National SCIENCE Challenges

SUSTAINABLE SEAS

Ko ngā moana whakauka

Stocktake and characterisation of Aotearoa New Zealand's seaweed sector: market and regulatory focus

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August 2021

Report

Report for Sustainable Seas National Science Challenge project

Building a seaweed sector: developing a seaweed sector framework for Aotearoa New Zealand (Project code 2.5)

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For more information on this project, visit:
https://www.sustainableseaschallenge.co.nz/our-research/building-a-seaweed-economy

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About Sustainable Seas Challenge

Our vision is for Aotearoa New Zealand to have healthy marine ecosystems that provide value for all New Zealanders. We have 60+ research projects that bring together around 250 scientists, social scientists, economists, and experts in mātauranga Māori and policy from across Aotearoa New Zealand. We are one of 11 National Science Challenges, funded by Ministry of Business, Innovation & Employment.

www.sustainableseaschallenge.co.nz

Cover image: Kelp in Kaikōura. Leigh Tait/NIWA

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Executive Summary

This report provides a characterisation of the New Zealand seaweed sector today including current demand, supply, and regulation, along with opportunities and barriers to growth. It is the first stage in the development of a Seaweed Sector Framework for New Zealand, and part of the broader Blue Economy workstream of the Sustainable Seas National Science Challenge.

Seaweed has huge potential to contribute to the Sustainable Sea's vision of "healthy marine ecosystems that provide value for every New Zealander". A prosperous seaweed sector could provide meaningful economic, environmental, social and cultural benefits to local communities, along with broader impacts nationally. However, the New Zealand seaweed sector is still in its infancy and is not keeping pace with international markets. The development of a Seaweed Sector Framework is an important step to help support and guide the sector's development.

Inputs to this research report included reviews of sector reports and scientific papers, along with interviews of individuals directly involved in seaweed research, businesses, regulation and development projects. The focus is on identifying opportunities and barriers to sustainable growth of the New Zealand seaweed sector.

The International Seaweed Sector Today

There are three types of seaweeds (often referred to as macroalgae): green, red, and brown, all of which are farmed or harvested in some manner. However, red seaweeds (52%) and brown seaweeds (47%) make up most of the global supply. Most farmed seaweed is used for human consumption, either directly or as a food ingredient (85%). The balance (15%) is used for a range of markets including livestock feed supplements, extracts (e.g. agar) and other uses such as soil biostimulants. Within seaweed food-products, China and Japan are the largest importers representing more than 71% of the global market.

Seaweed makes up almost a third of global aquaculture production volume. Global value of seaweed aquaculture in 2019 was estimated at US$14 billion with a growth rate of 7% per year on average over the last decade. Seaweed aquaculture production volume has tripled over the last 20 years and now accounts for 97% of total global production (over 34 million tonnes was aquaculture and just over 1 million tonnes was wild harvest in 2019). Asia dominates seaweed aquaculture (97% in 2019); China (58%), Indonesia (29%), South Korea (5%) and the Philippines (4%) are the top producers. For wild harvest, Chile, China, Norway, Japan, and Indonesia are the top suppliers of biomass.

The New Zealand Seaweed Sector Today

New Zealand has an emerging seaweed sector with pockets of product innovation operating at a small scale. However, this sector is constrained by an underdeveloped local seaweed supply-chain that itself is inhibited in many instances by low profit return to growers, fishers and gatherers, and by regulation. Central government has recognised the economic and environmental potential of the sector. However, this has not yet translated to meaningful growth. Small volumes are harvested from mussel lines (as by-catch or deliberately caught), and from limited wild harvest and beach-cast collection. This supply is supplemented by some imported raw stabilised product that is processed in New Zealand. There are almost no data on the scale of seaweed product supplied apart from the wild harvest of bladder kelp, *Macrocystis pyrifera*, which is a fisheries quota species. Reliance on wild and beach harvest alone is unlikely to enable the seaweed sector to scale to a significant high value sector; the limited biomass of wild and beach cast harvest, reliability and quality of seaweed supply constrains seaweed processors' ability to expand and meet market demand.

Commercial seaweed farming from hatchery supplied seed does not exist in New Zealand, and there is no infrastructure in place for commercial seaweed hatcheries. As of 2020, there were 59 current permit holders eligible to farm seaweed in New Zealand spread across 170 marine farms, the majority of which are in the Marlborough Sounds. This reflects a common practice of 'future proofing' farming options by adding species when applying for or renewing resource consents. However, to date there has not been a push by the aquaculture sector to use consented water space for the sole use of seaweed farming. This is mainly due to lack of certainty in customers and market, value in terms of return on investment and demand, and uncertain or low economic return, as well as lack of seed supply source, making it too risky and expensive to be 'first' with seaweed.

The domestic market for seaweed as food for human consumption is relatively small and undeveloped compared to many overseas markets. Māori traditionally consumed green and red seaweeds as part of their diet and used bull kelp as pōha (e.g., for preserving mutton birds). Today, market demand for most seaweed products in New Zealand is still immature compared to international markets; most New Zealand harvested seaweed is used to supply products to the agricultural and horticultural markets. The most important product type is biostimulants with AgriSea New Zealand Ltd and Waikaitu Ltd among the market leaders and innovators. Profit return to marine farmers, fishers or beach-cast gatherers is low from these industries where value is created in the formulation and utilisation, and by a domestic customer base. Because the farm gate commodity return from these industries is low, marine farmers generally consider their focus on these products to be uneconomic.

Fresh seaweed consumption is still uncommon here, and seaweed is eaten mainly in New Zealand Asian restaurants from imported dried ingredients. Companies like Pacific Harvest Ltd and NZ Kelp are developing seaweed-based condiments and dried food products using a mixture of local and imported seaweed. Other companies such as Wakame Fresh Ltd have experimented with seaweed food exports into premium markets such as Japan, as well as supplying the domestic market. However, very specific market requirements combined with a reliance mainly on mussel-line by-catch have presented significant challenges. Lack of differentiation from supply from existing channels such as China, South America, Japan and Korea also presents a major hurdle.

Animal feed supplements is another important market today for New Zealand seaweed; however, they currently comprise only a small proportion of the local feed market. AgriSea is the market leader with animal health products for the dairy, dry stock, equine and apiculture industries. Other producers such as NZ Kelp have smaller product ranges. There has also been a growing interest in the potential for seaweed-based feed supplements to reduce methane emissions in livestock, particularly with the red *Asparagopsis* spp., however, intellectual property for its use as a methane reducing feed supplement is tightly controlled and must be licensed. In addition, there are significant scalability and application issues that need to be addressed to ensure this opportunity is practical and viable.

Other small volume markets for New Zealand seaweed today include seaweed extracts used in health products (e.g., bacteriological agar produced by New Zealand Seaweeds Ltd), beauty and as ingredients to other products (e.g. food ingredients).

Regulation of the Seaweed Sector

Collection of wild seaweed (i.e. not from marine farms) is managed by Fisheries New Zealand under the Fisheries Act 1996. This provides "for the utilisation of fisheries resources while ensuring sustainability" (s8(1) Fisheries Act 1996). Commercial wild harvest is managed either through the Quota Management System (QMS) or as 'non-QMS species'. As all seaweeds except bladder kelp are non-QMS species, they do not require Total Allowable Commercial Catch (TACC)/Annual Catch Entitlement (ACE) quota in order to be collected; they are effectively 'open access', but they do require a commercial fisher to hold a commercial fishing permit and the requirement to report their

catch and land it with a Licensed Fish Receiver applies. These requirements do not apply when taking red seaweeds (Class Rhodophyceae) while it is unattached and cast ashore. In theory, this makes wild seaweed harvest relatively straightforward. However, there is a historic fishing permit moratorium over many species of interest that was brought in as a result of environmental concerns, and this now restricts the ability to build a seaweed aquaculture industry (Schedule 4C of the Fisheries Act 1996). These are agar weed (*Pterocladia lucia* and *Pterocladia capillacea*), bladder kelp (*Macrocystis pyrifera*), brown kelp (*Ecklonia radiata*), bull kelp (*Durvillea* spp.), gracilaria weed (*Agarophyton chilense*, formerly *Gracilaria chilensis*)*, Lessonia variegate,* karengo (*Porphyra* spp.) and sea lettuce (*Ulva* spp.).

Before setting up a marine farm, a Resource Management Act (RMA) resource consent is required from the relevant regional council (also known as a coastal permit). If granted, the council will ask for an undue adverse effects test (on recreational, customary, and commercial fishing) under the Fisheries Act. There is considerable inconsistency in the approach of local councils to consenting seaweed on marine farms as a result of the RMA process and how effects are considered within regions. In addition, regional coastal plans must give effect to the New Zealand Coastal Policy Statement (NZCPS), but each plan is region specific. Policy 11 of the NZCPS requires that any effects to indigenous biodiversity be considered, and so this must be taken into account in the location and establishment of seaweed farms. The Fisheries Act lists some 'harvestable spat' species (Schedule 8A) that can be farmed providing they naturally settle on marine farming structures; however, many of the species listed do not naturally settle on marine farms. Marine farmers cannot harvest species that naturally settle on their farms for commercial use if they are not on this schedule (or exempted). This may allow a pathway to farming, depending on species, but it is complicated and goes around the system rather than tackling the issues that prevent farming within the Fisheries Act. There are also regulatory challenges to collecting wild broodstock for a seaweed hatchery and supplying this commercially to marine farmers.

Land-based aquaculture operations also require RMA land use, water take and discharge consents as well as a fish farm licence issued under the Freshwater Fish Farming Regulations 1983. MPI (Biosecurity New Zealand) is the primary agency for biosecurity regulation although regional councils have some functions as well. The Biosecurity Act 1993 controls the entry of notifiable pests and diseases into New Zealand. For land-based operations, water intake and discharge along with biosecurity considerations often present challenges to obtaining consent. However, at present, land-based farming presents a simpler, albeit far more expensive pathway to development.

There are signs that the seaweed sector regulatory framework has been evolving in response to emerging drivers and information. However, the process for those who have tried commercially orientated seaweed research and farming trials has been lengthy, costly, and frustrating stymying progress and investment. An ideal regulatory framework for seaweed would be more responsive, collaborative and enabling.

Gaps and Barriers to Growth of the Seaweed Sector

Successful seaweed sectors overseas have hatcheries, large and small-scale farming operations, significant processing capability, and established seaweed-based products supplied to established markets. These activities are assisted by ongoing R&D, workforce support, and regulatory support. In the New Zealand sector today, there are important gaps halting progress and growth:

- Low cost (and sometimes low quality) dried seaweed can be sourced easily from Asia.
- Regulatory barriers can be significant for taking seaweed, for establishing seaweed hatcheries and for consenting water space for marine farming for many seaweed species.
- There are no commercial seaweed hatcheries so there is no reliable source of seed supply for potential seaweed farmers.

- There are no established large-scale commercial seaweed farms operating in New Zealand so there is also no workforce development support (although support may come from existing aquaculture producers).
- While there has been some specific or niche seaweed research projects funded, the sector and research has not made significant progress towards commercial hatcheries or seaweed farms, or sustainable commercialisation of products for higher value sectors. It is still very expensive and risky to start these endeavours as published information on how to do this for NZ species in NZ conditions is missing. There is a role for government to coordinate and support early-stage commercially orientated research to improve knowledge of our species so that investors can then take on the commercial risk.

Market-led Opportunities for Growth of the Sector

New Zealand will have difficulty competing internationally in generic low-cost product categories with large, well-established foreign seaweed markets that have developed supply chains and are based on low labour costs. New Zealand exporters will need to focus on export markets where there are opportunities for higher-quality and higher-value products that have a unique selling point. To build a high value and sustainable sector, New Zealand producers will need to progressively develop products that return a high profit for niche markets and those where competitive advantage can be readily maintained. Based on the research presented in this report and with stakeholder representatives' input, an assessment was undertaken of New Zealand's priority market opportunities and is summarised here and detailed below.

Product	**Fit** Potential competitive advantage for New Zealand Seaweed Sector	**Profit** Expected profit margins once product category is mature	**Scale** Revenue potential of target market	**Readiness** Proven technology/viability and consumer demand
Health products	High	High	Low	Low
Human food	High	Med	Low	Low
Animal feed	High	Med	High	Med
Biostimulant	High	Low	High	High
Ecosystem services	Med	Low	Med	Low

There is an immediate volume-based opportunity to increase supply to the biostimulant and animal feed supplement product categories. These require higher volumes of seaweed so provide a pathway to farm seaweed at scale. They are currently heavily supply-constrained compared to domestic demand, and there is already demand for exports of these products. However, these product categories also have lower margins so will require seaweed farmers to achieve scale and efficiency in order to lower costs and operate profitably. For the New Zealand aquaculture industry to achieve its collective value target of $3B by 2035, it is a risky proposition to invest in another low returning marine candidate that requires massive scale to be profitable. The positive trials using *Asparagopsis* spp. in animal feed as an effective way to reduce methane emissions in livestock may help spur investment and growth in *Asparagopsis* spp. farming in New Zealand and act as a catalyst

towards development of the key infrastructure and supply chain gaps to develop other, more profitable candidates for aquaculture.

Trends in developed countries to promote seaweed as a 'superfood' present an opportunity for sector growth with more favourable product margins. Developing fresh food markets for seaweed domestically will require considerable consumer education to change food habits. Therefore, to grow a buoyant sector, there needs to be a focus on export opportunities. Processed food categories where seaweed is used an additive (e.g. in pasta) or as a condiment (e.g. seasoning) require less consumer education, but also do not require much seaweed. This makes them a safer starting point for new market entrants.

Seaweed-based extracts incorporated into nutraceuticals and health products provide a pathway for high margin growth. However, these also require considerable investment in research and development, intellectual property protection, and often processing equipment. They also typically require only small amounts of seaweed and have higher returns over the long term for all of the supply chain.

There is a seaweed-based environmental services market emerging internationally. Focused mainly on 'blue carbon' offsets, and on bioremediation of nutrient-heavy discharges from commercial users of water, it is attracting local interest. New Zealand producers, regulatory agencies, philanthropists and 'off-setters' could position themselves at the forefront of international developments in establishing environmental service markets based on seaweed. Government support will be needed to complete the necessary research required to support this to ensure we capture the opportunity for New Zealand to be recognised as a country that has designed and implemented this industry well.

Seaweed product categories that are less likely to suit New Zealand include bioplastics and biofuels. These typically require massive volumes of seaweed to be supplied at low cost, and large capital investment in processing. Also, the economics of biofuel relies on much higher international oil prices than have been seen for many years.

Next Steps and Recommendations

For New Zealand to have a sustainable and high value seaweed sector, this report suggests the following:

- Establish a seaweed sector group/hub to foster collaboration and stakeholder engagement, share information and inform decision making, and set priorities and aspirations for development of the industry.
- Scope, fund and develop high profit, high fit seaweed industries.
- Develop a clear pathway for ecosystem services markets from seaweed that can be managed and ensured viable in New Zealand.
- Map out and strategically prioritise research and development to support the sector. Initiatives that overcome collective hurdles and unlock the highest value opportunities for NZ should be prioritised. Consideration should be given to overseas research initiatives that can be integrated, to maximise New Zealand's research spend and avoid duplication.
- Develop a Government strategy, which informs regulatory solutions and funding priorities in line with the seaweed sector group's priorities. Develop a fit-for-purpose cross-agency regulatory framework including international harmonisation, marine spatial planning, consenting, permitting, and standards setting requirements.
- Develop a governance framework for the sector that incorporates Māori and mātauranga.

Subsequent work planned as part of this project will look at the current state of seaweed research (both nationally and internationally), the potential of specific seaweed species, ecosystem services

of seaweeds as well as Te Tiriti o Waitangi considerations. This will provide background information for the development of a framework for the New Zealand seaweed sector that will then be tested and refined through local case studies.

Introduction

Sustainable Seas National Science Challenge

This report contributes to the Sustainable Seas National Science Challenge; Theme 2: Creating value from a blue economy. Sustainable Seas' (2021a) objective is "to enhance utilisation of our marine resources within environmental and biological constraints" and its mission is:

> "Transformation of Aotearoa New Zealand's ability to enhance our marine economy, and to improve decision-making and the health of our seas through ecosystem-based management."

Sustainable Seas defines the blue economy as "marine activities that generate economic value and contribute positively to social, cultural and ecological well-being" (Sustainable Seas, 2021b).

"Fostering and growing the blue economy is crucial to meeting the Challenge objectives."

Background

New Zealand's marine environment and its associated economies represents some of the most innovative and emerging industries, as well as historical and traditional ones. Seaweed is an example of this but with a difference; it is anything but business as usual. There is growing interest in this sector, both internationally and here in New Zealand, for its potential to expand New Zealand's blue economy horizons in aquaculture technology, its supply chains, and the environment itself. New Zealand is naturally well positioned to take advantage of this growing industry due to the ecological suitability of our environment for seaweed aquaculture (Figure 1).

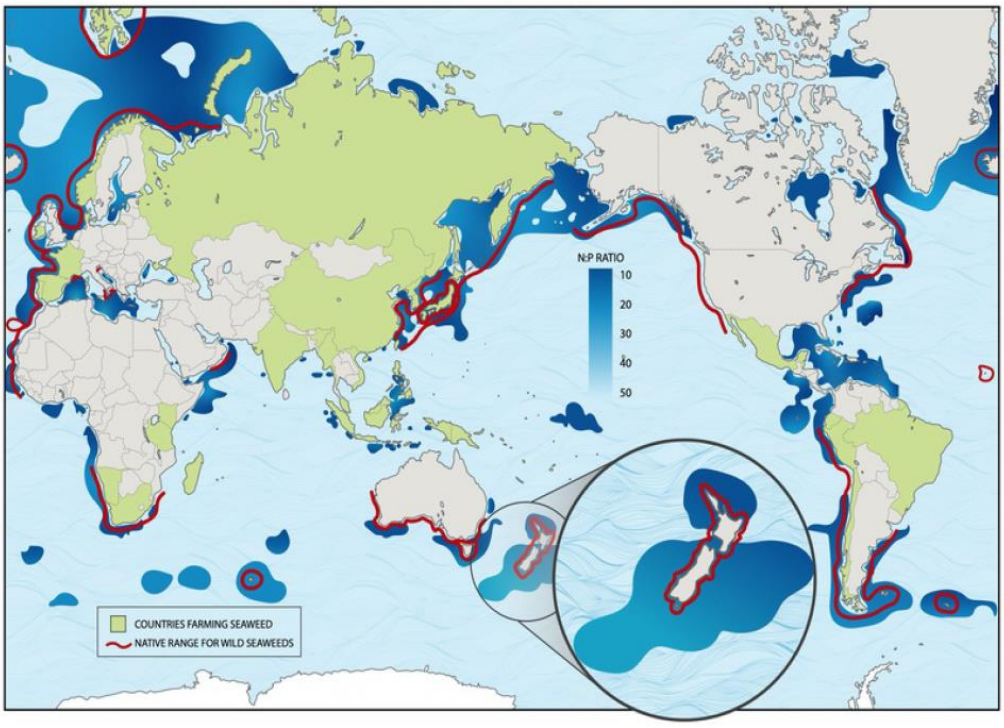


Figure 1. Ecological suitability map for seaweed aquaculture. Adapted with permission from Froelich et al. (2019).

Seaweed farming creates habitats and products that provide ecosystem services including the potential for carbon sequestration and nutrient removal (Gentry et al., 2020). These characteristics

are particularly relevant to the sustainability principle of ecosystem-based management (EBM) and the blue economy more broadly. However, without an understanding of the real-world environmental benefits and risks (i.e., a robust knowledge-based and tailored approach), the opportunity to achieve blue economy outcomes could be wrongly assessed, or potentially missed.

The need and scope for this research was identified in the *Transition to a Blue Economy: Scoping & Horizon Scanning* project following interviews with multiple people involved in the Aotearoa New Zealand blue economy (Envirostrat, 2019). This project identified that numerous new initiatives and businesses are targeting seaweed as a novel primary resource for the blue economy. However, there is no overarching vision for a seaweed sector to guide regulatory frameworks, ecological sensitivities, climate change, relationship to protected areas, inclusivity, and systems implications of uncoordinated economic development. The opportunity is to create space for niche, regenerative, high-value blue economy enterprises, whilst also encouraging larger operations to develop high-value blue economy approaches from the outset to avoid creating yet another primary sector commodity trap.

Aims and Objectives

The overall aim of this Sustainable Seas research is to develop and test a framework for a sustainable and high value New Zealand seaweed sector that is focused on identifying a future for the sector based on EBM principles. The purpose of this report is to provide a characterisation of the status of the seaweed sector which feeds into the framework. This includes a seaweed sector stocktake, identifying market opportunities for New Zealand, and exploring environmental market opportunities and effects of the industry. The report looks at international trends and promising market opportunities for New Zealand, the readiness of the New Zealand seaweed sector to realise its blue economy potential, barriers and solutions to sector development, as well as regulatory considerations.

New Zealand's seaweed sector is in its infancy. By identifying potential markets and future direction, we will be able to better understand implications of these on development of the sector and the pathway forward, as well as constraints on growth that need to be overcome to enable the sector to be successful.

Current Seaweed Sector Status

International Seaweed Industry Status

The seaweed market globally is supplied by two sources, wild harvest (including beach-cast), and aquaculture. Seaweeds are classified into three major groups: brown algae (Phaeophyceae), green algae (Chlorophyta), and red algae (Rhodophyta), all of which are harvested through either wild harvest or aquaculture. In 2019, of the total wild-harvest and aquaculture seaweeds produced, 52% were red seaweeds, 47% brown

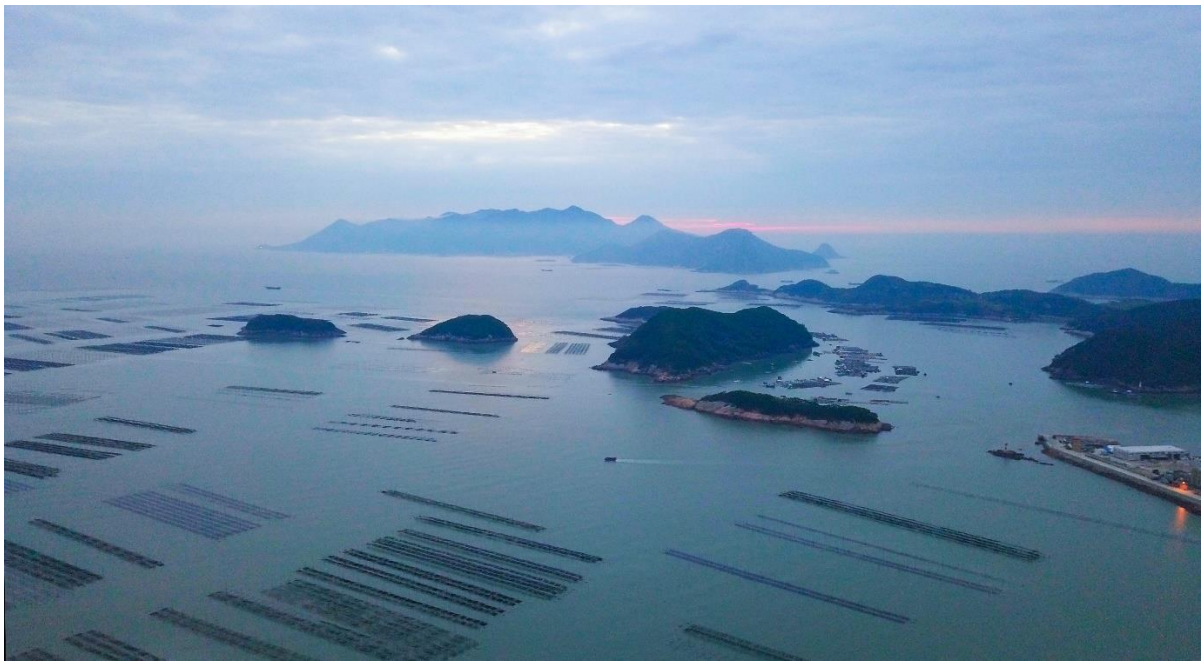
Key global seaweed market trends include:

- >35 million tonnes of worldwide production
- Aquaculture production predominantly meets the global demand
- Annual global growth rate ~ 7 %
- Less developed countries currently have greater market share
- The majority of both production and consumption is driven by Asian countries, although demand is increasing across the globe, including in the United States. Top producing Asian countries include China and Indonesia.
- Diversity of species and end-products is increasing; most products are food related
- There is a global movement toward more plant-based diets and products, particularly in Western countries.

seaweeds, and <1% were green seaweeds (FAO, 2021a). The majority of seaweed production comes from a select number of species, Japanese kelp (*Saccharina japonica*), *Eucheuma* spp., *Gracilaria* spp., wakame (*Undaria pinnatifida,* hereafter wakame), nori (dried *Pyropia* spp.) and *Kappaphycus* spp. (FAO, 2021a; FAO 2021b). *Saccharina* spp*., Pyropia* spp. and wakame are commonly used for food and health products while seaweeds such as *Kappaphycus* spp*., Eucheuma* spp., and *Gracilaria* spp. are predominantly grown as raw material for the production of carrageenan or agar for consumer products (FAO, 2018). Asian countries have increased demand for edible seaweed. As a direct food product, this provides better incomes for farmers compared to supplying seaweeds to the polysaccharide industry in Western countries (Garcia-Poza et al., 2020).

The value of the global seaweed market was estimated at over US$14 billion in 2019 and represents almost a third of global aquaculture production volume (FAO, 2021a). Over the last decade, the price of seaweed globally has remained much the same at around US$2500 per tonne. In 2019, aquaculture accounted for 97% of total global seaweed production (over 34 million tonnes from aquaculture and just over 1 million tonnes wild harvest production (FAO, 2021a; FAO 2021b)). In the past decade, aquaculture has experienced annual growth of 7% on average, while wild harvesting has remained relatively static.

Asia is the top producer of farmed seaweed (97% in 2019) (Figure 2; FAO, 2021a), and China (58%), Indonesia (29%), Korea (5%), and the Philippines (4%) are the top producing countries within Asia. Other regions, including Africa, the Americas, Europe, and Oceania produce more than 150,000 tonnes from aquaculture collectively (FAO, 2021a). In terms of wild seaweed harvest, Chile, China, Norway, Japan, and Indonesia are the top producing countries (FAO, 2021b).



Seaweed farms in Xiapu, Fujian, China. Image credit: iStock.com/redtea

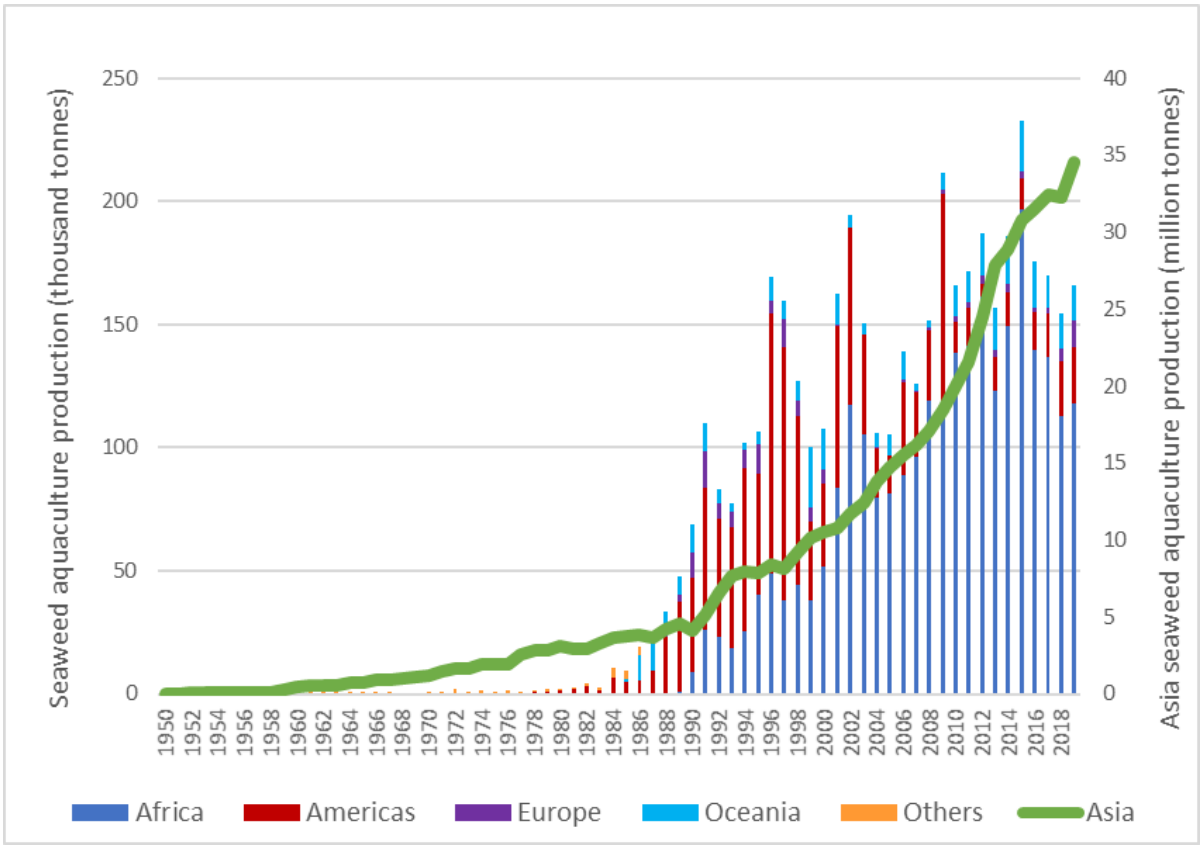


Figure 2. Total seaweed aquaculture production in Africa, Americas, Europe, Oceania, and other areas (primary x-axis, thousand tonnes, wet weight) and Asia (secondary x-axis, million tonnes) 1950 to 2019 (FAO, 2021a).

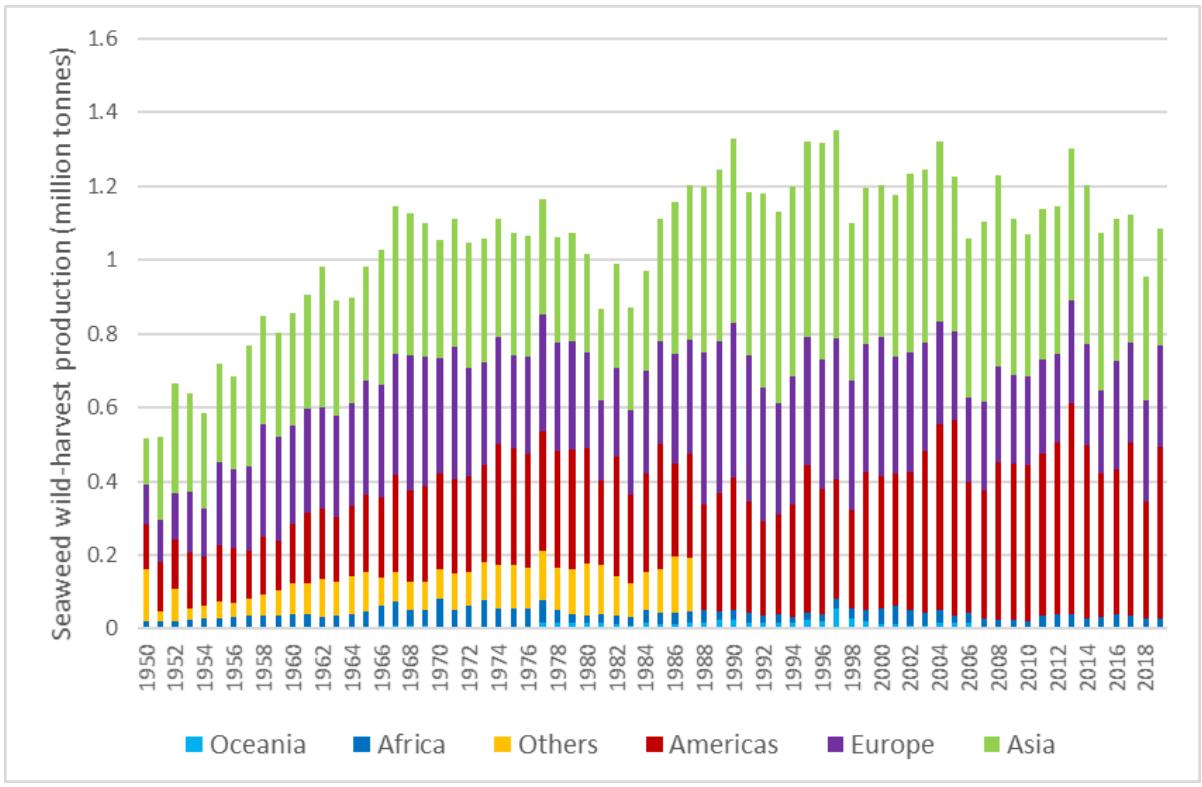


Figure 3. Global total seaweed wild-harvest production (wet weight, million tonnes) by region from 1950 to 2019 (FAO, 2021b).

Key Players

While the majority of production occurs in Asian countries, there are key players in the seaweed industry supply chain located around the world and operating in a range of markets (Table 1) (Markets and Markets, 2020).

Table 1. Global Seaweed Industry Key Players (Markets and Markets 2020).

Key Player	Country of Origin	Seaweed Product(s)
AtSeaNova	Belgium	Supplies to seaweed farms in the form of direct seeding and equipment.
Groupe Roullier	France	Animal, plant, and human nutrition; aquaculture; pet food; and cosmetics.
CP Kelco U.S., Inc	USA	Hydrocolloid ingredients.
Acadian Seaplants	USA	Food-products, biomedical, agricultural, and agrichemicals.
Qingdao Gather Great Ocean Algae Industry Group	China	Marine chemicals, fertiliser, feedstuff.
Qingdao Seawin Biotech Group Co. Ltd.	China	Pure extract, seaweed functional fertiliser, seaweed secondary, and micro element fertiliser.
Qingdao Bright Moon Seaweed Group Co.	China	Alginate, sugar alcohol (Mannitol).
Seaweed Energy Solutions AS	Norway	Raw seaweed material, seaweed seeds.
The Seaweed Company	Netherlands	Supply to sectors in food, health and wellbeing, animal health, pharmaceuticals, bio-growth stimulants, materials (plastics, textiles, etc.), renewable energy.
Algea	Norway	Animal feed, fertilisers.
Seasol	Australia	Fertilizer.
Gelymar	Chile	Alginate, carrageenan.
Algaia	France	Carrageenan, alginates, plant bio stimulants, specialty seaweed extracts, customised solutions.
CEAMSA	Spain	Carrageenan, alginate.
Compo Expert	Germany	Biostimulants.
Irish Seaweeds	Ireland	Supply raw material for food ingredients, pharmaceutical, nutraceutical and cosmetic companies.
Cargill Incorporated	USA	Food products, agriculture, nutrition, and risk management.
DuPont de Nemours Inc.	USA	Dietary supplements, nutrition and biosciences, construction materials, pharmaceuticals, biomaterials, and water solutions.
Beijing Leili Marine Bioindustry Inc.	China	Fertiliser, humic acid, amino acid, potassium humate, and microelement.

Seaweed Demand: Intermediary and Consumer Demand

Seaweed aquaculture has expanded rapidly over the past decade and is expected to continue to grow to meet increasing demand and as new applications for seaweed are developed. The end use industries driving international markets include edible seaweed, nutraceuticals, pharmaceuticals, and antimicrobials (Cottier-Cook et al., 2016; Shannon & Abu-Ghannam, 2019; Piconi et al., 2020). Seaweeds are also being considered for their prospects to provide compounds and chemicals for novel industrial and biotechnological uses (Lorbeer et al., 2013; Piconi et al., 2020). There is also a growing interest, particularly in western markets, in seaweeds as an alternative source of protein, as food supplements, and for sustainable textural compounds (Kim et al., 2017).

Currently, the largest sector utilising seaweed is food and food ingredients (FAO, 2018; Piconi et al., 2020). Food products and ingredients including beverages represent an estimated 85% of all end-products made from seaweeds, 90% of which are aquaculture-sourced (FAO, 2018; Piconi et al., 2020). Edible seaweed is also the most imported class of seaweed (Figure 4). However, only a few countries have developed import markets, with China and Japan representing more than 71% of the import market (Piconi et al., 2020).

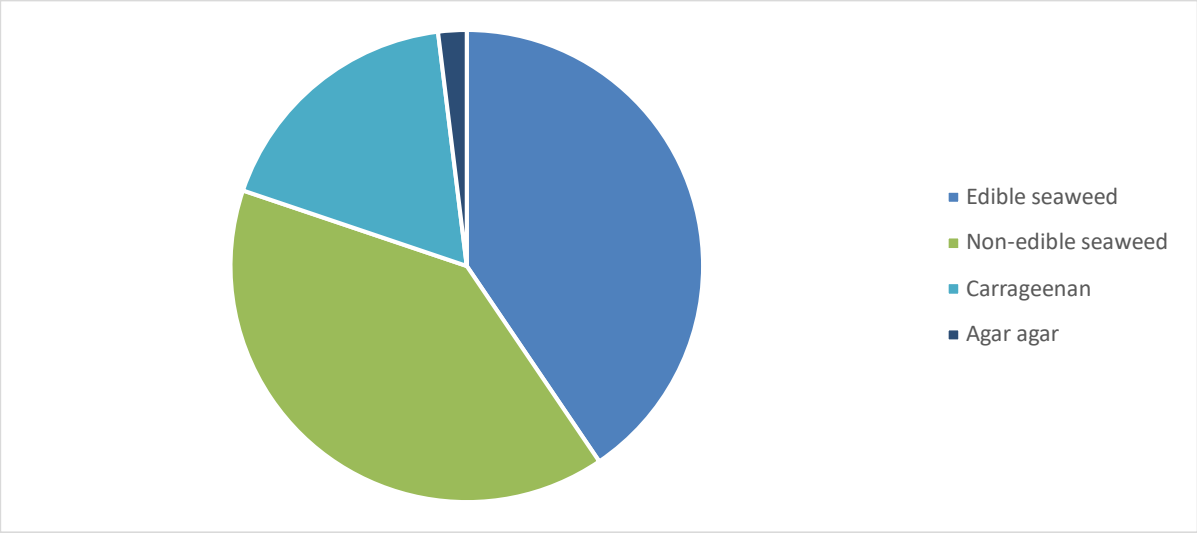


Figure 4. Seaweed imports into the top 35 countries during 2013-2016 (percent wet weight) (FAO, 2018).

Current Regional Trends

Asia and Oceania

The Asia-Pacific market sector of seaweed harvest dominates representing more than 97% of total global production (FAO, 2021a; FAO, 2021b). This is mainly due to suitable weather conditions and lower labour costs allowing for easily available and accessible raw material (FAO, 2020). Also, many traditional meals in Asia have utilised seaweed for thousands of years. Both the Chinese and Indonesian seaweed market sectors can be considered as mature in comparison to other countries, with cultivation and government support dating back to the 1940s. Indonesia is one of the leading countries in production growth. Pushed by a national policy which aimed to continue growth, production of the tropical species, *Kappaphycus alvarezii* and *Eucheuma* spp., increased more than 10-fold from 2005 to 2015 lifting Indonesia's share of global seaweed aquaculture from 6% in 2005 to 35% in 2014. Production has now steadied at 28% in 2019.

In contrast, the Australian sector is very small, contributing to less than 1% of the global market (Kelly, 2020). However, it is gaining momentum with industry growth attributed to new entrants, research, and sector support. The Australian seaweed industry has set targets for growth by 2025 of

AU$100 million (gross value of production), employing 1,200 people and reducing domestic greenhouse gas emissions by 3%. However, this relies on the expansion and development of ocean cultivation for market demand of high value functional foods and products for humans, animals and plants. Furthermore, the industry has identified that cultivation of *Asparagopsis* spp. "at scale is the single biggest opportunity for rapid industry growth and optimising social and environmental outcomes" (Kelly, 2020). According to the Australian Seaweed Blueprint, farming of *Asparagopsis* spp. will generate an estimated 70% of Australia's industry growth (Kelly, 2020).

North American Sector

The North American seaweed harvest accounts for less than 1% of total global seaweed supply (16,049 tonnes wet weight in 2019; FAO, 2021a; FAO, 2021b). The sector therefore relies on imported product. For example, in the United States, 95% of the edible seaweed is imported to meet demand (Piconi et al., 2020). Domestic harvesting, processing and distribution infrastructure are in their relative infancy, as is demand creation capability. Production levels have only begun to accelerate within the past two years with an increase in domestic edible seaweed aquaculture production. Maine and Alaska account for the majority of the growth and overall market share in the United States.

Central and South America

In Central and South America, very little seaweed (just over 1% of total global seaweed supply) is produced from either aquaculture or wild harvest (471,192 tonnes wet weight in 2019; FAO, 2021a; FAO, 2021b). Chile is the key supplier in South America of both sources and the main species that are harvested are *Agarophyton chilense* (formally *Gracilaria chilensis*) and *Gelidium* spp., mainly for agar (Alemañ et al., 2019; FAO 2018; FAO, 2021a; FAO, 2021b).

Africa

Africa is the second largest producer region of farmed seaweed species and yet this represents only 0.4% of total global supply (117,791 tonnes farmed and 27,117 tonnes wild harvest FAO, 2021a; FAO, 2021b). Farmed seaweed accounts for just under three quarters of production and the main countries participating in both farmed and wild harvest are South Africa, Tanzania and Morocco (FAO, 2018). Amongst other uses, seaweed in South Africa is often used as a biostimulant for plants and as feed for farmed abalone, and in Morocco much of the seaweed is used to produce agar.

European Sector

The European seaweed sector produced 287,386 tonnes of seaweed (wet weight) in 2019, a drop from 378,524 tonnes in 2000 (FAO, 2021a; FAO, 2021b). Of the seaweed harvested in 2019, 11,478 tonnes was obtained through cultivation (4%), and the rest (275,908 tonnes) was harvested from the wild (96%). The European sector is the second largest import market for seaweed in terms of volume at nearly 180,000 tonnes of seaweed and seaweed products in 2016 and top importer by value at US$613 million (FAO, 2018).

Major countries producing seaweed in Europe are Norway, France and Ireland (Netalgae, 2012). The United Kingdom, Spain, and Portugal are comparatively smaller with production almost non-existent in the United Kingdom; the last processing plant closed in Scotland recently. The plateau of wild harvesting has been attributed to, among other reasons, unrestrained harvesting and variable weather patterns. Aquaculture development has faced many challenging factors including complex licensing processes, costly technologies, lack of industry infrastructure, a fragmented value chain, and limited investment (Netalgae, 2012).

The New Zealand Seaweed Sector

New Zealand has a long history of seaweed utilisation. Māori traditionally consumed green and red seaweeds (collectively known as rimurimu) as part of their diet, and used bull kelp (*Durvillaea* spp.) as pōha (bags to store food such as mutton birds). Commercial harvest has occurred since the 1940s, and has largely consisted of small-scale beach-cast collection and wild harvest. Trials on seaweed cultivation in New Zealand began in the late 1980s; however, they did not gain momentum and only a few initiatives have reached commercial cultivation. Consequently, New Zealand does not yet have commercial seaweed hatcheries or farming at scale.

Seaweed Supply

New Zealand's seaweed supply chains are fragmented and undeveloped due to low economic returns and a reliance on wild and beach-cast harvest. While commercial seaweed farming does not exist in New Zealand as a stand-alone activity, harvesting bycatch from mussel lines, wild harvest and beach-cast collection does occur. A range of sector participants use these seaweed sources alongside some imported raw product that is processed in New Zealand to supply the limited domestic market (Table 2). The limited reliability and scale of these supply sources limits the ability of New Zealand processors to expand and meet market demand.

Domestic demand for seaweed emerged from the demand for agar from red seaweeds during World War Two, which was originally supplied from Japan. Following this period, the domestic supply dropped when cheap and reliable international imports of seaweed emerged. More recently, the market is dominated by the supply of a mix of beach-cast seaweeds (White & White, 2020).

Agrisea: A leading New Zealand seaweed business case study

AgriSea is a whānau-owned business and leading supplier of seaweed products in New Zealand, exporting internationally to Europe, the United States, Australia, India, Pacific Islands, and the Middle East. AgriSea uses primarily beach-cast *Ecklonia radiata* to produce biostimulants, foliar sprays, fertilisers for soil, plant, animal and bee nutrition.

AgriSea is a domestic market leader and innovator in products made from New Zealand seaweeds. AgriSea is supported by research partnerships with New Zealand Universities and Crown Research Institutes (Lincoln University, Scion, Landcare Research, AgResearch, University of Canterbury, University of Otago, University of Auckland and University of Waikato). Although seaweed-based biostimulants are a very small sector within New Zealand's fertiliser market, research and demonstrated efficacy have generated growth in demand that now exceeds supply.

Supply of *Ecklonia radiata* is almost exclusively from beach-cast seaweed. It is not included in the Quota Management System (QMS) and cannot be commercially fished as it is included in the list of species for which there is a moratorium (Schedule 4C of the Fisheries Act 1996).

Table 2. Stocktake of New Zealand Seaweed Sector Participants.

Company	Products / markets	Website
AgriSea New Zealand Ltd	Biostimulants	https://agrisea.co.nz/
Wakame Fresh	Supplies for various products	https://wakamefresh.com/
Pacific Harvest	Supplies health and organic shops, chefs, health practitioners and the public	https://pacificharvest.co.nz/
Waikaitu (NZBioActive)	Biostimulants	https://www.waikaitu.com/
CH4 Global	Animal feed supplements	https://www.ch4global.com/
Bio Marinus/United Fisheries	Fertiliser	https://biomarinus.co.nz/
BioStart	Biostimulants	https://biostart.co.nz/
Kiwi Fertiliser Co Ltd	Fertiliser	https://www.kiwifertiliser.co.nz/
Farmlands	Biostimulants	https://www.farmlands.co.nz/
NZ Kelp	Food products, animal feed and crop additives	https://www.nzkelp.co.nz/
Chaos Springs	Compost	https://www.chaossprings.co.nz/
BioAg	Biostimulants	https://www.bioag.co.nz/
Abron Ltd	Fertiliser	https://abron.co.nz/
Quality Seaweeds	Biostimulants	https://www.qualityseaweeds.co.nz/
BioSea	Biostimulants	http://www.biosea.co.nz/
Enzalg	Food, beauty and supplements	http://enzalg.co.nz/
OceanGreen Organics	Health, wellness and beauty products	https://www.oceangreenorganics.com
Syrene	Beauty products	https://www.syreneskincare.co.nz/
Kiwi Wakame	Food condiments	https://kiwiwakame.com/

As of 2020, there were 59 permit holders eligible to farm seaweed in New Zealand. There are 170 marine farms; the majority of which are located in the waters of the Marlborough Sounds, around the Coromandel Peninsula and in Wellington Harbour. These licenses allow farming of different species (up to eight species). There has been a positive increase compared to 1999 when there were 29 permit holders owning 72 farms. However, the farms are not actively farming solely seaweed,

and are listed as multi-species (mainly mussels) (White & White, 2020). This reflects a common practice of 'future proofing' farming options by adding species when applying for or renewing resource consents. The lack of drive towards seaweed farming by the aquaculture industry is mainly due to lack of certainty in customers and market, value in terms of return on investment and demand, and uncertain or low economic return, as well as lack of seed supply source, making it too risky and expensive to be 'first' with seaweed.

Seaweed Species

There are around 938 species of seaweed (macroalgae) known in New Zealand, of which 46 are exotic (Nelson et al., 2019). Many of these seaweeds have not received monographic treatment and therefore, are yet to be fully described scientifically. Adams (1994) and Nelson (2013) both have detailed descriptions of many New Zealand species and their distributions and Neil et al. (2016) is also a useful guide for the brown species of New Zealand.

According to Fisheries New Zealand, seaweeds of commercial, customary, and recreational value include (Ministry of Fisheries, 2007):

Brown Seaweeds

- *Ecklonia radiata* – widely distributed on many rocky shores throughout New Zealand from the northern tip of the North Island to the Snares Islands (Adams, 1994; Nelson, 2013; Neil et al., 2016).
- Bladder kelp (*Macrocystis pyrifera*) – found on the southern coasts of the North Island, the South Island, at the Chatham Islands, Stewart Island and all of the subantarctic islands except the Snares (Adams, 1994; Nelson, 2013; Neil et al., 2016).
- Bull kelp also known as rimurapa or kōauau (*Durvillaea antarctica*) – dominates exposed coastlines of New Zealand and our offshore islands (e.g. Three Kings Islands, the Subantarctic islands) (Adams, 1994; Nelson, 2013; Neil et al., 2016). There are other *Durvillaea* species that are sometimes confused for *Durvillaea antactica* and these may also be of commercial interest.
- *Lessonia variegata* and *L. brevifolia* - *Lessonia* spp. occur on exposed coasts in subtidal and deep water around the North and South Island of New Zealand and Stewart Island (Adams, 1994; Nelson, 2013; Neil et al., 2016). *Lessonia variegata* is an endemic species.

Red Seaweeds

- *Agarophyton chilense* (formally *Gracilaria chilensis*) - found in the intertidal and upper subtidal regions on rocks, pebbles and shells on sheltered shores including estuaries and habours as well as on moderately exposed coastlines throughout New Zealand and also the Chatham Islands (Adams, 1994; Nelson, 2013).
- *Karengo (Pyropia* spp. and *Porphyra* spp.*)* – these species are annuals and are widely distributed throughout New Zealand including the Chatham Islands as well as the Subantarctic Islands (Schiel & Nelson, 1990; Adams 1994). They are found in both the intertidal and subtidal zone growing on either rock or other seaweeds. There are many species that are not well resolved taxonomically.
- Agar weed *(Pterocladia capillacea* and *P. lucida*) – *Pterocladia* spp. are found throughout New Zealand and the outer islands of the Kermadecs, Three Kings and Chatham Islands on sheltered to exposed shores. *Pterocladia lucida* and *P. capillacea* are often found together in these locations (Schiel & Nelson, 1990; Adams, 1994; Nelson 2013.0).
- *Gigartina* spp. (rehia, rimu rehia) – many *Gigartina* spp. are endemic, occupying specific regions and habitats throughout New Zealand including the Subantarctic Islands (Adams, 1994).

Green Seaweeds

- Sea lettuce (*Ulva* spp.) – found throughout New Zealand waters as far north as the Kermadec Islands and as far south as the Subantarctic. *Ulva* spp. are tolerant of a wide range of environmental conditions (Adams 1994; Nelson 2013; White & White, 2020).

Wakame (*Undaria pinnatifida*) is an invasive brown seaweed that has been commercially harvested in New Zealand (see South et al., 2017 and Cunningham et al., 2020 for review). It is the most established introduced species in New Zealand due to its high reproductive output and wide environmental tolerance. It was initially found in Wellington Harbour in 1987 but has spread throughout New Zealand and has been recorded as far south as the Snares Islands (Hay and Luckens 1987; Adams, 1994; Nelson et al., 2013; Neil et al., 2016; South et al., 2017). This seaweed is managed as an unwanted organism and all fishing and farming of *Undaria* must be authorised by an approval issued under sections 52 and 53 of the Biosecurity Act 1993 (Biosecurity New Zealand, 2019).

Durvillaea antarctica. Image credit: Paul South, Cawthron Institute.

Currently Harvested Species

Seaweeds that have commonly been harvested in New Zealand include many red seaweed species, including agar weed (for agar), and a range of brown seaweeds such as bull kelp, bladder kelp and *Ecklonia radiata* as well as wakame mainly for fertilizers and biostimulant products (see White and White, 2020 for recent review). Red seaweeds including agar weed are beach harvested seasonally in rural coastal areas including Wairarapa, Bay of Plenty, Bay of Islands and Ahipara (Schiel & Nelson, 1990; White and White 2020). *Ecklonia radiata* is also harvested as beach-cast seaweed while *Undaria pinnatifida* is harvested from both the wild and from mussel farm lines that it has naturally settled on (White and White, 2020).

Commercial Harvest of Bladder Kelp

Attached bladder kelp was introduced to the Quota Management System (QMS) in October 2010 and is currently the only seaweed species managed under the QMS (Fisheries New Zealand, 2013; Fisheries New Zealand, 2021). The combined Total Allowable Commercial Catch (TACC) of attached

bladder kelp is 1,500 tonnes within Quota Management Areas (QMA) 3 and 4, and most of it is harvested in QMA3 (Figure 5). To date, bladder kelp has been used as a dietary supplement, a fertiliser, a bio-remediator, and as a feed for pāua and kina.

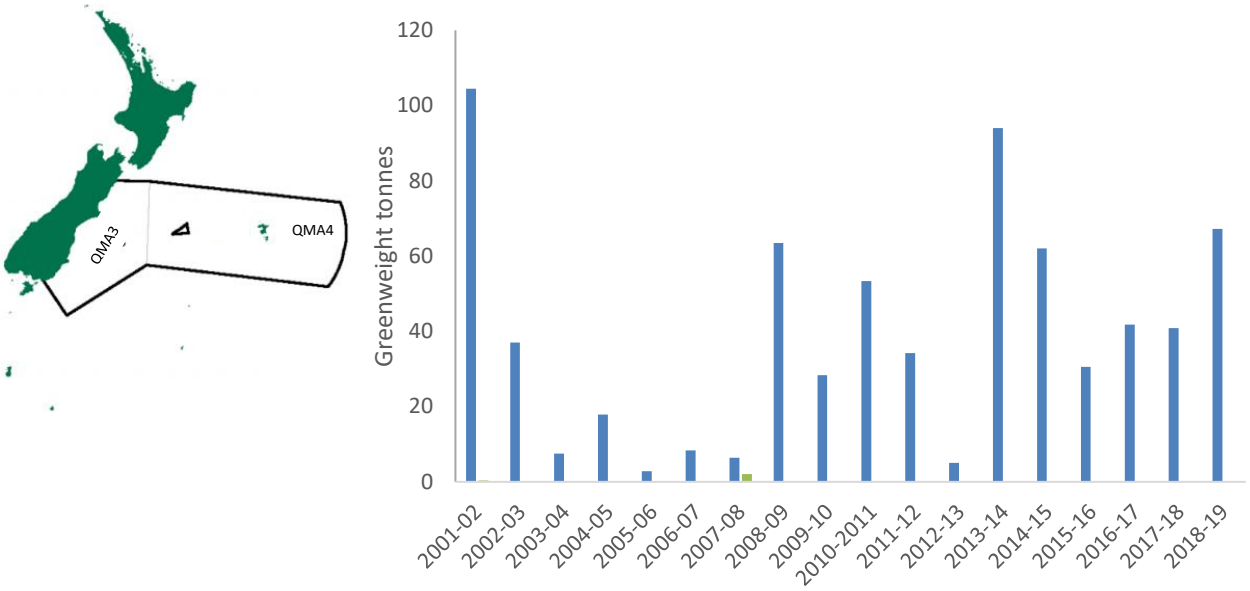


Figure 5. Reported landings (greenweight, tonnes) of attached bladder kelp (Macrocystis pyrifera) in Quota Management Areas (QMA) QMA 3 (blue) and QMA 4 (green) from 2001-2019. Note that pre-2010 landings also include beach-cast, free-floating bladder kelp (map and data modified from Fisheries New Zealand (2020)).

There is also a well-established mussel spat fishery along Te Oneroa-a-Tōhē, Ninety Mile Beach for which seaweed is an integral bycatch (Jeffs et al., 1999; Alfaro et al., 2004; Jeffs et al., 2018). Beach-cast and floating free seaweeds are harvested to collect the small, attached mussel spat which supports around 80% of New Zealand's mussel farming industry. Seaweed/spat harvest is opportunistic during the winter and spring months when the prevailing winds wash large quantities of seaweed/spat ashore that is then collected. This fishery is managed under the QMS (GLM 9) (Fisheries New Zealand, 2021). All seaweed/spat is harvested under a fishing permit and catch is recorded against Annual Catch Entitlement (ACE) at set ratio of 25:75 spat:seaweed by weight (Ministry for Primary Industries, 2018).

Demand

Market demand for most seaweed products in New Zealand is still immature compared to international markets. Very large-scale, well-established foreign markets with developed supply chains and low labour costs mean that New Zealand will have difficulty competing internationally with global players in generic low-cost product categories that are dominated by Asian countries.

A sector in which demand currently exceeds supply is the market for seaweed-based biostimulants (fertiliser replacements). Products are well established in New Zealand and these are used across a wide range of sub-categories in agriculture and horticulture. Due to supply not meeting demand, some New Zealand seaweed producers are importing raw product for processing (and then export).

Aside from demand for current products, several parts of the seaweed market face larger demand with environmental impact mitigation being of significant interest from consumers. One of these potential product markets are bioplastics. Unlike other materials for plastic alternatives, seaweed has high biomass potential, an ability to grow in a wide range of environments with minimal impacts on the food chain and does not require chemicals for manufacture (Rajendran et al., 2012).

However, bioplastics require very large volumes of low-cost biomass which is likely to be a constraint to the development of these products in New Zealand.

New Zealand's Regulatory Environment for Seaweed Harvest and Farming

The seaweed sector has a range of regulatory mechanisms and considerations operating across the value chain (Figure 6). Since the sector is a fledgling but highly dynamic sector operating at small scale, there are unique challenges and opportunities in the regulatory context.

Wild Harvest

Collection of wild seaweeds (i.e. not from marine farms) is managed by Fisheries New Zealand under the Fisheries Act 1996. Collection purpose can range from providing seed for aquaculture (e.g. mussel spat attached to seaweed for the Greenshell™ mussel industry to on grow) or for direct use in a range of products.

Almost all commercial seaweed harvest is managed outside the Quota Management System (QMS) as 'non-QMS species'. The only seaweed species managed under the QMS is bladder kelp within QMAs 3 and 4, and the seaweed bycatch that mussel spat attaches itself to in QMA 9 (as outlined above). Harvest of these seaweed stocks is limited by the stock's Total Allowable Commercial Catch (TACC) and all catches must be balanced against Annual Catch Entitlement (ACE).

Any person wanting to harvest seaweeds irrespective of the state of the seaweed (i.e., attached, free-floating, or beach-cast), and whether QMS or non-QMS species, for any commercial purpose, must hold a valid fishing permit issued under the Fisheries Act 1996; the exception being beach-cast red seaweeds which are exempt from this requirement. However, commercial fishers are prohibited to take as 'target species' specific seaweeds listed on Schedule 4C of the Fisheries Act 1996. There are nine species listed on the schedule: agar weed (*Pterocladia lucia* and *Pterocladia capillacea*), bladder kelp (*Macrocystis pyrifera*), brown kelp (*Ecklonia radiata*), bull kelp (*Durvillea* spp.), gracilaria weed (*Agarophyton chilense*, formerly *Gracilaria chilensis*)*, Lessonia variegate,* karengo (*Porphyra* spp.) and sea lettuce (*Ulva* spp.). Most, if not all of these species are of commercial interest, but their harvest is prohibited because it is recognised that there could be potential management and sustainability issues under the current 'open access' fishing regime. There are a few fishers that were entitled to catch these species before 1992 that can still access these species and all fishers are allowed take these seaweeds (on Schedule 4C) if they are taken as 'inevitable bycatch'. They can also be taken if they are taken in a 'beach-cast state' from within an approved commercial seaweed harvest area (which is defined in the Fisheries Beach Cast Seaweed Area Prohibition Notice 2005). Schedule 4C means that there are complications for aquaculture operators who wish to access seaweed for broodstock. MPI is intending to develop a seaweed strategy which may include issuing 'specific purpose' special permits which authorise the harvest of limited quantities of seaweed for aquaculture broodstock purposes (Ministry for Primary Industries, personal communication). Furthermore, there are several Deed of Settlements between the Crown and Iwi under the Treaty settlement process that have prohibitions on commercial fishing of several seaweed species within them. These settlements have implications for both wild-harvest and aquaculture.

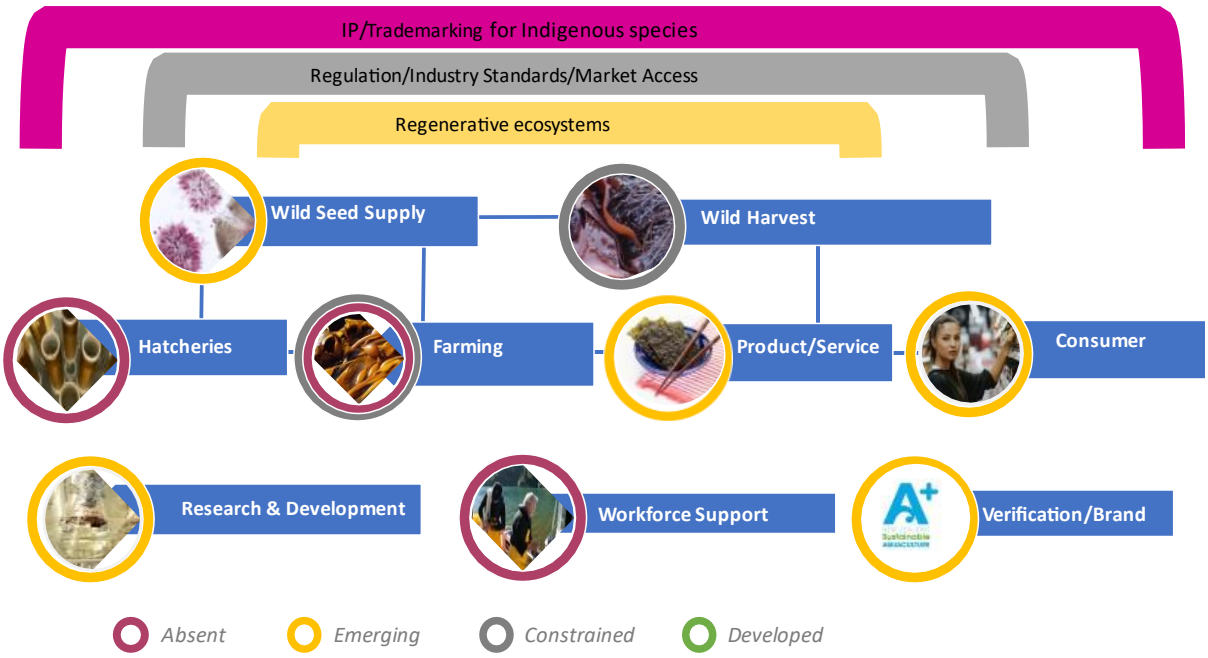


Figure 6. Seaweed sector elements and status. Image credits: Cawthron Institute, GreenWave, Paul South (Cawthron Institute), AQNZ, Unsplash (Joshua Rawson-Harris, Patrick Perkins)

Seaweeds from Marine Farms

Before setting up a marine farm, a Resource Management Act (RMA) resource consent is required from the relevant regional council (also known as a coastal permit) to undertake an aquaculture activity. If granted, the council will ask for an *undue adverse effects test* (on recreational, customary, and commercial fishing) under the Fisheries Act 1996. The outcome of which is an aquaculture decision (Ministry for Primary Industries, 2013).

The RMA allows for development subject to environmental effects being avoided, remedied or mitigated. Activities are assessed on their likely suite of effects and status with regional coastal plans (which informs whether activities are more or less in the public interest) and regional policy statements. Because marine farming is carried out in public water space, the RMA sets a high standard for those looking to gain and retain approval to farm (see regulatory barriers section of this report).

Regional councils are required to develop regional coastal plans under the New Zealand Coastal Policy Statement (NZCPS). These plans provide policy guidance and rules for activities in the coastal marine area. All marine aquaculture and some land-based aquaculture will require resource consents from a regional council under one or more of their policies and plans.

The decentralised approach means that each of New Zealand's regional councils guide and regulate different activities in different ways. However, there are also overarching policies and regulations influencing certain activities and/or effects. For example, the NZCPS provides overarching policy guidance about activities in the coastal environment. In a broad sense, the NZCPS requires that:

- Activities cannot have a significant adverse effect on natural character, landscape features or on indigenous biodiversity; and
- Activities cannot have an adverse effect on outstanding natural character, landscapes features or on significant indigenous biodiversity.
- Activities cannot have adverse effects on water quality to the point where it prevents aquaculture.

The NZCPS requires regional coastal plans to consider the effects of activities like aquaculture on seascapes, marine mammals, seabirds and benthic habitats. The potential benefits of seaweed aquaculture such as positive effects for climate change and ecosystem biodiversity are not weighted accordingly under the RMA or NZCPS.

Once consent has been obtained, farmers (both marine and land-based) may only acquire and be in possession of seaweed (as well as all other aquatic life) from those legal sources listed in section 192A of the Fisheries Act 1996. This means farmers can only farm seaweed species that are either:

(a) purchased or acquired from another fish farmer or a licensed fish receiver; or

(b) lawfully bred or cultivated by the fish farmer (i.e. in hatcheries); or

(c) deemed as harvestable spat under Schedule 8A that settled on fish farm structures (only applies to a selection of species – see below)

For example, if the seaweed has naturally landed / settled onto the marine farm, then only those listed in Schedule 8A of the Fisheries Act 1996 (or those that have a gazetted exemption) can be subsequently harvested by the farmer. The species in Schedule 8A are:

- Bladder kelp (*Macrocystis pyrifera*)
- Bull kelp (*Durvillea* spp.)
- Karengo (*Porphyra* spp.)
- Lessonia (*Lessonia variegate*)
- Agar weed (*Pterocladia* spp.)
- Sea lettuce (*Ulva* spp.)
- Sea moss (*Gracilaria* spp.)

Note that *Ecklonia radiata* and *Asparagopsis armata*, for example, are not on this list as a 'harvestable spat', so marine farmers cannot farm and harvest these species from marine farms. Instead, the farmer is required to obtain seaweeds for farming purposes from another fish farmer or commercial fisher (via a Licensed Fish Receiver). Wakame is not on Schedule 8A, but is exempted, so farmers are able to harvest naturally settled seaweed provided they are consented to do so and hold an approval under the Biosecurity Act 1993.

MPI is considering utilising a technical amendment to the Fisheries Act 1996 scheduled for late 2021 to remove Schedule 8A and instead provide a 'gazetted list' of harvestable spat which could then be updated over time as appropriate. The marine farmer must also ensure they are registered for seaweed species on their Fish Farmer Registration before harvesting, as required under the Fisheries Act 1996.

Land-based Aquaculture and Hatcheries

Land-based aquaculture (including seaweed hatcheries and farms) require RMA resource consent(s) as well as a fish farm licence issued under the Freshwater Fish Farming Regulations 1983. Resource consenting for land-based aquaculture is regulated at a regional council and territorial authority level. As with marine farming, there are differing plans and policies regarding land-based aquaculture depending on the region or district. In general, land-based aquaculture is categorised in regional planning as 'intensive farming'. There are a range of sub-activities associated with land-based aquaculture which may or may not require consent depending on the nature of the effects and the relevant plan rules.

The more challenging of the activities will include any that are carried out in the coastal marine area (CMA) and particularly those that include structures or discharges. Coastal hazards, including potential future inundation, will also be a consideration. As with marine farming, applications can

attract stakeholder and iwi opposition depending on the region, the location and the nature of the activity.

For all land-based aquaculture operations, including seaweed hatcheries and farms, the fish farm licence must specify the species to be grown. The process is relatively straightforward once the appropriate pre-authorisations are in place (Ministry for Primary Industries, 2020a). These include resource consents to take and discharge water, consultation with the local Fish and Game Council and consultation with the Department of Conservation for any freshwater species.

A key consideration is 'stock containment'; the ability to prevent entry of local aquatic life into the farm and exit of farmed stock into the local environment. Biosecurity considerations are not directly regulated under a fish farm licence, although the licence can include conditions that require biosecurity to be addressed. Land-based operations therefore do need to have appropriate biosecurity management protocols and plans in place.

Biosecurity regulation in New Zealand

Biosecurity awareness and management are critically important for the sustainable growth and development of the aquaculture industry in New Zealand. New Zealand's geographical isolation and strict border controls protect the country from many of the biosecurity risks that affect aquaculture production in other parts of the world. However, the threat of exotic pathogens and pests being introduced and then spread throughout our waters is an ongoing risk for the aquaculture industry.

Ministry for Primary Industries (Biosecurity New Zealand) is the primary agency for biosecurity regulation although regional councils have some functions as well. The Biosecurity Act 1993 controls the entry of notifiable pests and diseases into New Zealand, controlling, managing or eradicating them if they arrive and enabling a national or regional Pest Management Strategy to be developed for each of the important pests.

There have been a number of discussions over recent years about the most ideal biosecurity management and regulatory framework for New Zealand aquatic systems, particularly in the marine environment since the coastal environment doesn't have the same 'borders' as those on land.

Consideration was given to adding an RMA requirement for all marine farms to have a Biosecurity Management Plan in place by 2025; however, regional councils and key stakeholders identified a number of complications, and there is still more work to be done to make sure that the best approach can be progressed (Ministry for the Environment, 2020; Ministry for Primary Industries 2020b).

In the meantime, Biosecurity New Zealand, in conjunction with the aquaculture industry, has collated a set of best practice guidance material for aquaculture operations relating to biosecurity (Ministry for Primary Industries, 2020c). This includes an 'Aquaculture Biosecurity Handbook' which relates to land-based and marine-based operations. Biosecurity for seaweed aquaculture operations will therefore, like other aquaculture, be guided by existing legislation and 'best practice' while associated regulatory requirements are developed. These include:

- Stock health management – application of good hygiene practices to minimise disease risk.
- Stock movements and containment – identification and use of disease-free stock, procedures for stock transfers and prevention of stock 'escapes'.
- Water – filtration and treatment of intake and wastewater to minimise the risk of pests and pathogens entering the farm or establishing in the surrounding environment.
- Equipment, vehicles and vessels – cleaning and disinfection of culture equipment to minimise disease, and procedures to minimise the risk of pest transport via vehicles or equipment.
- People management – staff biosecurity training and routine disinfection.
- Wildlife, scavengers and vermin – less likely to be an issue for seaweeds.

- Record keeping – good record keeping and reporting of anything unusual to MPI.
- Monitoring and surveillance – education and surveillance to facilitate early detection of pests or diseases.
- Waste (other than water) – waste streams to be assessed for biosecurity risk to the farm and the environment.

There will potentially be issues arising for the seaweed sector relating to differences in the risk profiles and operations. It will be important that the seaweed sector has ongoing involvement in the progression of the best practice standards as they evolve. It will likely be more desirable to continue the biosecurity standards as 'best practice' rather than regulation in order to ensure that they can evolve alongside the potentially rapidly emerging and innovating sector.

Wakame (*Undaria pinnatifida*) An invasive species case study

Developing wakame as a commercial opportunity has its own particular regulatory challenges as a result of its classification as an 'unwanted organism' under the Biosecurity Act 1993. This classification means that all harvest must undertaken in accordance with approval under the Act.

Wakame has been identified by a number of New Zealand operators as a species with strong potential as a premium export food product to Asian markets, and for its fucoidan properties. It was accidently introduced to New Zealand in the 1980s on marine vessels and became well established in number of harbours throughout the country. It is now a nuisance species for marine farmers in these regions due to its ability to 'overcrowd' mussels. Several regulatory challenges have been overcome by farmers to be able to harvest it from their farms but there is currently only one marine farm in Wellington Harbour that is permitted to 'farm' wakame. All farming is presently restricted to 'heavily infested areas' only: Wellington Harbour, Marlborough, Akaroa and Lyttleton Harbours. Farming outside these areas is currently prohibited.

Biosecurity New Zealand has recently made further changes to its status so that now it is possible to apply for an approval to farm wakame provided that appropriate biosecurity management protocols are in place (Biosecurity New Zealand, 2019). Once the approval is in place then, depending on the region, it may be possible to obtain a resource consent to farm it. Even with consent in place, it is possible that the nature of consent conditions, including monitoring and protocols will result in the activity being uneconomic.

On the face of it, the regulatory framework for wakame has been evolving in response to emerging drivers and information; however, the process for those involved has been lengthy, costly, and frustrating. An ideal regulatory framework for seaweed would be more responsive and collaborative.

Te Tiriti o Waitangi/Treaty of Waitangi Considerations

Māori fisheries and aquaculture rights are established under the Treaty of Waitangi (Fisheries Claims) Settlement Act 1992 and the Māori Commercial Aquaculture Claims Settlement Act 2004 and Māori continue to seek protection over these rights. The '*Scoping and Horizon Scanning*' report for the blue economy National Science Challenge (EnviroStrat, 2019), identified that "Māori are

significant participants in New Zealand's marine economy with interests in wild fisheries, aquaculture, marine tourism, and non-market customary harvest" which necessitates a range of regulatory considerations in the development of a seaweed sector. "Māori are politically engaged at multiple scales including pan-iwi, iwi, hapū, marae komiti, and whānau. Unique and dynamic structures have been developed to manage political tensions and interests across these scales to support economic development, the protection of property rights, governance, and management of the marine estate. Māori are concerned that new governance, conservation, and management regimes may abrogate their Treaty rights. New Zealand is actively engaged in international marine governance and is party to many international conventions" (Envirostrat, 2019).

The report stated:

- "The marine legislative and regulatory framework in which Māori blue economy operates is complex and contested.
- Māori rights and interests face threats from regulatory changes that may impact the full and final nature of the Fisheries Settlement and the financial value of the settlement. There are tensions between individual iwi and pan-Māori rights. For example, iwi quota is held within non-traditional corporate structures. Settlement quota is often uneconomic to fish at an iwi level, yet it cannot be sold and can only be traded amongst iwi, devaluing it.
- The division between commercial and customary rights continues to undermine rights and interests (Māori cannot exchange or sell fish caught under these rights, while Māori 'commercial' fishers at times fish for customary occasions); creating customary management areas & acquiring customary rights is difficult, requiring social or financial capital; Maori commercial fishers often supply iwi with customary harvest, which is a complex, contentious process; customary areas create tensions with some recreational fishers.
- Te Ohu Kaimoana (TOKM) published a number of priorities for 2017-2020 that identified opportunities for the legal framework to be improved – these priorities have implications for customary rights, environmental management practices, and the rights structures of the QMS as well as its administration" (Envirostrat, 2019).

Amongst other initiatives, the TOKM priorities need to be recognised in any future regulatory framework for seaweed.

Post-harvest, Production and Marketing Regulatory Requirements for Seaweed Suppliers in New Zealand

Wholesale

Seaweed wholesaling is seaweed from wild harvest, marine farms or land-based farms which is sold 'as is' to entities that will process it post-harvest into a value-added product or service. As a wholesale product, it will be up to either the producer or the purchaser to ensure that it meets the various regulatory requirements that apply to the intended use. In that regard there have been no particular 'wholesale specific' regulatory issues identified in this analysis.

Food

Food produced in New Zealand is regulated under the Food Act 2014. Where applicable, there are also regulations relating to the Animal Products Act 1999 and the Agricultural Compounds and Veterinary Medicines Act 1997. As seaweed is not an 'animal product'; its food products fall solely under the Food Act. The Food Act focuses on how a particular food is produced as opposed to where a food is made; it helps ensure that food sold in New Zealand is safe to eat. Higher risk businesses require food control plans (FCPs) which are written plans for managing food safety on a day-to-day basis. Medium to low-risk businesses sit under national programmes and follow set food safety rules. For this, they must still register, meet food safety standards, keep some records, and get checked.

Generally, new entrants into the food industry have access to 'templates' or examples of food control plans that have already been successfully implemented. The system is not set up to address seaweed and early entrants have needed to write relatively comprehensive food control plans which were likely more detailed and comprehensive than they needed to be relative to the risk. An unintended consequence of this is that the operator is then tied down to a particular food production method and system which then hampers the kind of innovation and development that new food businesses generally require. Experience has been that the process has been lengthy, complicated and costly, and that the regulators are not well equipped to assess real and relative risk in this emerging industry.

As new technologies and products emerge, whole new food control plans will need to be redesigned and resubmitted and there will be a similar experience with lack of knowledge or understanding within the regulatory personnel. This can serve as a substantial barrier.

Seaweed as food. Image credit: Patrick Perkins (Unsplash).

High Value Nutrition Products

High value nutrition is a 'catch-all' that incorporates a spectrum of products from nutraceuticals i.e., natural product extracts sold in dosage form (Coriolis, 2011) to functional foods or food with added nutraceuticals. There are differing regulations across the spectrum though; while all are regulated under the Food Act and potentially the Biosecurity Act, there are additional requirements for dietary supplements under the Dietary Supplements Regulations 1985 and supplemented food under the New Zealand Food (Supplemented Food) Standard 2016. There are also requirements covered in the Australia and New Zealand Food Standards Code (the Code) and the New Zealand Food (Supplemented Food) Standard 2016 that stipulate how information on the food is included on labels and promotional material.

Export certification is possible for dietary supplements which have been manufactured in New Zealand through Medsafe. However, the certification does not cover the safety nor the quality of the product or the adherence to New Zealand Law (Medsafe, 2019). Furthermore, such supplements must meet the regulations of the country they are being exported to, and these may be different and specific to a particular country.

Cosmetics

Rules for cosmetics (or personal care products) are set by the New Zealand Environmental Protection Agency (EPA) and in the Cosmetics Products Group Standard (CPGS). The CPGS covers importation, manufacture and sale of cosmetics. It prohibits a list of substances from being used as ingredients, and restricts the quantities of other ingredients. Cosmetics making therapeutic claims are regulated through Medsafe. The CPGS also specifies labelling, packaging and storage requirements. This includes providing a list of hazardous ingredients on product labels or packaging as well as contact details for the manufacturer or supplier and the manufacturer's original source or batch code.

It is unlikely that personal care products relating to seaweed will have particularly unique regulatory barriers or require specific interventions.

Agriculture and Horticulture

Agricultural compounds, including veterinary medicines (ACVMs) describe substances that are used to help manage plants and animals and are regulated under the ACVM Act 1997. The Act controls how ACVMs are used, sold, imported, and manufactured in New Zealand (Ministry for Primary Industries, 2020d). Agricultural compounds are arranged into the following classes*:*

- Veterinary medicines – substances used for animals, including companion animals.
- Agricultural chemicals – substances used for plants, including herbicides, fungicides. insecticides, plant growth regulators, surfactants, and adjuvants.
- Vertebrate toxic agents – substances that kill or limit the viability of animals, such as possums, rodents, and other unwanted mammals.
- Fertilisers, plant biostimulants, and soil conditioners.
- Pet food and animal feed – including dietary supplements.

ACVM requirements do not necessarily need to be followed for export products but producers will need to meet the requirements of the importing region. Additional batch certificate requirements apply to New Zealand's 'Mutual Recognition Agreement' countries (Australia, Canada, the European Community and Switzerland).

Carbon Credits

There is growing interest in the role that seaweed farming can play in New Zealand's overall carbon sequestration goal. However, our current Emissions Trading Scheme settings are not set up to account for blue carbon and the recent Climate Change Commission report noted a need to undertake substantial new afforestation without covering how New Zealand's oceans might contribute to a lower carbon economy. This means in the short to medium term, the opportunities for blue carbon will need to be developed using voluntary (i.e. non-regulated) markets – this is consistent with the development of blue carbon methodologies globally.

Market Access

Market access issues vary across the range of products or services being offered to the market. The main commonality is country to country 'recognition' of the products being offered. This can be an issue of varying proportions for all primary producers but as seaweed is an emerging industry without well-established formats and protocols, the issues will be more upfront. There will be

ongoing challenges for New Zealand and overseas regulators regarding which 'boxes' to put the products in and what requirements will need to be met.

For example, since seaweed is not regulated under the Animal Products Act, the products will not qualify for official assurance to export markets. In order to get market assurance though, requirements will need to be met on a market-by-market basis and they can vary significantly depending on the importing region. This can make it very difficult to gain 'recognition' for the countries being exported to that the seaweed product is 'safe'.

Biosecurity will also be a key market access issue, similar to other primary produce and again each region will have its own biosecurity considerations and requirements. Experience to date has included challenges obtaining border clearance and that there are variations on the process according to the border worker or the broker. Government support in terms of facilitating collaborative standards and associated assurances will be helpful in this regard.

Barriers to Growth

Seaweed sectors from around the world share a number of barriers which are limiting their growth besides specific barriers within each country due to market readiness, laws and regulations (FAO, 2018). In addition to these sectorial issues, there are environmental constraints which can be either anthropogenic or biological that cannot be fully predicted or controlled (World Bank, 2016). The seaweed sector in New Zealand is no different, and a number of key barriers and gaps to the industry's growth have been identified (Table 3. Seaweed sector growth: barriers and gaps).

Market Barriers

New Zealand has historically competed in seafood markets through supplying either premium products (king salmon, rock lobsters) or through consistent high-quality products (Greenshell™ mussels) that are globally recognised (Symonds et al., 2019). However, in seaweed markets, New Zealand species are not currently recognised as being premium; New Zealand is relatively unknown as a seaweed producer (KPMG, 2020). Additionally, as the majority of seaweed is produced in countries with cheaper labour costs than New Zealand, local producers will not be able to compete on cost, and will need to produce high-quality premium seaweed targeted at specific markets.

To access larger international markets, there is an emphasis placed on reliable products at a scale which can meet market demand (KPMG, 2020). Ensuring reliable, quality products will need to be an area of focus as the sector matures. An emphasis on breeding reliable cultivars for local conditions (Kim et al., 2017), harvesting techniques that limit damage to the seaweed, and grading products (KPMG, 2020) will all play a part in achieving this goal. The scale of the seaweed sector will primarily be limited by the amount of water space available and the intensity at which the seaweed species can be farmed. Access to water space is a regulatory issue that is commonly encountered by the aquaculture industry, whereas the intensity at which seaweed can be farmed is a product of the systems used and the biology of the species. In addition, there is a need for science and research investment targeted to support market health and function claims, combined with market entry and branding strategies to enable New Zealand's seaweed sector to target high value, niche and differentiated products.

New Zealand's domestic market is small but growing as consumer preferences shift towards sustainable plant-based alternatives and organic approaches to agriculture, horticulture and apiculture. New Zealand therefore needs to focus on domestic market niches that suit our strengths (agriculture, horticulture, environmental quality, etc.) or export markets where there are opportunities for higher value products. There is no seaweed-based environmental services market

for either bioremediation or blue carbon offsets in New Zealand currently. Internationally, there are some examples of the former, and emerging examples of blue carbon markets based on seaweed (Oceans2050 pers. comm., 2020). There is strong international and local interest in these sorts of services, so New Zealand could be at the forefront of establishing environmental services markets based on seaweed.

Environmental Impacts on Seaweed Production

The ocean environment for seaweeds is highly dynamic and complex (Callaway et al., 2012). The forces that seaweeds experience impact their growth and abundance. For seaweed farms, changes in weather, such as storm events, can impact loading on farm infrastructure, like lines and moorings, and farms and biomass can be at risk in storm events. Similarly, changes in rainfall affect nutrient concentrations and as a result can impact seaweed production. The effect of increasing seawater temperature on seaweeds through climate change is not yet clear. However, it has been suggested that increased temperature combined with reduced winds at some latitudes may reduce vertical mixing and consequently, decrease nutrient upwelling and seaweed productivity. This could mean that some areas become unsuitable for growing seaweed unless nutrients are deliberately added. Moreover, because temperature affects seaweed growth, changes in temperature may impact productivity as well as increase susceptibility to diseases or pests (Ward et al., 2019).

Regulatory Barriers

Table 4 summarises the regulatory challenges and assigns a generalised risk to inform priorities. Some barriers will be unique to seaweed or short term, and others may be across a range of sectors or longer term requiring a more strategic approach.

Wild Seaweed Harvesting

Challenges faced by industry that have been experienced to date include:

- Challenges with the ‘interplay’ of the Resource Management Act 1991 (RMA) and the Fisheries Act as they relate to beach-cast seaweed in that the Fisheries Act 1996 does regulate activities ‘on the beach’. This is best illustrated with the ongoing discussions between the mussel industry, MPI, ‘mussel spat collectors’, Iwi, TOKM and the Northland Regional Council about the best management framework for the continued collection of mussel spat on beach-cast seaweed at Te Oneroa-a-Tōhē.
- There is no ‘fit-for-purpose’ fishing permit for access to wild seaweed broodstock for research enterprises looking to develop commercial activities. MPI instead have to utilise ‘workarounds’, which will not be ideal in the longer term.
- Regional marine protection provisions constrain the emerging wild harvest of bladder kelp which produces a range of premium products.
- Ongoing challenges relating to harvest of wakame.

In effect, the current regulatory settings are not set up to provide ‘wild seaweeds’ as either a viable primary industry or as a broodstock for aquaculture activities. This has not necessarily been a major issue to date but will require review as the sector develops.

Table 3. Seaweed sector growth: barriers and gaps

Category	Component	Barrier or Gap	Implication
Market	Markets and products not established	International recognition, competition with larger cheaper markets, products to capture bioactivity of seaweed-derived compounds	International markets do not recognise New Zealand as a producer of seaweed. Therefore, there needs to be support from NZTE and other government agencies to support those looking to export. Limited domestic market. Competition with cheaper markets (Asia-Pacific) mean that premium export quality products need to be produced. Despite studies which demonstrate the bioactivity of seaweed-derived compounds, there are limited effective products on the market. Making health claims on foods is regulated both in New Zealand and overseas (New Zealand Food Safety, 2021). All claims (nutrient content claims, other function claims and reduction of disease risk claims) are regulated on a country-by-country basis and making a health claim may require several clinical studies demonstrating efficacy.
Market	Scalability	Reliability of volume or quality for harvest	While there is currently available space to farm seaweed and access to some seaweeds for seedstock, regulation is recognised as a major barrier to utilisation of these spaces and thus scalability is an issue.
Knowledge gap	Workforce skills, knowledge, experience	Skills and knowledge are limited at scale	Growing industry lacks experience and a capable workforce. International expertise required and the development of training programmes for workers.
Knowledge gap	R&D	Funding, collaboration, technology	There is a need for new technology. Presently, there is a lack of automation, which ties to difficult scalability without investment or investors in New Zealand. Furthermore, there is fragmentation among researchers and innovators.
Knowledge gap	Hatcheries or seedbanks	Limited if any available hatcheries or seedbanks	Significant investment required as well as R&D and scalability for hatcheries and seedbanks to be developed.
Knowledge gap	Species knowledge gaps	Industry lacks strategic direction	Lack of direction as to which species to invest in and the technology required to grow and process them. For example, current processing methods for fucoidan extract lose 15% of nutrient content during drying (Personal communication with sector participant, 22 April 2021).

Category	Component	Barrier or Gap	Implication
		for investment and development	
Environmental	Environmental variation	Environmental including climate change impacts	Costs and disruption to supply chains from climate change, pests and disease as well as environmental events such as cyclones, floods, droughts and earthquakes.
Environmental	Biosecurity	Risk of introducing and further spread of unwanted marine pests in New Zealand's freshwater and marine areas that may damage ecology, fisheries and aquaculture.	Some seaweed species with aquaculture potential are invasive species (e.g. wakame). New on farm biosecurity management and protocols will be required for the seaweed sector (Cunningham et al., 2020).
Regulatory	Regulation and licensing of seaweed capture and aquaculture harvest	Complex regulation around the harvesting of wild seaweeds. Onerous and costly food safety certification processes.	Commercial fishers need permits from Fisheries NZ to harvest wild seaweeds. Marine farmers need a consent from their regional council which can be at a high cost. Acquiring certification in New Zealand is hard and expensive to comply.

Table 4. Regulatory barriers and associated risks

Regulatory barrier	Risk	Comment
Wild seaweed framework for broodstock is not fit for purpose.	Med	Access to quality broodstock is a key issue for all aquaculture activities – future seaweed cultivation requires mechanisms that are fit for purpose, allowing sustainable access.
Beach-cast seaweed is regulated by the Fisheries Act.	Low	While beach-cast seaweed is not necessarily a priority 'source' for development of the seaweed sector, the ongoing tensions relating to fishing methods used to collect mussel spat on seaweed at Te Oneroa-a-Tōhē (Ninety Mile Beach) are a reminder that regulatory frameworks can have unintended consequences.
Wild harvest of seaweed for products/services is likely to be constrained by environmental concerns relating to removal of seaweed from the ecosystem. An example is that Schedule 4C of the Fisheries Act limits wild harvest of some seaweeds.	Low	If wild harvest seaweed is to play a significant role in the future sector, then initiatives such as marine spatial planning and 'whole-of-ecosystem' research will be important for identifying where and at what levels harvest should occur.
Seaweed marine farming is subject to the same RMA constraints as other marine farming.	High	The current RMA framework is a major constraint to accessing new space for aquaculture. Despite seaweed presenting a more favourable ecological opportunity, it is likely that considerable investment in 'evidence' and stakeholder engagements will be required to enable new seaweed aquaculture and the costs may outweigh the shorter-term economic gains.
Some regional coastal plans fall outside the National Environment Standards for Marine Aquaculture (NES-MA) and do not have enabling provisions to convert existing aquaculture to seaweed.	High	For example, there is strong interest in adding seaweed species to existing marine farms in the Tasman region but the plan does not readily enable this.
'Harvestable spat' species are set by Schedule 8A under the Fisheries Act 1996.	Med	This constrains access to future species and requires a regulatory amendment to review.
Transition from experimental marine farms to commercial opportunities is challenging.	Med	There are only a few 'experimental' marine farms due to similar locational constraints as production farms. Thought should be given to the best way to enable transition.
Land-based seaweed activities may also be constrained by RMA processes.	Med	Land-based consenting is not as difficult as marine-based, but there are still some challenges relating to water intakes and discharges and consent conditions that may limit opportunities or prove prohibitively expensive for land-based coastal infrastructure.

Regulatory barrier	Risk	Comment
Some research is lacking or unavailable which would provide evidence of the positive benefits of seaweed aquaculture.	Med	This issue relates mostly to the RMA framework but is also pertinent across a range of regulatory frameworks.
The biosecurity regulatory framework is not fit for purpose.	Med	Biosecurity can pose significant risks to all aquaculture ventures; it will be important that the seaweed sector provides leadership regarding the optimal biosecurity management protocols and framework for the sector.
The pathway to enable wakame farming has been challenging to date and early applicants have had to be 'leaders'.	Med	A more strategic approach to species such as (and including) wakame may open up new opportunities in a timely manner while still ensuring effects are well managed.
Growing water quality controls in place are set up to regulate bivalves and finfish.	Med	Seaweed will have its own unique requirements which should be planned and provided for.
Product processing, packing and labelling requirements don't anticipate seaweed products in their various future formats.	Med	Seaweed will have its own unique requirements which should be planned and provided for.
New Zealand's primary production export assurance programmes are not enabled for seaweed. Substantial work will be required to assess and meet key markets' import requirements.	Med	Seaweed will have its own unique requirements which should be planned and provided for.
Classifications and associated compositional standards for high value nutrition and agricultural compounds and veterinary medicine formats may not suit seaweed.	Med	Seaweed will have its own unique requirements which should be planned and provided for.
The Emissions Trading Scheme settings may not be optimised for seaweed.	Med	Seaweed has significant potential for New Zealand to meet its climate change aspirations. The settings should enable this.
Māori rights and interests in the seaweed sector may not be optimised.	High	Māori will play an integral role in the future seaweed sector and the regulatory settings should recognise and provide for this.

Regulatory barrier	Risk	Comment
There is a general lack of knowledge and understanding amongst regulatory agencies, including within government agencies and across different regional councils.	High	This issue is not uncommon for emerging industries but presents substantial barriers for new entrants across a range of regulatory frameworks. It has already been experienced by seaweed sector participants in adding seaweed species to existing marine farm consents and in setting or meeting food safety requirements.
There is fragmentation within and between agencies which can hamper innovation.	High	The interest in seaweed as an opportunity for New Zealand is growing fast, it will be important to ensure good 'cross-agency' collaboration and information sharing as the sector develops. It might be worthwhile having dedicated people across agencies collaborating on 'new innovative' sectors or products that can also include seaweed. Developing understanding and support for seaweed at a Local Government level is also needed.

Marine Seaweed Farming

Challenges that have been experienced to date include:

- An assessment of the opportunities to convert to existing marine farms to seaweed farms in the Marlborough, Tasman and Southland regions in 2020 found that while the settings in Marlborough and Southland are relatively enabled (the farms fall within the National Environment Standards for Marine Aquaculture (NES-MA)), in reality the opportunities are only small scale at present due to uncertain economic returns or incentives from conversion. While there is more interest in conversion in the Tasman region, it falls outside the NES-MA. Under the current plan, applications would need to be made across the range of stakeholders that farm each Aquaculture Management Area and include amendments to the existing environmental management plans. Furthermore, the current Tasman plan does not have any rules set up for seaweed, instead seeking to define it as an 'extractive' species.
- Planning issues and inconsistencies between local and central government have limited investment and innovation in the aquaculture sector (Bardsley et al., 2020).

RMA processes for aquaculture activities generally attract significant stakeholder interest or opposition and require 'pre-consultation' and potentially negotiations throughout the process. Key stakeholders include mana whenua, environmental groups, local residents, the Department of Conservation, commercial fishers and regional councils. As a result, making an application for new aquaculture water space is generally regarded as significantly challenging, complex, costly, lengthy and uncertain.

There is a spectrum within this; smaller applications in lower profile areas that don't include fed aquaculture will be much easier than large-scale applications for example. In theory, an application for seaweed aquaculture should be more straightforward because of the scale and nature of its potentially positive effects. However, the process and considerations will be the same as they are for large-scale finfish farms and lack of information might pose some challenges.

Adding seaweed as a species to existing farms should be more straightforward option. The new National Environmental Standard for Marine Aquaculture (NES-MA) supports the renewal of existing aquaculture, and the addition of seaweed species to existing aquaculture, but a lack of understanding or experience at a regional level means that adding seaweed can still be challenging.

Even once consent for new water space is granted, the unintended adverse effects test can pose substantial challenges and costs. Examples are the decades-long proceedings that preceded approvals for mussel farms in Tasman Bay and Golden Bay, and off the coast of Opotiki in the Bay of Plenty. For seaweed farming to be carried out at any scale, it will likely need to be carried out in new water space. The complexity and cost of this would currently be prohibitive to an emerging sector. This is probably the most significant regulatory barrier of any identified.

Resource Consenting

Issues that have been experienced to date include:

- An assessment of the opportunities to establish a seawater seaweed aquaculture hatchery in the Marlborough, Tasman and Southland regions in 2020 found that the biggest challenges were the cost of coastal land and the resource consenting challenges of establishing coastal water intake and discharge. The opportunity was

greater in the Southland, where there is greater interest in economic returns and jobs but the distance from corresponding new water space precluded that option (Aquaculture Direct Ltd, personal communication, January 25, 2020).

- Resource consent conditions are generally set according to the level of 'known' or 'unknown' effects at the time of consenting. This can have the effect of hampering innovation over time. For example, the consent conditions relating to seawater discharge at an aquaculture facility which was initially consented for bivalves is not set up to recognise the positive effects that seaweed aquaculture has on the nitrate levels at discharge (Aquaculture Direct Ltd, personal communication, January 25, 2020).
- Resource consenting is generally much more challenging when the consenting staff are unfamiliar with the activity and its effects. Considerable time, effort and investment is likely to be required to get council staff up to speed for emerging seaweed activities.

Experimental Seaweed Farming

'Experimental aquaculture' settings in regional coastal planning processes were anticipated to enable short term smaller scale marine trials which could then inform and enable longer term commercial opportunities, potentially in different locations. The reality is that, while there are a few experimental aquaculture farms, there remains an 'opportunity gap' between research trials and full commercialisation for new species and techniques. This gap between research and commercialisation also appears to exist in other elements of the sector and may require a transition strategy that enables future opportunities.

Food and High Value Nutrition

As new technologies and products emerge, updated food control plans will need to be redesigned and resubmitted for approval and there will be a similar experience with lack of knowledge or understanding within the regulatory personnel. This can serve as a substantial barrier. The Ministry for Primary Industries developed a list of key regulatory considerations for the National Science Challenge – High Value Nutrition Science Programme and for high value nutrition food producers to consider (Alexander & Lau, 2019):

- food classification
- food composition in relation to relevant compositional standards
- novel foods or food ingredients
- the availability of safety or toxicology data for a novel food
- whether certain ingredients added for nutritive purposes require approval
- how a particular food meets the criteria for a health claim in New Zealand or in countries that it is being exported to (given it also meets the compositional requirements)
- whether sufficient randomised controlled trials have been carried out examining the food-health relationship which enable a systematic review to be undertaken.

All of these considerations will be particularly challenging for emerging seaweed high value nutrition products due to lack of data, knowledge, understanding or protocols both in New Zealand and in the export markets. Recent experience has already highlighted the need to have comparative assessments of relative nutrient profiles for New Zealand species against other competitors. For example, there are more than 35 different species of karengo in New Zealand, belonging to four different genera (Nelson et al., 2012), some of which fall into the same genera as Japanese 'Nori' (*Pyropia*). Many of the New Zealand species are unresolved taxonomically (Nelson et al., 2012; Nelson et al., 2019).

Animal Feed and Feed Supplements

Use of seaweed in animal feeds or as a feed supplement must comply with the Agricultural Compounds and Veterinary Medicines Act 1997 (e.g. See https://www.mpi.govt.nz/animals/pet-food-animal-feed-nutritional-supplements/requirements-pet-food-animal-feed-supplements/). Most feeds and feed supplements will be granted an exemption from registration provided certain conditions are met and complied with. However, it is possible that feed supplements such as methane inhibitors and those that reduce urinary nitrate excretion in livestock, for example, as has been found with *Asparagopsis* spp. and *Ecklonia radiata*, may be more regulated through this act in the future. The sector will need to work with regulators to ensure that the regulations support future product forms and innovations as required.

Market Access

Market access issues vary across the range of products or services being offered to the market. The main commonality is country to country 'recognition' of the products being offered. This can be an issue of varying magnitude for all primary producers but as seaweed is an emerging industry, without well-established formats and protocols, the issues will be more upfront. There will be ongoing challenges for New Zealand and overseas regulators regarding which 'boxes' to put the products in and what requirements will need to be met.

For example, since seaweed is not regulated under the Animal Products Act 1999, the products won't qualify for official assurance to export markets. In order to get market assurance though, requirements will need to be met on a market-by-market basis and they can vary significantly depending on the importing region. This can make it very difficult to gain recognition for the countries being exported to that the seaweed product is safe. Biosecurity will also be a key market access issue, similar to other primary produce and again, each region will have its own biosecurity considerations and requirements. Experience to date has included challenges obtaining border clearance and that there are variations on the process according to the border worker and/or the broker. Government support in terms of facilitating collaborative standards and associated assurances will be helpful in this regard.

Workforce

Most primary production industries in New Zealand are experiencing workforce issues as they transition from large-scale 'lower-skilled' workforces to those that combine automation and innovation with a range of higher-skilled roles. Currently, there are significant 'regulatory' issues relating to accessing lower-skilled migrant workers and/or training/attracting New Zealand workers, over and above those issues that have arisen because of COVID-19. Depending on the nature and progression of the seaweed sector, some of these issues may also be experienced but they would not be seaweed-sector specific. The seaweed sector framework is a good opportunity to plan for workforce issues strategically into the future.

Future Prospects and Opportunities to Unlock Growth

International Trends

Seaweed production was valued at US$14 billion in 2019 and has been growing at around 7% annually over the past decade (FAO, 2021a, 2021b). This growth is projected to increase and production is projected to more than double by 2025 to more than US$30 billion (Markets and

Markets, 2020; Market Data Forecast, 2020). There are a number of influences driving this projected growth including global megatrends of increasing consumer focus on health, nutrition and wellness as well as a shift in consumer preference towards plant-based diets (Markets and Markets, 2020; Market Data Forecast, 2020; Piconi et al., 2020). Technological developments such as automation, machine learning, and artificial intelligence have the ability to propel the market forward as well as the implementation of selective breeding and strain selection practices, and optimised farming and management or monitoring systems.

New Zealand Trends and Opportunities

The New Zealand government has set a collective target for the aquaculture industry of NZ$3B by 2035 (Ministry for Primary Industries, 2019). The positive sustainability outcomes and broad range of economic opportunities for seaweed (from ecosystem services to functional foods) have led to a large amount of interest in commercialising seaweed in New Zealand, with multiple parties looking to develop and expand the seaweed sector. There are clear opportunities for the sector to grow; however, a strategic approach is required to ensure that the sector realises its full potential. To date, there has not been significant push from the aquaculture sector to use consented water space for the sole use of seaweed farming. This is mainly due to lack of certainty in customers and market, value in terms of return on investment and demand, and uncertain or low economic return, as well as lack of seed supply source, making it too risky and expensive to be 'first' with seaweed.

Advances in automation and technology and initiatives such as selective breeding can improve both productivity and viability and ensure that there are also positive impacts on the socioeconomics of communities and ecosystems, as well as contributions to climate change mitigation.

An assessment of New Zealand's priority market opportunities based on research presented in this report and on stakeholder representatives' input is summarised in Table 5.

Table 5. The priority market opportunities for New Zealand's seaweed sector.

Product	**Fit** Potential competitive advantage for New Zealand Seaweed Sector	**Profit** Expected profit margins once product category is mature	**Scale** Revenue potential of target market	**Readiness** Proven technology/viability and consumer demand
Health products	High	High	Low	Low
Human food	High	Med	Low	Low
Animal feed	High	Med	High	Med
Biostimulant	High	Low	High	High
Ecosystem services	Med	Low	Med	Low

Functional Foods and Health Products

Recent trends of increased awareness of health and wellbeing, combined with the recognition of seaweeds as a potential 'superfood' and the demand for plant-based products, has had and

will continue to provide opportunities in market growth. This is driven by growing awareness of environmental sustainability and animal welfare. The global plant-based meat market stood at US$12.1 billion in 2019 and is expected to grow at a Cumulative Annual Growth Rate (CAGR) of 15% in the forthcoming years (ProVeg International, 2020). This growth will be influential on seaweed production as the product is a good source of protein allowing for utilisation as a meat alternative.

Plant-based products are not exclusively food, and seaweed products are gaining popularity across several sectors including dietary supplements and cosmetics. Due to popularity, innovation, and development this market sector is set to continue to progress. Seaweeds have been used within traditional Chinese medicine practices and in Japan to treat a range of ailments, such as goitre, hyperthyroidism and intestinal disorders, amongst others and they have been demonstrated to have anticancer, anti-inflammatory, antimicrobial and antiviral bioactivities (El Gamal, 2010; Holdt and Kraan, 2011; Liu et al, 2012; Cian et al., 2015; Perez et al., 2016; see also Biris-Dorhoi et al., 2020 for review).

Food and Food Ingredients

The majority of the global seaweed supply is used to produce seaweed food products for human consumption. Within New Zealand there are a range of existing seaweed-based food suppliers. Most food products offered by companies such as Pacific Harvest, NZ Kelp and Kiwi Wakame are dried seaweed-based food seasonings. Some companies such as Wakame Fresh offer frozen salted seaweed with a focus on the Japanese market. A common theme among suppliers spoken to is that the current limited supply of New Zealand seaweed is a constraint on growth and requires some to use imported seaweed in their products (sector participants, personal communications, August 2020). Many red seaweeds, including those within the *Porphyra* genus which includes our native Karengo species, have been found to have high amounts of protein and may provide an ingredient source for plant-based alternative foods (McHugh, 2003; Smith et al., 2010; Holdt and Kraan, 2011; Cian et al., 2015).

KPMG (2020) produced a market study report on the potential of wakame production in New Zealand based on the South Korean and Japanese markets. Demand between the two countries differs substantially with the Japanese wakame market offering greater potential for our export sector. Demand for wakame in Japan was described in the report as ‘huge’ and ‘stable’ with limited changes in volume. This demand is driven by wakame being a key ingredient in Japanese dietary staples; it is commonly used in domestic cooking as well as the restaurant trade and as an ingredient in manufactured foods. Japanese consumers perceive seaweed as a healthy food source that can be provided in multiple formats from condiments to salads.

The Japanese wakame market is also more attractive than the South Korean market due to a higher reliance on imports and greater forecast demand. Additionally, there has been a recent reduction in Chinese imports presenting opportunities for new suppliers. The price range for wakame imports into Japan and domestic production varies significantly, from US$1.50 to $30 per kg indicating that there is a price premium paid for quality wakame. To achieve a premium price in the Japanese market, an organisation needs to meet a complex set of regulatory and customer requirements throughout the entire value-chain. Initial findings indicate that New Zealand wakame sold into Japan could potentially move well beyond the current price of US$3 per kg to US$7-30 per kg by positioning New Zealand as a preferred country of export and competing with the premium Japanese domestic market (KPMG, 2020).

Wakame Fresh - Feasibility Case Study Japanese Market

Wakame Fresh is a seaweed supply company based in the Coromandel, New Zealand. In October 2019, Wakame Fresh completed a feasibility study, "Project Whakatiputipu" examining the commercial viability of harvesting, processing, and exporting salted wakame from New Zealand to Japan (Evans and Davis, 2019). Included in the study was a planning and finalising approach which allowed for a trial export of samples for market research.

The largest challenges found in the study were consistency and predictability of yield, which is normally associated with wild harvesting techniques. For Wakame Fresh to be successful, it must be able to access high quality wakame in sufficient quantities consistently otherwise exporting will not be viable. Previously, bycatch yield from Coromandel mussel farms has not presented an issue for Wakame Fresh for domestic sales, but exporting would increase the scale significantly. Operating and production costs are high in New Zealand due to labour costs in comparison to competing countries such as China. Automated solutions have been considered by Wakame Fresh, however, loss of quality and therefore the premium product 'status' is at risk with automation. Finally, Wakame Fresh does not have any representation in the Japanese market as a brand. This means that Japanese industry and consumer perceptions are based on little to no knowledge of the New Zealand product.

Katsoka Co., partners of Wakame Fresh, suggest that a long-term strategy must be set for the necessary reputation to be built. The two key elements of the strategy are:

1. Consistently deliver a quality product; and
2. Build a library of evidence-based marketing collateral that demonstrates the superior nutritional and health benefits of New Zealand wakame product.

The report concluded that commercial feasibility for Wakame Fresh is dependent on obtaining a premium price. Achieving a premium price in Japan will be challenging, and will need to be underpinned by quality products, science, marketing, and critical relationships.

Wakame growing on mussel lines. Image credit: Lucas Evans, Wakame Fresh.

Across Central and South America, Eastern Europe and the Middle East, the market for carrageenan extracts is growing significantly (Market Data Forecast, 2020). Similarly, in Southeast Asia demand for seaweed is increasing primarily due to the hydrocolloid industry (agar, alginate and carrageenan extracts) (Market Data Forecast, 2020). Indeed, the market in Southeast Asia and the Pacific is growing annually by 2-3%, because of hydrocolloid demand (Bixler & Porse, 2010). There has been local product innovation in this space from companies such as AgriSea who see export potential, but seaweed supply constraints are currently a barrier to growth (AgriSea, personal communication, April 2021).

In addition to its traditional uses as food and industrial thickeners, there are nearly 300 known organic metabolites in seaweed from which a wide range of seaweed-derived products could be manufactured. However, the dairy subsector for carrageenan use has the highest demand and is expected to use the majority of seaweed cultivation supply for the foreseeable future. This is due to the wide application of carrageenan, agar and alginate as thickening and gelling agents in products such as cream, cheese, ice cream, powdered dairy, desserts and dairy drinks (Market Data Forecast, 2020). Higher prices for products based on seaweed ingredients would likely be needed to secure a supply of seaweed as an input for these products.

Animal Feed

Seaweed has long been used in livestock feed in coastal regions because of its high levels of micro-nutrients, amino acids, minerals and other organic compounds. In New Zealand, animal feed and nutritional supplement products with a seaweed-base have proven to be effective nutritional support for livestock and bees (Beck 2020; Agrisea 2021). In addition, seaweed-based products have been proven to be effective in reducing urinary nitrogen levels in cows (Beck, 2020), providing environmental benefit. AgriSea is the market leader with animal health products for the dairy, dry stock, equine and apiculture industries. Other producers such as NZ Kelp Ltd have smaller product ranges.

There has been considerable recent interest in the potential for seaweed-based feed supplements to reduce methane emissions from livestock. This is especially relevant in New Zealand, where the agriculture industry is responsible for almost half of New Zealand's greenhouse gas emissions (Ministry for the Environment, 2021). Several recent studies have demonstrated the efficacy of the red seaweeds, *Asparagopsis armata* and *Asparagopsis taxiformis* to reduce enteric methane emissions from dairy cows, beef steers and sheep (Li et al., 2018; Roque et al., 2019; Kinley et al., 2020; Roque et al. 2021; Stefenoni et al., 2021). Both species are found in New Zealand waters (Nelson et al., 2019) and intellectual property relating to the use of these seaweeds as methane reducing feed supplements is tightly controlled and must be licensed.

There are significant scalability and application issues that need to be addressed to ensure animal feed opportunities are practical and viable; it is risky for the aquaculture industry to invest when it likely requires massive scale to be profitable. However, the potential environmental benefits for New Zealand are significant and worthy of further investigation. Moreover, these opportunities may serve as a good starting point for seaweed aquaculture in New Zealand and provide momentum for key infrastructure and supply chains that may then be used to develop other, more profitable seaweed aquaculture markets.

For all animal feeds and feed supplements, providing a more reliable supply of seaweed via aquaculture would help to unlock the main supply constraint. There is also export potential for value added products (e.g., organic certified and scientifically proven formulations) to markets such as the United States and Europe with feedlot systems.

Fertiliser and Biostimulants

Seaweed based biostimulants that promote pasture and crop growth, or soil health are a reasonably well-developed market category in New Zealand, with multiple suppliers and a diverse product range. A common theme among a number of these suppliers is that demand now exceeds ability to supply some markets due to the limited local supply of seaweed (sector participants, personal communications, August 2020).

Some suppliers have partnered with academic researchers to test and document the efficacy of claims for their products including: reduced oxidative stress, increased rumen function (volatile fatty acids), reduced urinary nitrogen in cows, and increased shelf life and elevated sugar levels in fruit (sector participant, personal communication, April 2021). Seaweed biostimulant products are also stocked by major agriculture retailers such as RD1 and Farm Source.

Seaweed based biostimulants are currently a small part of the fertiliser market in New Zealand. Commercial seaweed farming would create a reliable source of supply for these products and help to grow this market. However, profit return to marine farmers, fishers and beach-cast gatherers is low from these industries where value is created in the formulation and utilisation, and domestic customer base. Because the farm gate commodity return from these industries is low, marine farmers generally consider their focus on these products to be uneconomic. Furthermore, additional investment would be needed to expand processing and manufacturing capacity and increase product marketing (EnviroStrat, 2019).

Ecosystem Services

Seaweed farming creates habitats and products that provide ecosystem services including the potential for carbon sequestration and nutrient removal on relatively short time scales. These characteristics are particularly relevant to the sustainability principle of EBM and the blue economy more broadly. However, without an understanding of the real-world environmental benefits and risks (i.e., a robust knowledge-based and tailored approach), the opportunity to achieve blue economy outcomes could be wrongly assessed, or potentially missed.

Carbon Sequestration and Climate Change Adaptation

Seaweed farming provides multiple positive environmental benefits that could be 'stacked' into high-quality offsets as a revenue stream for seaweed farms. Seaweed aquaculture for CO_2 mitigation has been proposed for commercial seaweed production in countries such as China, where seaweed farming is carried out at massive scale, filling entire bays and coastlines (Gao et al., 2016). These seaweed aquaculture beds along with natural beds and kelp forests represent major carbon sinks and could increase carbon sequestration in coastal regions (Chung et al., 2017). Seaweed farming could provide a new form of carbon offsetting. However, Froehlich et al. (2019) found large-scale global mitigation through carbon dioxide equivalent (CO_2eq) sequestration unlikely from seaweed aquaculture, but applications at local to regional scale more feasible. The report highlighted that production scale and costs were too high for sequestration of global agricultural CO_2eq and that even the aquaculture sector itself would require 14%–25% of current farmed seaweeds for offset.

Given the scale required, it may be challenging to generate viable returns from offsetting as a stand-alone model in New Zealand. Carbon markets are likely to be at the core of any 'stacked' environmental benefits from seaweed farming. Carbon sequestration from seaweed is still an emerging area of research, including within Project 2.2 *Restorative Economies* of the Sustainable Seas National Science Challenge. The New Zealand Emissions Trading Scheme does not allow for seaweed-based blue carbon credits, but voluntary certification markets are

emerging globally, and may provide revenue opportunities both domestically and internationally in the absence of domestic regulated trading markets. The key determinant of viability will be the price of carbon credits into the future.

The positive environmental benefits of seaweed have been behind numerous wild seaweed restoration projects overseas, that have been publicly or donor funded in the absence established market mechanisms for payment (Layton et al., 2020). These examples suggest that public and / or donor funding may be available towards similar projects here in New Zealand.

Algal Bioremediation of Waste Waters

Both seaweeds and freshwater macroalgae have been shown to remediate nutrients and metals from a number of human mediated activities such as urban runoff, agricultural effluent, industrial processes and even aquaculture (Lawton et al., 2013; Neveux et al., 2018). Algal bioremediation is broadly acknowledged as important and worthwhile by a range of agencies. Often this is driven by regulatory requirements, and sometimes it is an alternative to large infrastructure spend (e.g. waste water treatment plant expansion). This process of bioremediation has successfully been implemented internationally. For example, *Ulva* and *Gracilaria* spp. have been successfully used around the world in land-based systems since the 1980s (Neveux et al., 2018). In New Zealand, there is no market mechanism currently that enables the sale and purchase of such services (EnviroStrat, 2020). Although, there may be opportunities for direct bioremediation (e.g. from various waste water sources) that is both commercially viable and provides improved environmental outcomes.

Biorefinery and Circular Economy

An alternative strategy that may improve sustainability and commercial viability is to take a biorefinery approach, processing seaweed into a suite of different products, starting with the highest value and then moving through to producing lower value products with the left-over material (Figure 7). Taking this further and considering a circular economy, there is an opportunity to take an approach that is also restorative and regenerative and ensures optimal social and environmental as well as economic outcomes.

Faroe Islands based *Ocean Rainforest* has been leading a pilot project to address the key challenges, barriers, and thresholds that producers have encountered when refining seaweed biomass (Ocean Rainforest, 2021). A key learning for the New Zealand seaweed sector from this example is the need to focus on developing product categories that have well-established markets and strong demand. The approach is also likely to require strong partnerships, networks or a consortium approach given the number of potential markets for seaweed products.

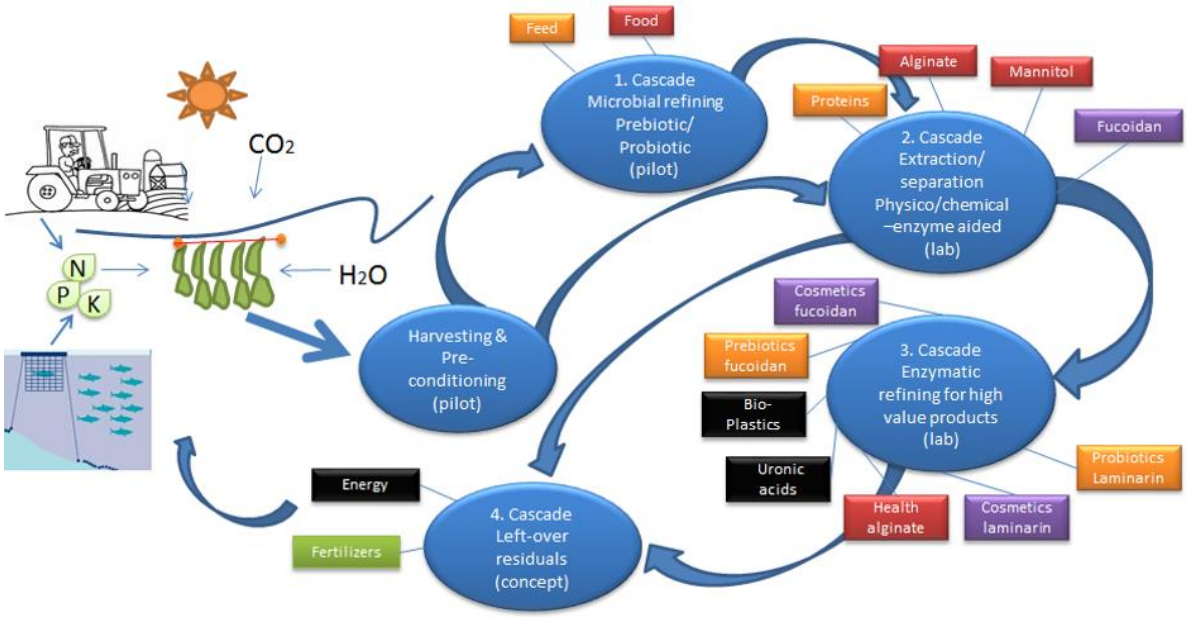


Figure 7. Bio-refinery and circular economy approach example for seaweed. A range of pre-processing and fractionation techniques combined with conversion techniques (mechanical, physicochemical, enzymatic and microbial) are used to generate a suite of products for industries such as food, feed, cosmetics, pharmaceutical and fine chemicals. (Source: Ocean Rainforest. http://www.oceanrainforest.com/cascade).

Seaweed product categories that are individually (as opposed to part of a biorefinery approach) less likely to suit New Zealand include bioplastics and biofuels (Rajendran et al., 2020). These typically require massive volumes of seaweed to be supplied at low cost, and large capital investment in processing. Also, the economics of biofuel relies on much higher international oil prices than have been seen for many years.

A New Zealand circular economy example utilising seaweed is Waikaitu (https://www.waikaitu.com/; Lewis et al., 2020). Waikaitu is based in Nelson and produces biostimulants and fertilizers using wakame (*Undaria*) that has naturally settled as an invasive species on mussel farm lines. The products produced are used in terrestrial horticulture, replacing chemical fertilizers and enabling growers to farm organically and earn export revenue. This is a relatively simple circular economy example, removing a pest species grown inadvertently on mussel farm lines and reducing the amount of chemical run off from land to the sea.

Regulatory Recommendations

Seaweed, like any emerging sector, faces the challenge of sometimes being 'ahead' of the regulatory agencies in terms of knowledge, information, and aspiration. Consequently, some participants have experienced differing approaches within and between agencies. The development of a seaweed sector framework at this early stage is a great opportunity to align information streams, policies and settings, and enable future collaboration. This issue also extends further to the need to foster collaboration among research providers, the sector, Māori and regulatory agencies. Applying a more strategic approach to research and development means shifting away from using incentives with short-term focus to those that align to strategic longer-term goals of the sector collectively (Bardsley et al., 2020).

The regulatory challenges identified in this report generally relate either to the emerging nature of the seaweed sector or the challenges of securing consent for aquaculture space in

the Coastal Marine Area (CMA). Many of the potential solutions therefore are mirrored in previous national conversations regarding coastal aquaculture or emerging primary industries. There are potential differences though, due to the unique nature of emerging seaweed opportunities, which are worth recognising. This includes the enhancement of ecosystems and benefits to humanity when aquaculture is managed within an EBM framework (Theuerkauf et al., 2019). The range of regulatory solutions identified here take both the similarities and the differences into account. Many of the solutions are 'cross-issue' i.e. they pave the way for a thriving seaweed sector which provides meaningful economic, environmental, social and cultural benefits to local communities as identified in a broader sense in this report.

Internationally, the challenges of optimising the settings for seaweed are being explored across several jurisdictions. Our recommendations draw on these while recognising the unique aspects of the New Zealand context including Te Tiriti o Waitangi. Because they are recommendations seeking to address regulatory barriers, it will be critical that delivery across all of the elements is carried out in a sector- government partnership approach.

At a high level our recommendations are:

1. Establish a seaweed sector group.
2. Develop a government strategy for seaweed.
3. Participate in international rules and regulation harmonisation processes.
4. Undertake seaweed specific marine spatial planning.
5. Develop a nationalised seaweed specific regulatory framework.
6. Establish a seaweed data or science hub.
7. Produce a workforce development plan.
8. Provide investment or funding pathways.

Establish a seaweed sector group

A seaweed framework will provide a comprehensive focus for development of a thriving seaweed sector, but successful implementation will require strong leadership and ongoing collaboration. This should be provided through a seaweed sector group which includes representation across the elements of the sector as well as governance which enables Māori partnership and collaboration across its activities.

The seaweed sector group's stakeholders and activities will likely be broad and look well beyond regulatory issues. The terms of reference of this group are beyond the scope of this report, however, regulatory expertise and conversations should be enabled through its activities. Because regulatory issues are often solved with multi-disciplinary solutions, including science and communications, it is possible that a range of 'levels' of advisory panels or working groups may be required.

Some of the key functions of the sector group could include:

- Driving implementation of the framework.
- Working with government to identify a national strategy and priority needs and activities.
- Providing a platform for knowledge sharing across experts and stakeholders
- Participating in international collaboration guiding the development of the seaweed sector globally.
- Providing information and advocacy to a range of non-sector stakeholders.

- Enabling development and implementation of key sub-strategies across science, regulation, workforce and other elements of the overarching strategy.

The importance of a seaweed sector group is well recognised in other jurisdictions, including Australia, and internationally by United Nations. Benefits obtained include knowledge sharing, capacity building, leadership, and collaboration to overcome shared barriers the industry faces (Kelly, 2020; Lloyd's Register Foundation, 2020)

Once established the seaweed sector group should guide the development of the remaining recommendations.

Develop a government strategy for seaweed sector

Opportunities in seaweed cross many different formats, from freshwater to land-based, to marine and from animal nutrition to carbon capture. Any government-led solutions, therefore, will be cross-agency and include regulatory, policy and funding elements. It will also need to recognise Te Tiriti o Waitangi and to have both national and international elements. As seaweed has a multitude of potential ecosystem and social benefits, but is still emerging as a sector, there will be a strong need for government support and funding, particularly in the early years as the sector develops.

Government activities should be guided by a strategy for the seaweed sector which has been informed by a framework and seaweed sector group. Public engagement will also be important as the strategy develops. Some of the key elements of the government strategy will complement those of the seaweed sector group. They should include:

- Enabling cross sector engagement including with the seaweed sector group.
- Supporting the platform for knowledge sharing across experts and stakeholders.
- Participating in international collaborations guiding the development of the seaweed sector globally.
- Providing information and advocacy to a range of non-sector stakeholders.
- Enabling development and implementation of key sub-strategies across science, regulation, workforce, and other elements of the overarching strategy.
- Developing national policies and regulations which optimise the development of the sector (e.g. for consenting, investment, environmental standards, quality standards, monitoring, biosecurity and general regulatory requirements) and ensuring that these are capable of adapting in a timely manner as the industry develops.
- Developing and implementing seaweed marine spatial planning which provides certainty but also allows for experimentation and future opportunities.
- Providing funding across the value framework, particularly as research activities transition through to commercialisation.
- Providing 'seaweed specialists' across key agencies to enable responsive solutions as new opportunities or issues arise.
- Enabling fit-for-purpose free trade and market access arrangements across the spectrum of opportunities and allowing for the industry requirements to adapt.
- Progressing suitable regulatory levers to recognise the ecosystem benefits that the sector can provide.
- Ensuring Māori are included and involved in the development of all these initiatives and their aspirations and values are recognised.

The importance of government leadership is well recognised, as is the need to develop a strategy that balances innovation, sustainable aquaculture development and investment while safeguarding marine ecosystems and biosecurity values (Bardsley et al., 2020).

Participate in international rules and regulation harmonisation processes

New Zealand has a range of unique challenges and strengths which will be reflected in its emerging seaweed sector. While it is important to optimise our own opportunities, it will also be essential to participate in the emerging and ongoing development of settings that guide the development of seaweed markets globally. There is a need to align policies, standards and regulations globally to support industry development (Lloyd's Register Foundation, 2020). Such settings might include specifications, quality standards, production safety standards, environmental standards, food safety standards, safety limits for residues, certifications, labelling, market access and carbon credit recognitions, amongst others. The seaweed sector group and government agencies should participate in these global conversations collaboratively, and determine where New Zealand specific solutions, standards and certifications are more appropriate as the sector develops.

Marine spatial planning

One of the key regulatory challenges is access to suitable coastal water space for marine seaweed aquaculture. This is an issue that has been challenging for the broader aquaculture sector since the late 1980s and it looks set to continue as there are increasing competing uses and values in the marine water space.

Marine spatial planning is a method of enabling community agreement about appropriate locations for a range of marine activities, from preservation or protection through to utilisation. Developing what is known as 'social capital' or 'social license' (norms, trust, and networks) is considered fundamental to collective action (Jones et al., 2009) and to enable permit applications to be fast tracked (Lloyd's Register Foundation, 2020). Previous studies have demonstrated that the perceptions of seaweed aquaculture are linked to "interpersonal relationships, perceptions of environmental risk, scale of decision-making and of operations, and communication" (Billing et al., 2021).

Despite the recognition of the importance of spatial plans, no substantive progress has been made in New Zealand toward either regional or national marine spatial plans, other than *Tai Timu Tai Pari Sea Change*, in the Hauraki Gulf. Lack of marine spatial planning or implementation of plans presents a barrier to seaweed sector development.

Marine spatial plans could identify locations where seaweed aquaculture could achieve approval through streamlined pathways, subject to a range of tests, recognising potential ecosystem benefits and dependent on a range of environmental, social or cultural 'standards'.

In a global-scale study, Theuerkauf et al. (2019) developed an index, the "Restorative Aquaculture Opportunity Index" to help identify areas where shellfish and seaweed aquaculture would provide ecosystem services and deliver a suite of environmental, socioeconomic, and human health benefits. Major opportunities for seaweed aquaculture were identified throughout Oceania, the Americas, Asia, and Europe and included regions of New Zealand.

Develop a nationalised seaweed specific regulatory framework

As noted above, the regulatory framework for seaweed is particularly complex because of the range of harvesting and growing methods, product and service formats, and because it is evolving rapidly, some of the opportunities are unknown. There will be numerous central and

local government policies, plans, regulations and standards which will require amendment or implementation to optimise the sector in a timely manner. Many of the solutions will be cross-agency. Solutions will also need to be developed over time as the sector develops.

For these reasons, a cross-sector nationalised framework should be developed. A stocktake of priority issues and the related agency or regulation would be a helpful start. From there, a range of activities across the relevant agencies could be programmed. A common theme to date has been frustration that personnel within government agencies are unfamiliar with seaweed sector issues and opportunities, and the sector itself is expending resource upskilling the agencies. Sector oversight from a key 'skills and knowledge hub' within government and in collaboration with the seaweed sector group will be important. This hub could be utilised by individual agencies where new questions and challenges arise. Internationally, recommendations for nationalised regulatory frameworks include the need for environmental standards (Kelly, 2020) and a regulatory framework that incentivises the use of seaweeds as alternatives to their more resource-demanding and high-carbon counterparts (Milledge et al., 2016).

Some regulatory elements, such as local consenting, may still require local approaches, however, an overarching national policy direction will still provide important guidance and prioritisation.

The Lloyd's Register Foundation (2020) listed the following priority areas for regulatory review in its Seaweed Manifesto:

- Food (and packaging) safety standards and regulations
- Identification of potential hazards and protocols developed for managing risk
- Biosecurity policies
- Certification tools
- Marine spatial assessments
- Insurance models for long-term investment.

Additional priorities relating specifically to the New Zealand context are:

- Extend the add-species mechanisms for existing farms to all aquaculture regions
- Develop appropriate mechanisms to enable access to new marine space for seaweed aquaculture subject to appropriate standards
- Review the Fisheries Act to enable access to broodstock for a range of seaweed species
- Review the Fisheries Act to enable aquaculture of a range of seaweed species
- Enable recognition of seaweed benefits in water discharges from land-based systems
- Optimise climate-related mechanisms to enable seaweed opportunities.

Establish a seaweed data and science hub

As noted above, many of the current regulatory challenges relate to the 'unknowns' in the emerging seaweed sector. Regulatory barriers, research and development, and sector opportunities need to be mapped out across stakeholders and prioritised. The development of a collaborative data and research hub where, as appropriate, information can be shared across issues and opportunities would be valuable. Funding mechanisms for engagement on research and data across a range of topics with stakeholders, including government, Māori, markets, interest groups and the general public would be helpful.

Particular research topics that would assist the regulatory context include:

- Biosecurity
- Seaweed ecosystem services
- A market/product/species knowledge centre
- Farming system ecological assessments
- Food safety and provenance traceability programmes.

Produce a workforce development plan

Workforce issues in New Zealand are generally similar across the primary industries and many of the solutions will be non-specific. However, there are opportunities for the seaweed sector group to develop a workforce plan which maps out projected workforce needs and capabilities over time, career pathways and training, and to align with training institutes and other seaweed sector stakeholders to deliver benefits to both the sector and communities (Bardsley et al., 2020; Kelly, 2020). An engaged workforce can assist with regulatory challenges by becoming 'seaweed ambassadors' in their community.

Provide investment/funding pathways

Investment and funding to enable sector establishment in its developing years is critical across the seaweed framework. Funding can enable the bridging of gaps between research and development, and ultimate commercialisation. In seaweed, some of the eventual 'commercialisation' opportunities may not be solely economic and resource will be needed to define how the broader benefits of seaweeds can be accounted for. An example is the development of methodologies and standards to recognise carbon benefits. As noted above, there is a need to 'upskill' the regulators and share the expanding knowledge base as the industry develops in order to best streamline the regulatory framework. Investment and funding will be required to support this.

Next Steps and Overarching Recommendations

New Zealand has a fledgling but highly dynamic sector operating at small scale. The fragmentation and uncertainty facing investors and producers, and the complexity of the decision-making they currently face reinforce the need for an overarching framework. There are important examples of product innovation and science-based applications, but these are limited by a constrained supply chain that does not include aquaculture which has high labour and space costs associated with it.

New Zealand's seaweed sector framework needs to guide the sector's development towards a collective vision for a sustainable and high value future. It needs to clearly form New Zealand's value proposition and develop a pathway that addresses the current industry and regulatory barriers outlined. For New Zealand to have a sustainable and high value seaweed sector, this report suggests the following:

- Establish a seaweed sector group/hub to foster collaboration and stakeholder engagement, share information and inform decision making, and set priorities and aspirations for development of the industry.
- Scope, fund and develop high profit, high fit seaweed industries.
- Develop a clear pathway for ecosystem services markets from seaweed that can be managed and ensured viable in New Zealand.
- Map out and strategically prioritise research and development to support the sector. Initiatives that overcome collective hurdles and unlock the highest value opportunities for

New Zealand should be prioritised. Consideration should be given to overseas research initiatives that can be integrated, to maximise New Zealand's research spend and avoid duplication.

- Develop a government strategy, which informs regulatory solutions and funding priorities in line with the seaweed sector group's priorities. Develop a fit-for-purpose cross-agency regulatory framework including international harmonisation, marine spatial planning, consenting, permitting, and standards setting requirements.
- Develop a governance framework for the sector that incorporates Māori and mātauranga.

Subsequent work planned as part of this project will look at the current state of seaweed research (both nationally and internationally), the potential of specific seaweed species, ecosystem services of seaweeds as well as Te Tiriti o Waitangi considerations. This will provide background information for the collective development of a framework for the New Zealand Seaweed sector that will then be tested and refined through local case studies.

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