Review

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**Seaweed utilisation in New Zealand**

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**Abstract:** The commercial landscape of seaweed use in New Zealand (NZ) has shifted and evolved since it was last reviewed in 2006. One of the largest changes saw the introduction of *Macrocystis pyrifera* and green-lipped mussel spat (which is landed attached to beach-cast seaweed) into the Quota Management System—the primary tool for commercial fisheries management in NZ. There have also been policy changes around commercial harvesting and farming of *Undaria pinnatifida*, an introduced brown alga native to Asia. Traditionally, commercial algal utilization has been limited to agar production and beach-cast collection for aquaculture feeds, though demand for seaweed products has increased with a growing Asian population in NZ. The NZ seaweed industry is at an early developmental stage, but it has the potential to offer high quality seaweed stock and value-added products to the world market. The exploration of seaweed farming, the growing demand for seaweed fertilizers and the development of high-value bioactive products such as fucoidan has attracted interest from marine farmers and entrepreneurs. The key to success for the NZ seaweed industry rests in developing high-value products for an export market, from integrated farming, harvesting and processing that can deliver the most value, consume the least energy and generate minimal waste.

**Keywords:** aquaculture; legislation; seaweed; utilisation; wild harvest.

1 Introduction

New Zealand/Aotearoa (NZ) has a natural coastline of 15,134 km (Metzner et al. 2003) and over 1000 known algal species (Nelson et al. 2019). The indigenous Māori have a long tradition of using seaweed for food. The most commonly consumed species by Māori are red algae *Pryopia* spp. (karengo, parengo, kareko or reporepo in Te Reo Māori, the Māori language) and *Gigartina* spp. (rehia or rimu rehia; Hurd et al. 2004; Ministry of Fisheries NZ 2007). Bull kelp *Durvillaea antarctica* (rimurapa or kōauau) is used both as a functional food (Cambie and Ferguson 2003), and as a unique storage preservative for muttonbird (tītī) (Abbott 1996). Since the 1940s, the main commercial seaweed industry in NZ has been based on agar production from beach-cast red seaweeds, predominantly *Pterocladiella capillacea* and *Gigartina* spp., mostly hand-gathered by seasonal pickers on the east coast of the North Island. The scale of production and revenue generated by such activity is very small compared to that of other Pacific nations, e.g. Japan and China, where the seaweed industry contributes over US$ 6 billion annually, of which around US$ 5 billion is generated from food products, and the rest from hydrocolloids such as agar and alginate (White and Wilson 2015). The NZ seaweed industry does not play a remarkable role in the wider world currently, but it has the potential to provide high quality, pollution-free seaweed stocks, as well as value-added nutritional and cosmetic products such as fucoidan and fucoxanthin from the introduced seaweed species *Undaria pinnatifida* (White et al. 2014). The popularity of seaweed-based fertilizers is also on the rise, with more products seen in stores and being advertised or mentioned in the media.

The seaweed resources of NZ have been well documented in several publications (Brown et al. 1997; Nelson et al. 2019), and this paper will instead provide an update on the utilisation of NZ seaweeds as reported by Zemke-White et al. (1999) and Brown and Zemke-White (2006). This includes changes in governmental policies, trends in stakeholder seaweed harvest and cultivation, and it
outlines the increased interest in *U. pinnatifida*, as well as its journey towards becoming a potentially significant commercial species in NZ.

### 2 Methods

Data on the wild harvest landing of targeted commercial seaweed species between 2006 to 2018 were taken from fishing returns to the Ministry for Primary Industries (MPI), as well as the landing data of selected seaweed species between 2006 and 2017 from the United Nations Food and Agriculture Organisation (FAO) report. Information about the number of commercial-seaweed-harvesting permit holders under the NZ Fisheries Act 1996, and the number of permit holders to harvest *U. pinnatifida* under Biosecurity Act 1993 was disclosed from MPI under the Official Information Act 1982. Information regarding marine farms with a permit to cultivate seaweed was derived from data provided by FishServe, who manages the Fish Farm Register on behalf of MPI.

The green-lipped mussel spat was introduced into the Quota Management System (QMS) in 2004. The 13 species of brown and red algae that the mussel spat settle on are collectively managed under the landing code “MSP”, and reported collectively with mixed species of beach-cast seaweeds under the landing code “SEO”. This landing report however does not represent all beach-cast seaweed biomass, as harvesting beach-cast red seaweeds (non-spat material) does not require a permit, and no report of those landings is available (Fisheries New Zealand 2019).

### 3 Current legislation and policy on seaweed management

#### 3.1 Wild harvest

Seaweed fisheries are managed by MPI under the NZ Fisheries Act 1996 (the Fisheries Act). The Ministry definition of “seaweed” encompasses not only marine macroalgae but also seagrasses and freshwater algae in all three physical forms: attached, free-floating and beach-cast. In the context of this review, the term “seaweed” refers to only marine macroalgae. The Fisheries Act requires that any commercial harvesting of aquatic life including seaweed must be done under a commercial fishing permit (section(s)89). Permits are available on application to FishServe, which provides a permit issue service on behalf of MPI.

In addition to the Fisheries Act requirements, all general commercial fishing requirements and restrictions must be complied with, including landing all catches to licenced fish receivers, monthly reporting of catch (by the 15th of the month following the harvest), and balancing the Quota Management System catches against the annual catch entitlement (ACE), e.g. if the full ACE amount allocated to a fisher was not fulfilled at the end of a fishing year, he/she will be compensated with an “underfishing allocation” in the form of either the unused ACE or 10% of the ACE the fisher holds.

Due to the increased demand for seaweeds, commercial harvest of most seaweeds is “open access” with some exceptions listed below, and basically any fishing permit holder (e.g. permit holder for shellfish or fish) can harvest seaweed without catch limits, provided that all normal fishing requirements are met.

The exceptions to the “open access” policy are:

1. A moratorium (Schedule 4C, the Fisheries Act 1996) issued in 1988 is in place on issuing new commercial fishing permits for the species listed in Table 1, unless the applicant already holds a fishing permit between 1 October 1990 and 30 Sep 1992, with no unlawful activities on record.

2. The Act enables the harvesting of beach-cast red seaweeds without fishing permits (meaning the above commercial fishing requirements do not apply) (s89(2), s91(4)). This is due to historical reasons and the low quantity of landings (Zemke-White et al. 1999).

#### Table 1: Targeted commercial seaweed species in New Zealand.

<table>
<thead>
<tr>
<th>Seaweed type</th>
<th>Common name</th>
<th>Scientific name</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gracilaria weed/ Sea moss</td>
<td><em>Gracilaria chilensis</em> C.J.Bird, McLachlan et E.C.Oliveira</td>
</tr>
<tr>
<td></td>
<td>Nori(^a)/Karengob(^b)/ parengo(^a)/ kareko(^a)/ reporepo</td>
<td><em>Pyropia spp.</em></td>
</tr>
<tr>
<td>Brown (Phaeophyceae)</td>
<td>Bladder kelp</td>
<td><em>Macrocystis pyrifera</em> (Linnaeus) C.Agardh 1820</td>
</tr>
<tr>
<td></td>
<td>Brown kelp</td>
<td><em>Ecklonia radiata</em> (C.Agardh) J.Agardh 1848</td>
</tr>
<tr>
<td></td>
<td>Bull kelp/ Rimurapa(^a)/ kōauau(^b)</td>
<td><em>Durvillaeae spp.</em></td>
</tr>
<tr>
<td>Green (Chlorophyta)</td>
<td>Sea lettuce</td>
<td><em>Ulva spp.</em></td>
</tr>
</tbody>
</table>

\(^a\)In Japanese.  
\(^b\)In Māori.
A commercial fishing permit is not required to harvest *U. pinnatifida*, which is managed under s52 and 53 of the Biosecurity Act 1993, which included restrictions to move, transfer and sell. *U. pinnatifida* also must only be harvested from man-made surfaces.

Brown and Zemke-White (2006) pointed out that the NZ seaweed management regime is largely ad-hoc, being passively responsive rather than systematic and strategic, and that seaweed in an attached form was not managed by the QMS as other fisheries in NZ. This is no longer the case, since bladder kelp *Macrocystis pyrifera* (in an attached state) (KBB G) was introduced into the QMS on 1 October 2010. The harvesting of KBB G is restricted to two Fisheries Management Areas (FMA) only, which are FMA3 (east coast, SL) and FMA4 (Chatham Island) (Figure 1). Landings are reported under the codes KBB 3G and KBB 4G, respectively, in these two areas (Fisheries New Zealand 2019) and are controlled under Total Allowable Commercial Catch (TACC) and balanced by ACE. There are currently 10 entities who own quota to harvest *M. pyrifera*, and it is unknown how many are actively harvesting.

Beach-cast seaweed harvesting area and status were also reviewed in 2009 (Ministry of Fisheries NZ 2009a,b; Zemke-White et al. 2005). MFish consulted widely with stakeholders regarding the potential for expanding the harvesting area for beach-cast brown and green seaweed species, as the current scale of commercial harvesting no longer meets the demand for the fertiliser, aquaculture, food and pharmaceutical industries (Ministry of Fisheries NZ 2009a). The minister announced the expansion of beach-cast seaweed area to FMA 1, 2 and 8 (North Island) with restrictions (Ministry of Fisheries NZ 2009b). Harvest must not be executed in specifically excluded areas within the FMAs, as well as ecologically sensitive areas.

### 3.2 Marine farming

Marine farming is primarily managed under the Resource Management Act 1991, through resource consents. Currently only naturally settling seaweed on a marine farm is permitted for the farmer to grow. The commercial species of interest are the same ones listed in Table 1.

There are 59 current permit holders who are eligible to farm seaweed; they own 170 marine farms, which are mostly located in the Pelorus and Marlborough Sound of the South Island, as well as Coromandel peninsula and Wellington Harbour of the North Island (Table 2). Some of the permit holders have licences for as many as eight seaweed species. This is an increase from 1999, when there were 29 permit holders who owned 72 farms (Zemke-White et al. 1999). Data on seaweed produced from the farms since 1999 were unavailable, however, based on communications with industry stakeholders, it was very little. As outlined below, however, ambitions in seaweed farming are rising, specifically with the invasive species *U. pinnatifida*. This seaweed is farmed extensively in Asia and has a worldwide market. It usually generates sporophytes once a year in Asian countries, but it persists all through the year in NZ due to a narrower sea temperature range of approximately 10–20 °C (Hay and Villuota 1993; Parsons 1994), in contrast to 0.1–29.5 °C in Japan (James et al. 2015), making it a desirable species for commercial cultivation.

Farming of *U. pinnatifida* offshore is permitted but restricted to four heavily infested areas under the Biosecurity Act 1993 (MAF 2011) – Wellington Harbour, Marlborough Sounds, Lyttelton Harbour and Akaroa Harbour. To obtain a permit to farm *U. pinnatifida*, in addition to seeking a permit from MPI, an application for consent with the regional council is also required (Ministry for Primary Industries 2013).
From our communication with MPI in August 2019, it was specifically emphasized that current permits to farm *U. pinnatifida* do not exist, due to the many complications and restrictions from its “unwanted organism” status. Permits to farm *U. pinnatifida* must be granted under both the Biosecurity Act 1993 and the Fisheries Act, and permit seekers must acquire seed stock from a legal source, as well as being in possession of the farmed stock according to the Fisheries Act (s192A). This is currently impossible for the following reasons:

1. *U. pinnatifida* is managed under the Biosecurity Act 1993 and cannot be harvested under a commercial fishing permit under 192A(1)(a).
2. *U. pinnatifida* cannot be retrieved from any fish farm as no fish farm can acquire or be in possession of the species under 192A(1)(a).
3. Not only is it illegal for any fish farmer to breed or cultivate *U. pinnatifida*, the farmer is unable to acquire seed stock from other sources to start with under 192A(1)(b).
4. *U. pinnatifida* is not listed as a harvestable spat species under Schedule 8A of the Fisheries act (192A(1)(c)).

Intriguingly, there is one farm in NZ that has recently had resource consent to add *U. pinnatifida* to its marine farm license. The farm is located at Mahanga Bay, Wellington Harbour; however, it is not currently operative due to the reasons listed above.

### 3.3 Land-based farming

Land-based farming is managed under the Freshwater Fish Farming Regulations 1983. Farming is restricted to the species listed on Gazette Notice MPI842 (Notice No. MPI 842) (New Zealand Gazette Office 2017). The permitted species are summarised in Table 3.
NZ started in 2012 at 730 t and almost doubled in 2017 (1300 t).

Total beach-cast seaweed landings, including mussel spat material as well as other green and brown beach-cast species, was 5087 t (wet weight) between 2006 and 2018, which contributed the most to the commercial seaweed landing volume. Brown kelp species, specifically bladder kelp (M. pyrifera) and Ecklonia radiata are becoming increasingly important. In fact, these two kelp species along with U. pinnatifida have been showing the most progress towards the development of their potential commercial values (Gibbons 2014).

### 4.1 Green-lipped mussel spat

The green-shell/lipped mussel (*Perna canaliculus*) industry is the dominant aquaculture export in NZ, with 200,000 t of mussels produced annually, generating over US$ 260 million in revenue (Alfaro et al. 2011). Extensive research has gone into the production of mussel spat in hatcheries, yet the industry is still almost entirely reliant on wild-harvested mussel seed (spat), which settle on beach-cast seaweeds. The majority of these wild seed mussels (more than 80%) are harvested from FMA9—Ninety Mile Beach in the far north of the North Island (Alfaro et al. 2010; Jeffs et al. 2018), where a single wash-up event can land 70 t of spat material (Alfaro and Jeffs 2002), locally known as “Kaitaia spat” (Edge 2019). Over 100 t of the mussel spat is harvested at this single location annually for distribution at various mussel farms, which contains over 100 billion individual mussel seed (Alfaro et al. 2011).

Other areas where spat is harvested are Golden Bay and Tasman Bay (Edge 2019). Around 200 t of spat material is commercially harvested annually for mussel production in hatcheries around NZ (Alfaro et al. 2010). The commercial harvesting of beach-cast seaweed containing green-lipped (shelled) mussels was introduced into the Quota Management System on 1 October 2004, and the Total Allowable Commercial Catch (TACC) is 1720 t over seven of the 10 FMAs (1–3, 5 and 7–9), based on the assumption that 50% (w/w) of the spat material is mussel spat, which is an overestimation of the mussel spat quantity according to Jeffs et al. (2018). These authors investigated the composition of the spat material over three annual harvesting seasons between 2004 and 2016, and found that only 18.1% of the material on average was actually mussel spat, while the majority of the material was seaweed (48.4%); the data varied very little between the three seasons. This study has significant implications for the TACC of green-lipped mussels, which could be 2.8 times more based on the findings. This is advantageous for the growing mussel aquaculture industry, which is hindered by the limitation in spat resource.

### 4.2 Ulva (sea lettuce)

The genus *Ulva* L., commonly known as “sea lettuce”, is native to NZ and species are found in a wide range of habitats, as it is tolerant of many conditions. In NZ it thrives from the northern-most Kermadec Islands to the subantarctic islands in the south (Heesch et al. 2007, 2009), and it is among the most infamous fouling agents for ships (Schaffelke et al. 2006).
Sea lettuce is part of a traditional diet for Māori people, and it is a relatively popular food item in Scotland and Ireland (Priestly 2013). As one of the targeted commercial species in NZ, it is most commonly known as a “bad seaweed” (Nelson et al. 2015) for its ability to create “green tide” phenomena, where Ulva spp. produce massive biomass blooms in response to human activities (Heesch et al. 2007). Tauranga Harbour in the North Island and Avon-Heathcote estuary in the South have seen Ulva blooms that have negatively impacted local residents and water structures, as well as animals and plants (de Winton et al. 1992). In Tauranga, washed up sea lettuce can accumulate on the beach to around 950 t in one summer. Due to its high sulphur content, the hydrogen sulphide released from rotten sea lettuce poses health concerns to local people and animals. Tauranga regional council has budgeted NZ$ 60,000 per year to remove washed-up sea lettuce, dumping the seaweed into various commercial composters and organic orchards to help reduce pests and disease (Dean et al. 2013). Given the high cost for removal of this seaweed, creating high value products from Ulva will be beneficial both environmentally and economically. Ulvan, the sulphated polysaccharide from Ulva spp., has attracted lots of interest due to its purported anti-coagulant, immunomodulating, anti-cancer, antioxidant and anti-viral properties that are common among sulphated algal polysaccharides, as their structures mimic those of glycosaminoglycans (Kidgell et al. 2019). Interest in the extraction of fucoidan, a sulphated polysaccharide from brown seaweeds such as *U. pinnatifida* is at an all-time high. Potentially, ulvan (from *Ulva* spp.) could be an equally valuable product, and a good way to turn the rotten sulphur nuisance into health-promoting therapeutics. Selected species of *Ulva* can also serve in the bioremediation of wastewater from land-based aquaculture facilities (Lawton et al. 2013).

### 4.3 *Macroystis pyrifera*

*M. pyrifera* is found in the southern and central parts of coastal waters in NZ, mostly along the east coast and at Subantarctic islands such as Chatham Islands (Brown and Zemke-White 2006; Brown et al. 1997; Hepburn et al. 2007). It is one of the most fertile and fastest growing kelp species in the world (Schiel and Foster 2006), and commercial harvesting of *M. pyrifera* in various parts of the globe started in 1942 as a source of potassium salts (potash) (Rapson et al. 1942), alginates (Brown and Zemke-White 2006) and fertilizer (Fisheries New Zealand 2019), as well as feed for pāua/abalone (Schiel and Nelson 1990) and sea urchins (Gutierrez et al. 2006). In NZ, *Macroystis* spp. is mostly used for health food supplements and spices (kelp salt) (Schiel and Nelson 1990), and it is valued at NZ$ 15–25 per kg wholesale (Gibbons 2014).

Attached *M. pyrifera* (KBB G) was introduced into the QMS in October, 2010. Its Total Allowable Commercial Catch (TACC) (commercial, recreational, customary) remain unchanged. The combined TACC of KBB G from FMA 3 and 4 is 1500 t (wet weight) (Fisheries New Zealand 2019).

Bladder kelp is harvested all year long around NZ. The season officially starts on 1st October, and 30th September is the last day to report catch (Fisheries New Zealand 2019). Research on the impact of harvesting in NZ is sparse, and

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**Table 4: Annual landings of main commercial species in New Zealand between 2006 to 2018 (tonnes in wet weight, data released by the Ministry for Primary Industries).**

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<tbody>
<tr>
<td>Red</td>
<td>-</td>
<td>5.5</td>
<td>0.1</td>
<td>5.0</td>
<td>0.3</td>
<td>1.4</td>
<td>-</td>
<td>0.1</td>
<td>2.1</td>
<td>5.8</td>
<td>5.9</td>
<td>7.6</td>
<td>12.3</td>
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<tr>
<td>Agar weed</td>
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<tr>
<td>Pyropia spp.</td>
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<td>4.3</td>
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<td>5.0</td>
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<td>-</td>
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<td>1.9</td>
<td>5.7</td>
<td>3.4</td>
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<tr>
<td>Gracilaria weed</td>
<td>-</td>
<td>1.2</td>
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<td>0.3</td>
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<tr>
<td>Gigartina spp.</td>
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<td>0.1</td>
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<tr>
<td>Brown</td>
<td>12.1</td>
<td>5.9</td>
<td>34.6</td>
<td>45.3</td>
<td>44.4</td>
<td>67.8</td>
<td>33.5</td>
<td>50.8</td>
<td>93.9</td>
<td>63.2</td>
<td>31.5</td>
<td>51.3</td>
<td>58.3</td>
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<tr>
<td><em>Ecklonia radiata</em></td>
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<td>0.04</td>
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<tr>
<td><em>Macroystis pyrifera</em></td>
<td>12.1</td>
<td>5.9</td>
<td>34.6</td>
<td>45.3</td>
<td>43.4</td>
<td>67.5</td>
<td>32.2</td>
<td>50.7</td>
<td>93.3</td>
<td>63.0</td>
<td>31.3</td>
<td>51.1</td>
<td>58.1</td>
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<tr>
<td><em>Durvillaea</em> spp.</td>
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<td>0.2</td>
<td>0.2</td>
<td>0.8</td>
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<td><em>Lessonia</em> spp.</td>
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<td>0.8</td>
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<td>0.1</td>
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<tr>
<td>Green</td>
<td>-</td>
<td>-</td>
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<td>1.1</td>
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<tr>
<td><em>Ulva</em> spp.</td>
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<td>-</td>
<td>-</td>
<td>1.1</td>
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</tr>
<tr>
<td>Mixed beach-cast</td>
<td>211.8</td>
<td>180.0</td>
<td>214.8</td>
<td>244.6</td>
<td>316.7</td>
<td>348.8</td>
<td>334.4</td>
<td>361.6</td>
<td>204.8</td>
<td>302.9</td>
<td>448.8</td>
<td>1147.9</td>
<td>770.1</td>
</tr>
</tbody>
</table>

*Agar weed = Pterocladia lucida and Pterocladia capillacea; Gracilaria weed = Gracilaria chilensis.*
the fishery model is largely based on the Californian bladder kelp fishery (Kain 1982), where large scale harvesting for alginic production (North 1986) has been conducted. The only current restriction to bladder kelp harvest in NZ is the cutting length; the maximal allowance is set to 1.2 m.

The TACC of KGG B was established at a very conservative level. Between 2001 and 2016, the actual landing of Macrocystis spp. ranged from 5 to 104.5 t (wet weight) from FMA 3, and between 0 and 2.1 t (wet weight) from FMA 4 (Table 4), both significantly below the already conservative TACC limit of 1500 t wet weight. This indicates that the commercial harvest of this species is minimal, and all stocks are likely to still be in a virgin state (Fisheries New Zealand 2019), which allows room for larger scale harvest development. With sufficient understanding of the factors behind the biomass fluctuation through research over multiple years, it may be possible to establish a sustainable harvestable biomass for the QMS (Lotze et al. 2019).

### 4.4 Ecklonia radiata

*E. radiata* is native to NZ waters. It occurs from the Kermadec Islands at the northern end of the North Island (Nelson et al. 2018), to the Snares Islands 200 km south of the South Island (Schiel and Nelson 1990), mostly in the lower intertidal area on exposed coasts (Neill et al. 2016). *E. radiata* has important ecological significance to inshore fish and invertebrate species (Andrew and Choat 1985; Choat and Ayling 1987; Jones 1984).

Pacific Harvest, one of the most prominent food production companies utilizing seaweed in NZ, harvests beach-cast *E. radiata* for kelp seasoning, while AgriSea Ltd uses *E. radiata* concentrate for organic fertilizer and animal health supplements. In 2010, AgriSea Ltd funded research into the sustainable harvest of non-beach-cast *E. radiata* and announced a five-year research project at Hokiaega Accord Mid North Iwi Fisheries Forum (Anonymous 2010a). This research was endorsed by the then Minister of Fisheries NZ, and was carried out in Waihau Bay, the eastern Bay of Plenty over a four-to-five-year period (Anonymous 2010b) to facilitate the incorporation of *E. radiata* into the QMS. The investigative research supposedly included important ecological aspects including the reproductive cycle of the alga, and the development of sustainable harvesting tools. However, to date, the results are yet to be published, the policies around harvesting *E. radiata* remain unchanged and the combined landings of *E. radiata* from 2010 to 2019 were just 13 t (wet weight), according to data released by MPI under the Official Information Act 1982.

### 4.5 Undaria pinnatifida

*U. pinnatifida* is a kelp commonly referred to as *Wakame* in Japan, *Qundai Cai* in China and *Miyok* in Korea. It was introduced to NZ, presumably on the bottom of visiting vessels, and was first discovered at Lambton Harbour, Wellington (Hay and Luckens 1987). *U. pinnatifida* is classified as an “unwanted organism” and managed by Biosecurity NZ under the Biosecurity Act 1993.

Since its first appearance, *U. pinnatifida* steadily spread throughout NZ and is currently found mainly on the East Coast, from the Hauraki Gulf in the north, to Stewart Island in the south. There have been multiple attempts to eradicate this seaweed from various locations by the Ministry of Agriculture and Forestry (MAF) and its successor MPI, as well as the Department of Conservation (DoC). A National pest management strategy for *U. pinnatifida* was proposed by MFish, in which all commercial harvesting of *U. pinnatifida* was banned (MAF 2009). In 2004, the restrictions around harvesting *U. pinnatifida* were loosened, and harvesting the seaweed as a by-product of another activity (e.g. mussel harvesting) was allowed (MAF 2009); subsequently, commercial harvesting of *U. pinnatifida* from mussel farms was permitted in 2010, and the decision was made based on the inevitability of physical contact between mussel farmers and *U. pinnatifida* during mussel harvesting. The changes are summarised in Table 5. There was hope that this invasive species could be turned into commercially viable products that would compensate the losses for marine farmers (MAF 2010).

While a permit is compulsory when undertaking commercial harvesting of *U. pinnatifida*, reporting the landing is not. This makes it difficult to determine the current NZ harvest volume. However, while there is no empirical information on *U. pinnatifida* use, there are some publicly known NZ stakeholders that have been utilising the seaweed since 2004. KiwiWakame Ltd. is a food producer based in Invercargill. Employees hand-pick *U. pinnatifida* from Stewart Island and Foveaux Strait for food and fucoaidan production. NZ Kelp Ltd. have been

<table>
<thead>
<tr>
<th>Activity</th>
<th>2004</th>
<th>2010</th>
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<tr>
<td>Harvesting from artificial structures</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Harvesting as beach-cast, despite not being part of a control programme or by-product</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Farming in heavily infested farming areas, despite not being part of a control programme or by-product</td>
<td>No</td>
<td>Yes</td>
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harvesting giant kelp for Paua feed and are most enthusiastic about farming *U. pinnatifida* (Campbell Live 2012). Auckland-based company Pacific Harvest manufactures seasonings and other innovative food products based on seaweeds including *U. pinnatifida* (Seafood New Zealand 2006). Waikaitu Ltd. has established a key business of harvesting *U. pinnatifida* by lifting mussel lines and hand-harvesting in the Marlborough region. They have been vocal about their passion for turning the local pest into organic fertilisers. They also provide *U. pinnatifida* as a raw ingredient to a number of NZ companies including Ecostore, Zeavida and Enzalg Biosiences who produce cosmetic and health supplements containing fucoidan. Most recently Wakame Fresh Ltd received NZ$ 75,000 government funding towards turning the pest seaweed into a premium food export (Tantau 2019).

5 The future of commercial seaweed uses in NZ

Commercial use of seaweed worldwide includes the development of food products, hydrocolloids (food additives), health products, fertilizer, animal feed and biofuel. Restricted by the size of population, a lack of seaweed-harvesting using culture locally, and the current distance from the world seaweed market, the future of NZ commercial seaweed industry lies in producing high-value/value-added products for an export market (Hurd et al. 2004, Angeloni 2018).

While the red seaweeds *P. lucida*, *P. capillacea* and *Gigartina* spp. contributed to over 31% of the seaweed use from the 1980s as sources for agar and carrageenans in NZ (Miller 1999, Falshaw et al. 2003), brown seaweeds *M. pyrifera* and *Durvillaea* spp. were mostly harvested for fertilizer and alginates (McKee et al. 1992, Hay 1994). Liquid seaweed fertilizers, which were traditionally destined for the United States of America, Australia and Brazil since the 1980s, have gained traction in the domestic market in recent years, with consumers and producers seeking greener alternatives to chemical fertilizers (Tauntan 2018), and will continue to grow as an important part of the commercial seaweed market in NZ and internationally.

High-value health products fucoidan and fucoxanthin can also be extracted from *U. pinnatifida* and other brown algal species. These ingredients can be added to functional foods for additional health benefits that exceed basic nutrition. The development of functional foods, for risk management of chronic diseases, heart diseases, prevention of cancer and enhancement of the growth/ performance of children, has a net worth of over US$ 130 billion worldwide in 2015, with Asia being the largest market (White et al. 2014). *U. pinnatifida* was identified as one of the seaweeds with the most potential as functional food (White et al. 2014), having higher quality protein than other brown and red seaweed species, as well as a competitively high proportion of polyunsaturated fatty acids such as oleic acid, linoleic acid and linolenic acid (Dawczynski et al. 2007).

To produce consistent and large amounts of high-quality and value-added products, seaweed farming is imperative. Currently, there is growing interest in using *U. pinnatifida* in NZ; initially it was from the wild harvesting from the many mussel farms around NZ. This activity has already led to several commercial ventures. However, one of the issues with this product is its variability in quality. There are many different haplotypes of *U. pinnatifida* found in NZ, which most likely indicates multiple introductions (Uwai et al. 2006). These different forms of *U. pinnatifida* may well be suited to an extracted product of higher value (e.g. fucoidan and fucoxanthin), yet unsuitable for a food product (e.g. wakame) destined for Asian markets, where the consistency of the blade form and texture are important, and can be achieved through selective breeding when farmed as opposed to wild-harvested.

There is considerable interest in seaweed farming from a range of quarters in NZ, though the interest has yet to materialize in actual farming activities (Angeloni 2018). Over the last two years, the Nelson Marlborough District Council has had a “Smart and Connected” initiative, with one strand focused on increasing the value of marine farms. The District council, MPI and existing mussel farmers recognised that *U. pinnatifida* could provide an additional revenue stream for mussel farmers, as it could be possible to grow both species on the same farm at the same time. The initiative led to a working group of interested parties, who have since developed biosecurity plans for *U. pinnatifida* farming, and lodged an application with MPI to change the regulations to enable them to issue permits to farm *U. pinnatifida*.

Kelp farming including species such as *E. radiata* and *Macrocystis* spp. also have huge implications for environmental preservation. Seaweed aquaculture can sequester carbon dioxide and serve as an alternative source for biofuel to ease the demand for fossil fuels (Sondak et al. 2017).

6 Conclusion

NZ, with an abundance of coastal waters and seaweed species, and a temperate, clean, green oceanic
environment, has every potential to offer the international market high quality seaweed stocks, as well as value-added algal products such as fucoidan. Our seaweed industry is small but growing, currently based on wild harvest, with farming on the horizon, and backed by rising ambitions which call for more supportive government policies.

The rising trend globally of “clean”, “natural”, and “organic” health products, as well as a growing Asian population and its influence in NZ has raised the profile of the seaweed industry among the general public and the wider fishery industry (Gibbons 2014). Its success will depend on incorporating innovative technologies, integrated processes of farming, extraction and production, marketing to our strengths, which include the clean and green, sustainable philosophy and an appreciation of that image internationally.

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