitability framework has been used as a tool for policy decisions and could be a useful navigational aid for both farmers looking to create a new farm, and policy makers looking to produce more accessible regulations (Yin et al., 2018).

Bradford et al. (2020) interview provincial and local government officials, aquaculture farmers and researchers to determine the potential of non-finfish aquaculture. They conclude that the knowledge of local people, the need for economic improvement in rural areas, and the local environment in Nova Scotia create promising conditions for kelp aquaculture. However, they also find certain areas that challenge the expansion of such an industry. Infrastructure support, market access, farming scale, and regulatory frameworks were all cited as possible challenges by Bradford et al. (2020).

Nova Scotia has a number of boat launches and wharfs available for use giving new local farmers an advantage (Bradford et al., 2020). However, this infrastructure usually has small capacity and is becoming outdated creating a need for either upgrades in equipment or evaluation of the infrastructure for Sugar Kelp aquaculture (Bradford et al., 2020; Ragan et al., 2023). Market access is also seen as a logistical challenge by Bradford et al. (2020). Local seaweed markets are new in Nova Scotia. There are only a few licensed processors and getting to these prospective locations may include added expenses and logistical challenges for farmers (Howarth et al., 2023). Transportation may be a challenging economic factor connected to farm site location. Farm scale is a magnifying factor for many challenging aspects of kelp aquaculture including environmental and socio-economic components (Bradford et al., 2023). Bradford et al. (2020) acknowledges the use of small-scale farming as a mitigator for environmental concerns. Additionally, there were concerns from stakeholders over competition for ocean space between kelp farming and other industries, especially concerning increased scale. Careful consideration of other ocean users is necessary during site selection to manage these concerns. Bradford et al. (2020) discusses the potential for regulatory differences from community to community. Lack of understanding could lead to ineffective decisions in supporting local kelp farms (Bradford et al., 2020). Since it cannot be assumed that one model of farming fits every community it is important to analyse farms in a context specific way (Bradford et al., 2020). This provokes a need for regulatory frameworks that offer an effective way to analyse site specific socio-economic parameters to determine eligibility.

The novelty of kelp aquaculture in North America is a likely contributor to the lack of educational aids in Nova Scotia. Organizations have only recently begun to fill these gaps. GreenWave, an organization out of Connecticut in the United States of America, has created the Ocean Farming Hub which provides community support, logistics planning tools and online-course based training for kelp farming (GreenWave, 2024). Within their courses GreenWave includes a site analysis module that covers some social and environmental suitability factors (GreenWave, 2024). While this module does have many of the necessary environmental considerations, the socio-economic considerations fall short as they only contain dialogue around social licensing (GreenWave, 2024). Social licensing is an important part of site selection, but other factors contributing to healthy farm operations like proximity to infrastructure are not considered by GreenWave leaving out important information (GreenWave, 2024; Yin et al., 2018). Furthermore, a framework for decision making and analysis of site criteria is missing. Decision making analysis framework can fill this key knowledge gap in education and awareness contributing to the understanding of effective decision making. Currently, no such educational course like GreenWave’s nor a decision-making analysis framework tailored toward Nova Scotian kelp aquaculture exists.

2.3 Research Methods for Site Suitability Analysis

Deciding on a location for aquaculture development demands consideration of a multitude of different criteria. Decision making frameworks have existed for decades beginning with the Analytic Hierarchical Process (AHP) by Saaty (1990). This type of analysis uses a stepwise procedure for creating successful criteria, measurement scale for criterion, and comparison methods between discrete criteria. The AHP has since been built upon producing the Multi-Criteria Decision Analysis (MCDA) method commonly used in site suitability for aquaculture projects today (Estévez & Gelcich, 2015).

MCDA in aquaculture site suitability analysis plays an important role in spatial planning, policy decisions, and location identification by comparing factors across environmental, social and economic elements specific to sustainable aquaculture of a cultivated species (Yin et al., 2018; El-Gayar & Leung, 2001). MCDA framework works similarly to the AHP where the same three components are used to infer the best decision: (1) identify components of environmental and socio-economic criteria for successful farming; (2) design a measurement scale for each criterion; and (3) create a weighting system to compare criteria that considers the level of contribution to the decision process. First, environmental components outline the biophysical thresholds of the species to thrive and produce an economically feasible yield (Yin et al, 2018). Socio-economic components consider spatial conflicts like infrastructure accessibility, location utilization by coexisting entities, and institutional policies (Yin et al., 2018). Second, criterion can be measured on a fractional basis if results have a threshold with a large acceptable margin or a binary measurement of results that either meet or don't meet a threshold (Yin et al., 2018). These measurements are assigned fractions or whole values, depending on measurement style, from zero to one (Yin et al., 2018). Finally, the last step in MCDA is creating comparison weighting between criteria where each criterion is then assigned a percentage weight, the sum of which equals 1. There are multiple ways to assign percentages to criteria. Some assign percentages through participation via survey (Yin et al., 2018), some employ an equivalent structure where each criterion is weighted equally (Brigolin et al., 2015), and others weigh criteria using expert input (Jato-Espino et al., 2022). MCDA is a common practice in the aquaculture site suitability space (Estévez & Gelcich, 2015). MCDA has yet to have been used in Nova Scotia to aid farmers and policy makers in site suitability analysis. This technique is a useful tool for the advancement of the industry.

2.4 Small-Scale Aquaculture as a Sustainability Tool

Kelp aquaculture has been pointed to as a fix all blue-economy industry. There is an abundance of hype surrounding kelp farming due to its potential for bioremediation, carbon sequestration and low input low emissions products (UN Environmental Program, 2023). While there is potential for sustainable kelp farming practices there are several adverse effects of kelp aquaculture. The UN Environmental Program (2023) has shown that habitat competition, increased disease risk and invasive species introduction, among many other adversities, are cause for concern with seaweed aquaculture industry. A high level of caution should be taken towards large-scale aquaculture as it could increase the likelihood of risks given the intensity of farming in a single area. Large swaths of any type of monoculture are more likely to become detrimental to the environment (Park et al., 2018). For this reason, this paper will be tailored to small individual or community-based farms.

Taking a slow approach towards scaling the Nova Scotian kelp aquaculture industry will help policy and research keep up allowing proper management of environmental adversities. Quick expansion of aquaculture industries like shrimp and finfish aquaculture resulted in harmful environmental degradation (Folke & Kautsky, 1992). Given the nascence of the kelp industry in Nova Scotia, it is important that it does not follow in the footsteps of such aquaculture industries. Research in aquaculture has pointed to the need to increase efficiency of small-scale aquaculture as a mitigation technique for environmental detriment resultant of large-scale monoculture (Wang et al., 2023). A synergistic approach between industry, research and regulations should be implemented if sustainable growth is to be made in Nova Scotian kelp aquaculture (Martinez-Porchas & Martinez-Cordova, 2012). Starting the industry with small-scale aquaculture can lend itself to increased opportunity for research and regulatory advancement to reduce environmental harm further aiding farmers in their pursuit of sustainable livelihood.

Seaweed aquaculture's relatively benign environmental footprint and potential for economic benefit has captured UN's focus for decades with a particular resurgence in interest over the last several years. Seaweed industry has the potential to aid various countries in the achievement of multiple Sustainable Development Goals. While there are diverse environmental and economic benefits that come from strong seaweed aquaculture, there are several disadvantages to extensive seaweed farming. Lack of research in this space has raised concerns over scaling up these industries. However, the UN acknowledges that there is good potential for mitigating the drawbacks of scaling industries through active participation of regional research and policy during the development of new seaweed aquaculture industries.

Nova Scotia has great potential for seaweed aquaculture development especially for the species *Saccharina latissimi* or Sugar Kelp. The nature of Nova Scotia's coastline and the historical connection of rural communities to marine industry are particularly advantageous for a kelp aquaculture industry in the area. Much of the current research on seaweed aquaculture in Nova Scotia props up the need to address the lack of educational and awareness aids as well as site specific infrastructure challenges. Although GreenWave has created a useful free interactive website for new farmers, there is room for a robust site suitability framework that would address several of the issues alluded to in recent kelp aquaculture research.

Kelp aquaculture shows good promise in harnessing many of the benefits outlined by the UN. However, aquaculture industries in the past have resulted in environmentally harmful practices when scaling monoculture practices. Given that there are known disadvantages to a large-scale kelp industry, it is important that Nova Scotia mitigates this through a wholistic approach that produces effective research and policies that mirror the growth of economic development keeping the local environment free from harm. Due to the lack of research in the region, small-scale farming techniques are an impactful mitigation technique to reduce the potential for adverse ecological reactions to new kelp production.

Low impact small-scale kelp farming can be effective in providing environmentally conscious economic development in Nova Scotia. Current research has pointed to the need for site suitability framework to aid farmer education and its usefulness for policy decision making. The MCDA approach has been used widely in the aquaculture industry showing its effectiveness for site suitability analysis. The next chapter will delve into the approach used to create an MCDA framework for this thesis and its application to the Mahone Bay case study.

3. Methods

This study consists of two main parts: The creation of the Sugar Kelp site suitability framework using MCDA and the use of the framework to analyze an operational Sugar Kelp farm. These two components required their own unique methodologies to be completed. The framework was produced using similar MCDA methodology to Yin et al. (2018). Four elements went into formulating the MCDA: (1) create criteria for both socio-economic and environmental necessities for kelp cultivation; (2) determine thresholds for criteria; (3) assign numerical values to each criterion to rank importance through weighted comparison; (4) and specify the threshold at which final score fails or passes quantitatively assessing the result. A basic visual representation for the framework can be seen below. The case study, which used a Sugar Kelp farm in Mahone bay belonging to Indian Point Marine Farms Ltd., was conducted by obtaining and processing data at the farm and via online sources. These results were then put through the framework to obtain an analysis of the farm's site suitability. Both the MCDA and case study components will be discussed in further detail below.

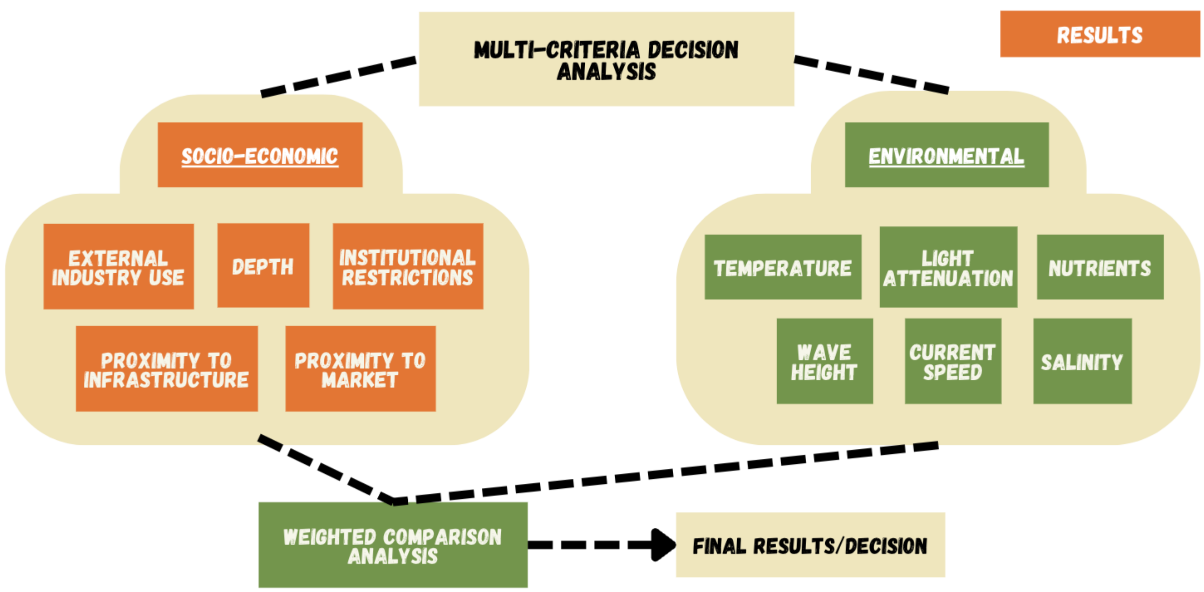

Figure 1: Visual representation of multi-criteria decision analysis site suitability framework.

3.1 Site Suitability Framework

Creation of Criteria

Criteria was created by first identifying three necessary objectives for Sugar Kelp farm operation. These objectives were, find an area that supports kelp growth, a location that is financially feasible, and a location that does not pose a risk to social or environmental spheres. This led to assigning the umbrella titles, environmental and socio-economic, to two sets of criteria to streamline the framework creation process and the use of the framework down the line. Environmental criteria were determined through Novanet and Google Scholar Searches for literature which stated the necessary parameters for growth of *Saccharina latissima.* Socio-economic criteria were found using the same search databases for aquaculture MCDA literature and choosing applicable criteria for Nova Scotian Sugar Kelp farming. Both sets of criteria are shown in Figure 1.

Threshold Determination & Analysis

Thresholds were made for each individual criterion in two ways, either binary or scaled suggested in Yin et al. (2018). Binary thresholds were assigned to factors such as external industry use, institutional restriction or any of the environmental criteria since any conflict or data outside the criteria threshold bounds would render the space unsuitable. The criteria in this binary type of threshold rendered a one if it was equal to or greater than the threshold or a zero if it was below. Additionally, those with a maximum and minimum bound yielded a one if the data was within this threshold or equal to either the maximum or minimum. Anything outside of the maximum and minimum bounds received a zero. Scaled thresholds were assigned to criteria like proximity to infrastructure and market which have a range of suitable results. The threshold for these criteria sits between two integers. For the analysis of the individual criteria, the upper limit was set to one and the lower limit was set to zero. If the sample data sat between the threshold bounds, it would receive a value between zero and one. If it sat below the lower limit, it would receive a zero and if it sat above the upper limit, it would receive a one.

Weighted Comparison Determination and Analysis

Since a survey was not conducted to find the most important criteria for the community and due to my level of expertise, it was decided that the most appropriate way to carry out the weighted comparison would be to equate all criteria to each other. This meant that all criteria were assigned a weighted comparison number of 0.09091. The weighted comparison number was found by dividing one by the sum of all criteria shown in the equation below,

Equation 1

$$W = \frac{1}{c_n},$$

where, W is the weighted comparison number and c_n is the number of criteria used in the MCDA framework. The analysis of the weighted comparison was carried out by multiplying each criteria's weighted comparison number by the integer received during the threshold analysis. This produced a weighted comparison number for each criterion that could then be summated to find the final score of the MCDA (see equation 2).

Final Score

A threshold was set for the framework's final score to determine overall site suitability. Since each criterion was equally as important as the next, if one criterion was not met then the analysis should read "not suitable." Because of this, the threshold for the final score was set at 0.90909. This was found by subtracting one by the weighted comparison number using equation 2,

Equation 2

$$Final\ Score\ Threshold = 1 - W.$$

The threshold was found this was since the final score of the MCDA was calculated using the sum of all the results during the weighted comparison analysis as seen in the equation below,

Equation 3

$$Final\ Score = \Sigma_i (C_i * W_i),$$

where *C* is the criteria threshold score. Any analysis that receives a score less than 0.90909 would be assigned the result "not suitable."

3.2 Mahone Bay Case Study

The case study analysis was carried out using data collected at a seaweed farm run by the Ecology Action Centre (EAC) and Indian Point Marine Farms LTD. in Mahone Bay, Nova Scotia, Canada. The farm was implemented as a small-scale educational operation for prospective seaweed farmers. The location of the site is roughly two kilometres southeast of Indian Point between Raus Island and Sheep Island shown in Figure 2.

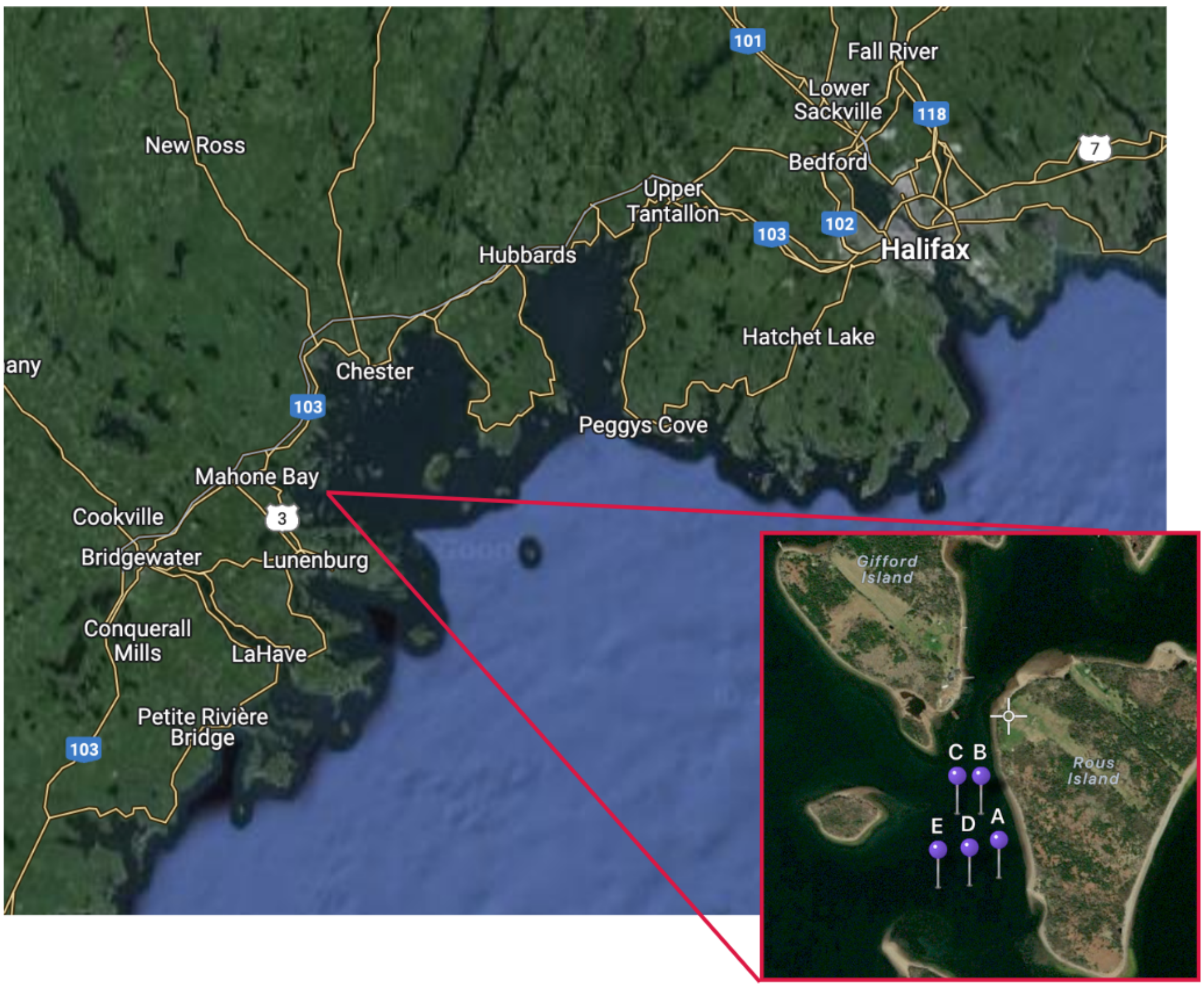

Figure 2: Location of the case study farm located in Mahone Bay 2 km southeast of Indian Point. The sampling sites at the farm are shown. These were taken at the perimeter of the farm.

Various techniques for data collection were used to obtain the information needed to carry out the framework calculations. Data collected for the socio-economic criteria section was found using Google Maps satellite distance measurements, nautical charts, government legislation and expert knowledge. Environmental data was collected using the closest monitoring site of the Centre for Applied Research's (CMAR) Open-Source Coastal Monitoring (OSCM) Program, in-situ water sampling collected during this research from 2022-2023 and coastal monitoring data by Keizer et al. (1996). Data collection and respective criteria are shown in Table 1. Explanation for both socio-economic and environmental criteria data collection are described below.

Table 1: Criteria for Site Suitability Framework

Categories	Criteria	Data Collection Method/ Source
Environmental	Temperature	CMAR Coastal Monitoring Open Data (Little Rafuse Island)
	Light Attenuation Depth	Keizer et al., 1996
	Nutrients	In-situ data collection
	Wave Height	CMAR Coastal Monitoring Open Data (St Margaret's Bay)
	Salinity	Keizer et al., 1996
	Current Speed	CMAR Coastal Monitoring Open Data (Heckman's Island)
Socio-Economic	Proximity to infrastructure	Google Maps Distance
	External Industry Use	Expert knowledge, DFO, Department of Fisheries and Aquaculture
	Proximity to Market	Google Maps Distance
	Depth	Mahone Bay Nautical Charts
	Institutional Restrictions	Government of Nova Scotia

Environmental Data Methods

Monthly environmental data for a single grow season, from November to April, were selected to determine the Mahone Bay Sugar Kelp farm's suitability using the MCDA built in this study. Data for three out of the six environmental criteria can be found using CMAR's OSCM data. The data is available on CMAR's official website through the Coastal Monitoring portal. Time series data for temperature, current speed and wave height can all be found through these means. However, the data is restricted to a discrete number of sample sites in certain bays around the province. Mahone Bay has several sample sites, but they are not all set to gather data for temperature, salinity, current speed and wave height. Temperature data was available from the closest sample site to Little Rafuse Island, about six kilometers away. Current speed was not available at this site. Instead, this data was found at the Heckman's Island site about 12 kilometers away. Wave height data was only available from St. Margaret's Bay site around 26 kilometers Northeast of the farm.

Light attenuation depth and Salinity data were found using data via site monitoring of Indian Point Farms Ltd. from 1992 to 1994 by Keizer et al. (1996). The data was harvested by the Bedford Institute of Oceanography with the Department of Fisheries and Oceans. This source was found through google scholar article search.

Nutrient data was a more involved data gathering process. Data for nutrients is not available for the area via previous studies or monitoring programs. For this reason, the data was gathered by sampling the sea water at the farm site monthly from November to April and testing for all nitrogenous species that Sugar Kelp uses for growth. These growth species are Ammonia (NH_4^+), Nitrate (NO_3^-), and Nitrite (NO_2^-). Five samples were taken during each sampling day at 5 different locations on the farm site's perimeter (see figure 2). The sampling process contained three steps: (1) rinse the drop bucket with sample location sea water three times before taking the sample, (2) use a wide-mouthed 500 mL light resistant opaque container to transport sample to the farm processing site located approximately two kilometers away, (3) using a syringe rinsed in sample water three times 30 mL of sample water were filtered with a 0.2 Micron filter attachment into a 30 mL container which was kept frozen and transported to Dalhousie University where it was stored frozen until nutrient analysis was carried out.

After the samples were gathered for the entire growing season, nutrient analysis was conducted on all samples. The analysis methods used were vanadium (III) reduction for nitrate and nitrite detection (Braman & Hendrix, 1989) and fluorometric ammonia analysis for ammonia detection (Holmes et al., 1999; ASTM, 2006; Taylor et al., 2007). Vanadium (III) reduction standard curves were made using nitrogen standard concentrations of 25, 10, 5, 2.5, 0.5, and 0 µM. Fluorometric ammonia standard curves were found using NH_4^+ standards of concentrations 10, 5, 2, 1, 0.5, 0.2 and 0 µM. Using these methods, concentrations for nutrients crucial to Sugar Kelp growth, known as dissolved inorganic nitrogen (DIN), were found using the sum of nitrate, nitrite and ammonia in a sample. An average was then taken using all five location samples during each monthly sampling period. This result was then analyzed through the MCDA framework.

Socio-economic Data Methods

Data for socio-economic factors was gathered for the Mahone Bay site via google maps, governmental documentation, nautical charts and expert knowledge. The method used was dependent upon the factor in question. Proximity to infrastructure was derived using the measure distance function on google maps. A private dock is accessible by the Indian Point Marine Farms farmers and therefore no government data was needed to obtain information on public dock access. Proximity to market was determined using google maps GPS route finding function using the farm dock and Halifax City Centre as the start and end points. Halifax City Centre was chosen as the starting point due to the lack of a Nova Scotian processing facility. The number of restaurants and farmers' markets here would currently be the largest fresh market for kelp farmers.

Institutional restrictions and External industry use were identified via government laws, by-laws and departmental documentation. Any Marine Protected Areas (MPA), shipping lanes or fishing allocations for the location would constitute a 0 rating for these factors. Additionally, since the farm is already in operation, input from the operator was used to gather external industry data. Depth was found using the farm coordinates in congregation with Nova Scotian nautical charts.

4. Results

4.1 MCDA Framework

Thresholds

Each section of the MCDA required analysis via existing literature: Identification of the criteria, thresholds for the criteria, identifying a weighted comparison schematic and deciding a pass or fail threshold for the final score. The results for each of these factors can be seen in Table 1. Economic criteria identified were temperature, salinity, light attenuation depth, nutrients, wave height, and current speed. Socio-economic criteria identified were external industry use, depth, institutional restrictions, proximity to infrastructure, and proximity to market. All environmental criteria were adapted from Yarish et al. (2017) and Sykes (2022). Socio-economic factors were adapted from Yin et al. (2018) who uses an MCDA to identify suitable blue mussel farm sites. The socio-economic criteria for blue mussel farming are almost identical to the socio-economic needs of Sugar Kelp farming. The evidence for the socio-economic criteria is reinforced by Yarish et al. (2017) and GreenWave's Ocean Farming Hub courses that describe similar factors for economic prosperity and social licensing of a Sugar Kelp farm.

Table 2: Results for the MCDA. Criteria for assessment is shown for both environment and socioeconomic factors. Thresholds are shown for each individual criteria with either upper, lower or both upper and lower bounds. Weighted comparison coefficient shows the weighted comparison number for calculation during analysis.

Criteria	Threshold	Weighted Comparison Coefficient
Environmental		
Temperature	0 °C > Max & Min < 15 °C	0.09091
Salinity	28 – 34 psu	0.09091
Light Attenuation	Min > 1.5 m	0.09091
Nutrients	Max > 1.1 μM	0.09091
Wave Height	Max < 6.4 m	0.09091
Current Speed	Max < 1.52 m/s	0.09091
Socio-Economic		
External Industry Use	> 100 m – 10 m	0.09091
Depth	30 m >MHW; MLW < 5 m	0.09091
Institutional Restrictions	> 1km buffer	0.09091
Proximity to Infrastructure	> 15 km – 1 km	0.09091
Proximity to Market	< 50km - 200km	0.09091

Temperature is characterized by the upper and lower bounds known for Sugar Kelp survival over their growth period from November to May (Yarish et al. 2016). The threshold for temperature is 0°C to 15°C determined by Yarish et al. (2017). Yarish et al. (2017) also found the thresholds for Sugar Kelp survival for light attenuation depth and salinity to be at a minimum of 1.5m and between 28 – 32 psu, respectively. Light attenuation depth is the depth at which a secchi disc, a plastic disc with black and white pigment on a metered rope, may be lowered into the ocean until it is no longer visible. Light attenuation is used as a proxy to determine the potential for light to penetrate the water so that kelp may carry out photosynthesis. Salinity refers to the concentration of dissolved salts in the water: Too much and too little will be detrimental to kelp survival (Yarish et al. 2017). Nutrients, in this context, are the concentration of dissolved inorganic nitrogen (DIC), the limiting growth molecule for Sugar Kelp. The threshold for this is the half saturation constant which refers to the theoretical minimum ambient DIC in water at the farm (Espinoza & Chapman, 1983). The half saturation constant found by Espinoza & Chapman (1983) for *Laminaria longicruris* is 1.1 μM. *Laminaria longicruris* is of the same genus as Sugar Kelp. Literature has used the half saturation constant for the nutrient minimum for Sugar Kelp research (Broch & Slagstad, 2012; Venolia et al., 2020). Current speed and wave height are the physical forces that may dislodge Sugar Kelp holdfasts from their substrate due to storms or inclement weather (i.e. farm growing lines). The maximum threshold for current speed and wave height at which loss of Sugar Kelp yield is detrimental has been quantified by Buch & Bucholz (2005) as 1.52 m/s and 6.4 m respectively.

External industry use refers to whether there are other stakeholders using the same location as the farm site in question. The threshold for this is simply a binary zero or one. If there are other stakeholders using the space, then the criterion receives a zero. This was adapted from Yin et al. (2018) and GreenWave (2024) from their evidence for social licensing and navigating external stakeholder usage. Depth is defined as the distance from the surface to the ocean floor at mean low water (MLW) and mean high water (MHW). This simultaneously ensures that the kelp has enough water to grow in as well as ensuring material cost is economically viable. Thresholds were found via GreenWave (2024) who quantified the minimum water level for growth and the maximum water depth before an engineer consultation is needed which would heavily increase the price of starting the farm. These thresholds are a minimum depth of 5 m at MLW and maximum depth of 30 m MHW. Institutional restrictions refer to any shipping lanes or marine protected areas. This criterion was adapted from Yin et al. (2018) who uses a buffer zone and Boolean distance between two points to calculate proximity to restrictive areas. The threshold is of a binary nature, if there is an institutional restriction within one km then it receives a threshold score of zero and outside of one km then it receives a one. Proximity to infrastructure refers to the availability of docks for access to the farm and to transport crop yield to market during harvest. The threshold was adapted from Yin et al. (2018). The maximum distance from a farm that dock infrastructure can be is 15km and the minimum distance is one km. Any results that sit between these two points were subject to a sliding scale that resulted in a score between zero and one. If a farm was more than 15 km from adequate docking infrastructure, then it received a 0 if it was one km or less than it received a one and any point between 1 - 15 km received a score between zero and one. Proximity to market works in a similar manner using a sliding scale between the distance threshold of maximum 200 km and minimum 50 km. This threshold was adapted from sources that gathered data on the distance producers were travelling to sell their produce at farmers markets (Åsebø et al., 2007; Govindasamy et al., 1998).

Weighted Comparison

Weighted comparison was adapted from Belton & Stewart (2002). The criteria are all weighted equally. Since a survey was not produced for this framework and expertise for such weighting was not available, this was the best path to reduce bias in the framework.

Final Score

The final score for a site that the framework deems suitable for small-scale Sugar Kelp harvest is 0.90909. Any score below this number is unsuitable. Since all criteria are weighted equally, this final score threshold ensures that if any criteria receive a score of zero in their threshold analysis stage, then the farm site fails. Furthermore, if sliding criteria have threshold analysis results that issue a combined score of 0.09091, then the farm site fails.

4.2 Case Study Analysis

The case study analysis results for Indian Point Marine Farms in Mahone Bay are shown in Table 2. All data collected for each criteria satisfied the criteria thresholds except proximity to infrastructure and market. Proximity to infrastructure was approximately 2 km based on Google Maps distance measurement function and proximity to market was approximately 89.2 km based on Google Maps route finding function (Google Maps, n.d.*a*; Google Maps, n.d.*b*). These two criteria received a threshold score of 0.93 for proximity to infrastructure and 0.74 for proximity to market. These threshold results were carried forward to the weighted comparison analysis where each criterion that scored a 1 in the threshold analysis also scored the full weight of the comparison score, 0.09091. Distance to infrastructure and market received a score of 0.08455 and 0.06727 respectively due to their reduced threshold analysis score. Adding the weighted comparison analysis results yielded a final score for the case study of 0.97001. This is higher than the suitability threshold of 0.90909. Indian Point Marine Farms is therefore considered a suitable site for Sugar Kelp cultivation by the MCDA framework. This compares to the yield in biomass which was 1-3 kg/m of average kelp growth on their grow lines. Further explanation of the remaining data gathering, and results of the case study data are described below.

Table 3: Case study analysis results for Indian Point Marine Farms using MCDA framework.

Criteria	Data	Threshold Score	Weighted Comparison Score	Suitability Score
Environmental				
Temperature	Max & Min: 14.2 & 0.687 (°C)	1.0	0.09091	
Salinity	Max & Min: 30 & 28 (psu)	1.0	0.09091	
Light Attenuation	Min: 4 m	1.0	0.09091	
Nutrients	Max 4.0 μM	1.0	0.09091	
Wave Height	Max: 4.43 m	1.0	0.09091	0.97001
Current Speed	N/A	1.0	0.09091	
Socio-Economic				
External Industry Use	0	1.0	0.09091	
Depth	17.3 m	1.0	0.09091	
Institutional Restrictions	0	1.0	0.09091	
Proximity to Infrastructure	2 km	0.93	0.08455	
Proximity to Market	89.2 km	0.74	0.06727	

Environmental Criteria Results

Temperature and wave height maxima and minima were taken from the Coastal Monitoring Project from CMAR by Dempsey et al. (2024) and Torrie (2024). Over the growing season from November to April the temperature reached a maximum of 14.2 °C and a minimum of 0.687°C which was inside the framework threshold receiving a one for the criteria threshold score. Wave height over the same period but different year had a maximum of 4.43 m which also received a one for the criteria threshold score. Current speed was also found using CMAR's open data. However, they did not have data for current speed during the growing period. Current speed was omitted but still received a criteria threshold score of one since the data that was gathered, although outside of the growing season, showed no report of having a maximum outside of the criteria threshold (Dempsey et al., 2022). Salinity and light attenuation were found via Keizer et al. (1996). Their sampling period lasted from 1992 to 1994. When only taking data from the growing season, the light attenuation depth was 4 m at the minimum. This exceeded the minimum value for light attenuation depth giving a criteria threshold score of one. Nutrients were found during the research for this paper. The sampling period only lasted during the MCDA framework growing period for 2023. The DIN was found to have a maximum of 4 µM which surpassed the threshold for this criterion. Therefore, this received a criteria threshold score of 1.

Socio-Economic Criteria Results

External industry use received a threshold score of one since no external industry uses the area either for recreation, fishing or other means (A. Riopel, personal communication, April, 2024). Depth was found to be 17.3 m (Mahone Bay Nautical Chart, 2024). This result was within the bounds of the threshold for this criterion yielding a one for criteria threshold score. There were no institutional restrictions in this area giving institutional restrictions criterion a threshold score of one (Branch L.S, 2024; Mahone Bay Nautical Chart, 2024). The closest docking infrastructure for the case study was 2 km away from the farming operation receiving a threshold score of 0.93 for proximity to infrastructure and the closest and largest market to the farm was found to be 89.2 km away giving a threshold score of 0.74 for proximity to market (Google Maps, n.d.*a*; Google Maps, n.d.*b*).

5. Discussion

The MCDA framework created in this research is designed for both provincial government application for zoning and Sugar Kelp aquaculture support for individual small-scale farming or community small-scale Sugar Kelp farmers interested in analyzing farming locations to predict site suitability. The scale parameterization of this research creates a limitation to the MCDA framework since socio-economic factors would change for large-scale farmers. Manipulation of the framework is possible for interests in considering large-scale operations. However, the potential for negative side-effects of large-scale Sugar Kelp farming should be researched in Nova Scotia prior to constructing such farms given the known potential for habitat shading, invasive species introduction and disease spreading (UN Environment Programme, 2023).

The case study yielded a positive result. The Indian Point Marine Farms site was considered suitable. The EAC has cultivated kelp at this location for multiple years for educational purposes (EAC, 2024). Since the site is known to cultivate kelp, the framework was correct in predicting site suitability. However, the farmers at Indian Point Marine Farms did not have a substantial yield compared with some estimates for growth by Coleman et al. (2022). The MCDA framework cannot predict yield nor the possibility of yield loss due to operational failures or detrimental physical anomalies like storms or ice cover. The framework simply predicts whether the site is suitable based on environmental conditions specific to *Saccharina latissima,* and socio-economic conditions from previous MCDA research and suggestions from NGOs for kelp cultivation (Yin et al., 2018; Yarish et al., 2017; GreenWave, 2024; Sykes, 2022). Additionally, the EAC are cultivating kelp at Indian Point Marine Farms for educational purposes, not for profit. This creates a considerable limitation to the case study analysis of the MCDA framework since their concerns with economic feasibility are not an important piece of their operation. Funding support from private donation and government funding allow the farm to exist without turning a profit. Testing the framework on for profit farms will aid in analyzing its effectiveness.

Understanding the limitations of the research is important when using this framework. Shortfalls and limitations to the MCDA framework itself are also observed such as a small amount of subject research, potential for inaccurate data, weighted comparison methodology inaccuracy, and data gathering challenges that are caveats to this work. These are further explained below.

5.1 Small Research Pool

The amount of literature on kelp was a barrier for this research. MCDA has been extensively studied since the advent of the Analytic Hierarchical Process (AHP) by Saaty (1990). Yet, there is a minute amount of MCDA articles that involve small-scale coastal Sugar Kelp cultivation suitability. This meant finding criteria that suited this work would need to be found using a combination of sources. Environmental determinants for growth seem to be solidified in the small amount of research between GreenWave (2024), Venolia et al. (2020) and Yarish et al. (2017). However, the socio-economic parameters still maintain variability in the literature (Yin et al., 2018; Sykes 2022). Adaptation from multiple sources was the only way to connect previous studies with Nova Scotian small-scale coastal Sugar Kelp aquaculture. While this method is useful, there is still potential for missing unforeseen criteria or more effective criteria.

5.2 Threshold Limitations

Environmental

Most of the environmental thresholds in this research have adequate evidence to support their parameterization except nutrients. The nutrient threshold is the only criteria taken from a different family of kelp, Laminaria *longicruris,* due to a lack of research specific to Sugar Kelp. Previous research uses the nutrient half saturation constant found by Espinoza & Chapman (1983) to be adequate for modeling Sugar Kelp growth (Venolia et al., 2020). However, using a different genus of kelp to determine nutrient threshold for Sugar Kelp may be a shortfall of this research. Additionally, it is important to understand that the ecotype differences specific to local Sugar Kelp habitat create potential for variation in the criteria thresholds (Sykes, 2022). For example, the threshold for nutrients, taken from Espinoza & Chapman (1983), varies between the Bay of Fundy and St. Margeret's Bay. The intraspecies variation means using this MCDA for sites located in the Bay of Fundy may be inaccurate.

Previous research also suggests that there are differences in temperature resilience between ecotypes of Sugar Kelp further complicating this limitation (Sykes, 2022). Research into the ecotypic differences of *Saccharina latissima* for all environmental parameters would help buttress MCDA research for Sugar Kelp in Nova Scotia.

Socio-economic

Socio-economic criteria distance to market, distance to infrastructure, depth and, to some degree, external industry use, are all factors that are up to the individual farmers' willingness to travel, spend capital and work with local industry. As a result, these criteria are subjective. However, this research bases the thresholds for these criteria in common maximum distance travelled, small-scale affordability and the least conflicting social path. Any farmers using this framework could manipulate these thresholds to support their interests. However, the basis for these criteria would be useful for decision makers looking to make broad aquaculture zones or policy.

There is no current processing plant for Sugar Kelp in Nova Scotia. This creates a market barrier for farmers. They must rely either on their own processing or on raw kelp market retail (Howarth et al., 2023). The implications of the lack of a processing centre for this research mean a threshold for distance to market must be determined based on small-scale market connections. In this case, the market of choice was Halifax farmers markets since this would be the largest access point to the local market with the least complications. As a result, the distance threshold was based off the distance travelled by producers who attended farmer’s markets to parameterize this criterion. The research available for this was minimal. Both the inception of a processing plant and research for distance travelled to markets by producers in Nova Scotia or Canada would help strengthen this criterion.

Previous research on MCDA for Sugar Kelp aquaculture has not considered distance to infrastructure as criteria for suitability analysis (Sykes, 2022). However, MCDA research on other species and NGO suggestions support this as a necessary constraint on cultivation (Yin et al., 2018; GreenWave, 2024). There are several small craft harbors and boat launch ramps in Nova Scotia that would give community scale Sugar Kelp farmers ample infrastructure for land-sea access (Ragan et al., 2023). However, the monetary support for this infrastructure is lacking

(Ragan et al., 2023). The lack of maintenance could see some of this infrastructure become commercially unviable. For provincial use of the framework, this factor must be addressed for analysis accuracy. Furthermore, the use of public dock space creates potential for overcrowding infrastructure (Sykes, 2022). This is important to consider during the external industry use criteria analysis, especially for application at provincial scales.

5.3 Accuracy of Data

A small pool of research as evidence to support threshold criteria reduces the accuracy of the criteria analysis. This inaccuracy could propagate an inaccurate final score when using the MCDA for site suitability analysis. While the evidence for the criteria of this paper comes from strong peer reviewed research, the accuracy of using single papers to determine criteria thresholds reduces the strength of the framework's accuracy. Furthermore, the use of the paper Espinoza & Chapman (1983), which is 40 years old, could use updated research given the change in oceanic temperatures of contemporary oceans.

Ecotypic variation in Saccharina *latissimia* also influences the accuracy of threshold data (Thomas et al., 2019). There are variations in the physical environmental conditions that Sugar Kelp populations in specific locations can withstand. This is evident in research by Espinoza & Chapman (1983) who found that there was a difference in saturation constants for kelp inhabiting St. Margaret's Bay, Nova Scotia versus the Bay of Fundy. Nutrient saturation constants for east coast kelp were lower than those for west coast kelp. Furthermore, it is well documented that there are variations in temperature thresholds for Sugar Kelp in different locations (Olischläger et al. 2014). The significance of this variability is that environmental thresholds are dependent on the location where their parent population resides. This could introduce inaccuracy in the MCDA framework proposed in this research since environmental thresholds may need to be constructed for different regions in Nova Scotia alone. Simply using east coast kelp to grow in west coast waters is not a possible answer to this problem as Nova Scotian seaweed farmers are restricted to harvesting their kelp for cultivation from wild kelp within a certain radius of their farm site (Aquaculture Management Act, 1996). This reduces the potential for unforeseen impacts as a result of species introduction into foreign regions.

Farmers assessing site suitability will likely be limited to gathering data over a single growing season due to the nature of the small-scale and low-cost targeted audience of this research. Multiple years spent data harvesting may be unrealistic for prospective farmers. Limiting the data pool for site suitability analysis to a single grow season may provide an inaccurate representation of the site's environmental suitability as anomalous conditions could render a positive or negative result. Data gathered by Keizer et al., showed anomalous surface water salinity during 1992 that reached below the threshold for site suitability for Sugar Kelp in this research's MCDA framework. Had this not been omitted based on the knowledge that this was an anomalous event due to multiple years of data, the site would have failed when it should not. Although, anomalous events may be suspicious for site suitability prospects. Multi-year data could aid in determining what caused such an anomaly to occur and whether there is a cycle in environmental conditions where crops may be susceptible to adverse changes. If there is a cycle of detrimental environmental conditions this would be an important consideration during criteria analysis in the MCDA framework. Given the conflicting nature of data anomalies discussed above, the consideration of including certain data anomalies while administering this framework are up to the individual discretion of those using the framework.

Because this research decided to omit current speed data, framework users may need to be aware of using out of growth season data to fill the data scarcity gap. The case study analysis showed that no current speed data was available during the growth period from November to April. As a result, data obtained during the summer months was consulted. This data found no maximum current speeds above the threshold. Having witnessed two successful growth seasons here, omitting the data and assigning the criteria a threshold score of one to not affect the final score, was a comfortable and logical decision. Users who are unfamiliar with the site location should get confirmation from local knowledge (e.g. interviewing fisherman or others partial to the ocean's yearly variation) when omitting data based on out of growth period data.

5.4 Weighted Comparison Shortfalls

Weighted comparison is an important part of the MCDA process (Yin et al., 2018). Not all criteria are equally important in decision making. This research decided to leave the comparison weighting as equal due to the low concentration of MCDA research in the Sugar Kelp space and since weighted comparison decisions would require a higher level of expertise. This follows previous research and their methods in MCDA frameworks for Sugar Kelp like Thomas et al. (2019) and Sykes (2022). These papers also used equal weighting between criteria. A more effective way of creating a robust MCDA framework is to administer a survey that captures local interests and community knowledge (Yin et al., 2018). This is possible if the framework is being used to assess individual farm locations surrounding communities but becomes more difficult to include on larger scale applications (e.g. provincial analysis).

5.5 Data Gathering Limitations

Acquiring the necessary data to run the framework is a point of concern. Socio-economic criteria demand simple equipment to harvest data, but environmental criteria are not so straightforward. For example, nutrient analysis was carried out by filtering water using relatively low-cost equipment but was run through a spectrophotometer and NOx analyzer which are very expensive and require a high level of chemistry knowledge. This method is inaccessible for most individual farmers looking to administer this MCDA framework on a potential Sugar Kelp aquaculture site. Farmers can obtain this data via Dalhousie's Oceanography Department. However, this requires a large budget for only the sampling of nutrients. Based on the CERC Laboratory (2023) pricing at Dalhousie University the sampling carried out in the case study alone for nutrients would cost $1085. If the sampling was reduced to only duplicates it would cost $434. This is a more manageable sum, yet this only assesses one site. If the government were interested in providing aid for these criteria or analyzing nutrients to provide data to prospective farmers, acquiring a SUNA nutrient analyzer would be useful. This tool allows for in-situ analysis of surface water nitrate, the main nutrient utilized by Sugar Kelp for growth. The cost of a SUNA is in the range of $30,000-35,000, too much for a single farmer looking to start a farm. However, this expense could be carried by the government to help create and support Sugar Kelp economy since it could be used to analyze multiple sites for multiple farmers every year. Furthermore, creating a public database with nutrient data like CMAR's Coastal Monitoring program would also be a useful tool to bolster the Sugar Kelp economy.

CMAR's Coastal Monitoring program was a large contributor to the case study analysis using this research. Without this, the available data for the case study analysis would likely be extremely low or unavailable since temperature, wave height and current speed were all obtained using the Coastal Monitoring program. While this was useful, this data source was still scarce. The Coastal Monitoring program was not close to the farm site making its resolution of data very low. The largest distance of data used from this platform was 26 km for wave height. This is fair to use since the area where the farm is located is sheltered from oncoming waves but for temperature or salinity data low resolution could miss important changes in the physical environment of the farm. Farmers looking at sites in more isolated areas will find this to be a large hurdle for analyzing potential farm locations when administering this MCDA framework.

6. Conclusion

Nova Scotia has a nascent kelp industry. It has an estimated potential of growth of approximately 38 million dollars of revenue (Changing Tastes, 2023). However, due to the early stages of the kelp industry, there are many barriers that stand in the way of reaching its full economic potential. The barriers to the kelp industry have been identified as stringent policy and lack of educational tools upon others. This research set out to help reduce such barriers by creating an MCDA site suitability framework for small-scale Sugar Kelp aquaculture in Nova Scotia. The effectiveness of this framework was gauged by applying this research to a farm run by the EAC and Indian Point Marine Farms in Mahone Bay.

The case study farm site was considered suitable based on the MCDA framework formed by this research. Since the case study site is currently running a Sugar Kelp farming operation that has successfully produced kelp for multiple seasons, the framework proved to be effective at gauging suitability. Although, it is important to understand that this is only a single case study, and the farm operates for educational purposes. The small sample size and the non-profit structure of this case study leaves unanswered questions surrounding the applicability of the framework to varying sites around Nova Scotia and gauging economic feasibility in the interest of for-profit farms.

There was a particular lack of research specific to MCDA frameworks pertaining to Sugar Kelp farming. This meant much of the criteria and criteria thresholds were consolidated by using a small array of scientific papers, industry reporting and adjacent aquaculture industry MCDA framework research. As a result, the accuracy of the framework may be low since single papers were used to decide thresholds and criteria in some cases. Additionally, the age of some research, the use of other kelp genus research, and the specification of markets as Halifax farmer's markets are gaps in this framework and will need further exploration.

It is important to understand the scope of this framework. The initial idea was for this research was to provide farmers and policy makers with a readily useable framework for site suitability. Applying the framework to the case study brought light to the expensive nature of harvesting data for individual farmers, especially regarding nutrient data acquisition. As a result of expensive data gathering, the MCDA framework would be better suited for utilization by governmental organizations looking to support the Sugar Kelp industry. This would leave the financial burden on government funding rather than on small-scale farmers interested in starting a business, which is already a large economic hurdle.

Additionally, the scope of this framework may only apply to east coast Sugar Kelp. Ecotype variation is evident between kelp in St. Margaret's Bay and kelp in the Bay of Fundy (Espinoza and Chapman, 1983). This means that some of the environmental criteria thresholds may not apply to kelp on the west coast. Since farmers are legally obliged to use kelp from a zone very close to the farm site for cultivation, one cannot circumvent this physical phenomenon by using east coast kelp on the west coast. Using introduced kelp ecotypes may also have environmental impacts unknown and wouldn't be recommended without research on the subject regardless of the legal implications. The gap in knowledge surrounding ecotypic threshold variation leaves space for further research to delve into the regionality of Sugar Kelp species to support MCDA framework development.

Suggestions for future work informed by this research are, to determine regional differences in criteria thresholds for Sugar Kelp, create a data harvesting system for framework criteria using pooled resource funding, and to make a survey to define better weighted comparison numbers for analysis. Tackling these future projects would further the accuracy and reduce data gaps within this MCDA framework research. Ultimately, coupling these future projects, especially a Nova Scotian framework data harvesting system with spatial data would lend itself to the formation of a GIS map which would create a visual representation of the areas suitable for small-scale kelp aquaculture in Nova Scotia. This would further reduce the lack of educational aids for interested kelp farmers and provide government with a reference for better policy making for Sugar Kelp aquaculture in Nova Scotia.

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