Development of a seaweed food safety program

by Clare Winkel, Integrity Compliance Solutions
April 2022

AgriFutures® Emerging Industries

Development of a seaweed food safety program

to meet the requirements of Food Standards Australia New Zealand and third-party hazard analysis and critical control points certification

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Foreword

The Australian seaweed industry is small but growing rapidly and has a gross value of production of $3 million. Australia is a net importer of seaweed at about $40 million, of which 85% is for human consumption. Other uses include for animal feed, fertilisers, cosmetics, pharmaceutical products and biofuels. Seaweed-based food products are sold in Australia online, at retail stores and markets, in restaurants, and to food processors.

In 2019, there were more than 36 food safety recalls/import alerts for seaweed-based foods globally, and Australia instigated 50% of these recalls/alerts. All Australian food producers must meet section 3.2.1 (Food safety programs) of the *Australia New Zealand Food Standards Code* as a minimum, but many local food safety authorities and regulators have little to no understanding of seaweed food safety hazards.

The primary objective of this project was to develop a food safety program for the Australian seaweed processing industry specifically covering seaweed for human consumption. The program outlines the potential food safety hazards that could occur in seaweed-based food products. Two case studies for land-grown and wild-collected seaweed food products are provided. Further, a food safety management system was developed to guide seaweed processors on meeting and exceeding market requirements. The management system has worked examples of management procedures, policies, forms and schedules required for third-party hazard analysis and critical control points (HACCP) certification. As well as using the management system as a guide, it is recommended seaweed growers and processors expand their knowledge of state and federal food safety regulations that apply to their business.

This project was completed as part of the AgriFutures Emerging Industries Program, which focuses on new industries with high growth potential. Emerging animal and plant industries play an important role in the Australian agricultural landscape. They contribute to the national economy and are key to meeting changing global agricultural product demands. Most of AgriFutures Australia's publications are available for viewing, free download or purchase online at www.agrifutures.com.au

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Clare Winkel is the Executive Manager – Technical Solutions with Integrity Compliance Solutions. Clare has worked in the food industry since 1987 across 14 countries, including those in Europe, North America, the Caribbean and the South Pacific.

Clare brings a unique perspective through working as a process line worker part-time while studying for her undergraduate degree, as a researcher with CSIRO, and as a consultant and third-party certification food safety auditor. This enables her to work with and find solutions for people working at all stages of the food supply chain. She has specialised in the seafood sector and became interested in seaweed for human consumption while working in Ireland (2006-2008) and attending conferences in countries like Iceland (2017).

Clare is passionate about growing the seaweed industry in Australia and supporting safe, thriving food communities. Clare has an MBA, a Bachelor of Applied Science (Biology) and an Export Management Diploma, and was awarded by the International Association of Fish Inspectors for Services to the International Seafood Industry in 2013. She was also highly commented in the 2003 Queensland Premier's Awards, in the category Public Sector Management – Partnerships and Reconciliation, for designing and delivering a series of practical training courses for Indigenous seafood processors across the Torres Strait in 2003.

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Abbreviations

ASC-MSC	Aquaculture Stewardship Council-Marine Stewardship Council, an internationally recognised United Kingdom (UK)-based third-party audited seafood sustainability management standard. See: https://www.asc-aqua.org/what-we-do/about-us/about-the-asc/
BRCGS	Brand Recognition Compliance Global Standard (previously known as the British Retail Consortium Standard), an internationally recognised UK-based third-party audited food safety management standard. See: https://www.brcgs.com/our-standards/food-safety/
Codex	Codex Alimentarius Commission, an international food-standards-setting body established by the Food and Agriculture Organization of the United Nations and the World Health Organization. Codex develops international food standards, guidelines and codes of practice for an international food code that contributes to the safety, quality and fairness of food trade. See: https://www.fao.org/fao-who-codexalimentarius/committees/cac/about/en/
EU	European Union.
FAO	Food and Agricultural Organization of the United Nations. See: https://www.fao.org/home/en
FSSC 22000	Food Safety System Certification 22000, an internationally recognised European Union-based third-party audited food safety management standard. See: https://www.fssc22000.com/
FSANZ	Food Standards Australia New Zealand. See: https://www.foodstandards.gov.au/code/Pages/
GFSI	Global Food Safety Initiative, an organisation that benchmarks different third-party audited food safety management standards for equivalence. See: https://mygfsi.com/how-to-implement/certification/
HACCP	Hazard analysis critical control point, a risk assessment method created by NASA in the 1960s and used in the food industry to reduce or eliminate food safety hazards.
MRL	Maximum residue limit.
SQF	Safe Quality Food, an internationally recognised United States (US)-based third-party audited food safety management standard. See: https://www.sqfi.com/resource-center/sqf-code-edition-9-downloads/

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What the report is about?

Seaweed-based food products are being sold in Australia online, at retail stores, at markets, in restaurants, into food service and to food processors. This report outlines the potential food safety hazards that could occur in seaweed-based food products as identified in existing publications, and presents two case studies of seaweed food processors in New South Wales (NSW).

Using the information contained in the case studies (land-grown and wild-collected seaweed), two example food safety hazard analysis critical control point (HACCP) plans were developed and complement this report. These food safety plans meet the requirements of the *Australia New Zealand Food Standards Code* (section 3.2.1).

To help small processors of seaweed-based food products meet market requirements that are over and above the regulations (i.e. obtain third-party HACCP certification), an example food safety management system manual was also developed and is available to processors on request to AgriFutures Australia.

Who is the report targeted at?

The report aims to provide value to existing small seaweed collectors and growers wanting to expand their activities and market access. The report is also targeted at food processors who want to use seaweed as an ingredient and are interested in validating the food safety status of the raw material supplied. Further, it is anticipated federal, state and local government food safety officers and researchers will want to expand their knowledge on the topic; this report can help them regulate and assist the Australian seaweed industry.

Background

Australia is a net importer of seaweed in this global growth market. Imports into Australia in 2017-18 approached $40 million, of which 85% was for human consumption. In 2019, there were more than 36 recalls/import alerts for seaweed-based foods worldwide, with Australia instigating 50% of these.

Currently, there is a small number of Australian seaweed processors producing food products, either as bulk wholesale ingredients or finished retail-ready products, using land-grown or wild-collected seaweeds. All Australian food producers must meet section 3.2.1 (Food safety programs) of the *Australia New Zealand Food Standards Code* as a minimum, but most local food safety authorities and regulators have little to no understanding of seaweed food safety hazards, and so do not inspect the premises where these products are being produced.

Objectives

The primary objective of this project was to develop a food safety program for the Australian seaweed processing industry specifically covering seaweed for human consumption. The program was required to meet market, industry stakeholder and consumer food safety standards and requirements, and be the basis of a readily adoptable program that seaweed processors can implement.

Methods used

The project objective was achieved by undertaking the following six major activities:

1. Conduct a literature review
2. Conduct a regulatory review covering the processing of seaweed/aquatic plants
3. Undertake stakeholder identification, engagement and awareness
4. Develop a food safety program that covers seaweed receival, processing and dispatch, considering several process types
5. Undertake a field assessment of transport, delivery and processing of seaweed to enable development of process maps using current manufacturing practices (this activity involved stakeholder review to approve the draft food safety program)
6. Develop food safety management system documentation.

Key findings

The literature review identified that potential food safety hazards in seaweed for human consumption include inorganic arsenic, cadmium, iodine and *Salmonella*. Hazards should be carefully assessed, as should other pathogenic bacteria. There are considerable food safety concerns related to potential adverse events associated with seaweed consumption.

With regards to legislation, there is much inconsistency between state government and local government regulations regarding seaweed collection, with each set of regulations containing different daily take limits and rules. Further, different parts of the *Australia New Zealand Food Standards Code* are contradictory regarding whether seaweed collectors and processors are required to work under a documented food safety program. This has led different state regulators perceiving either no one is processing seaweed for human consumption or the sector does not need to work under a food safety program.

The maximum residue limit (MRL) for iodine in seaweed for human consumption is different for products imported into Australia and products made in Australia. In October 2010, the maximum level of iodine in imported brown seaweed of the *Phaeophyceae* class at the Australian border was set at 1000 mg/kg, while there is no limit specified in FSANZ Schedules 19 and 20.

Stakeholders have been confirmed and identified, and a seaweed industry stakeholder database has been developed. Conference presentations in Australia and overseas have also been completed, and there are more planned to communicate the outcomes of the project.

HACCP plans/food safety programs have been developed for two industry case studies, land-grown sea lettuce (*Ulva* spp. Ulvophyceae) and wild-collected golden kelp (*Ecklonia radiata*). Food safety hazards and implemented controls were identified during this process. Worked examples of additional management procedures, policies, forms and schedules as required for third-party HACCP certification were developed to assist a seaweed processor with achieving certification.

Implications for relevant stakeholders

Consolidating information from the literature and regulatory review, communicating with stakeholders and developing the food safety program has highlighted a number of implications for industry regarding producing seaweed products for human consumption:

- Pathogens from the harvest area (*Vibrio* spp., *Salmonella* spp., haemorrhagic *E. coli* species, norovirus and hepatitis) are potentially significant as the seaweed may be intended to be consumed as a raw product, without any additional processing/kill steps.

- Naturally occurring toxins from the harvest area have been responsible for health problems related to the consumption of several *Gracilaria* species. These toxins are often heat-stable, meaning even if seaweed is heated, the toxin will remain in the final processed product.

- Environmental contaminants are also potentially significant chemical hazards because certain species of seaweeds exhibit a high affinity for accumulating heavy metals and other contaminants in their tissues. As most published data has been generated from analysing northern hemisphere species, the heavy metal contaminants in the review might not be as relevant within the Australian context. But other hazards were identified, including potential microbial, allergenic and physical contaminants.

- There is a worldwide lack of knowledge of how and why iodine is absorbed by different species at very different rates, and the possible controls to minimise inconsistent iodine levels in raw products.

- Beach collection of seaweed is controlled at either a state government or local government level, and each set of regulations contains different daily take limits and rules. This means in certain states it is harder to set up a small seaweed-based food company. As a result, certain species of edible seaweeds that are readily growing in some states cannot be collected and processed into a food product, even though an Australian market exists and is being supplied with imported products.

- There is much inconsistency even within federal regulations regarding the requirement to document food safety programs in the sector. Section 3.2.1 of the *Australia New Zealand Food Standards Code* states all food businesses, other than primary producers, must have a written food safety program. However, this conflicts with sections 4.1.1 and 4.2.1, which explicitly exclude seaweed growing, collecting or processing. This inconsistency makes it difficult for industry to know exactly what is required, and makes application of the law by state or local government officers problematic.

Recommendations

It is important Australian seaweed industry participants consider the information in this report, as this will help them maintain food safety best practices when producing seaweed products for human consumption, even with the state of regulatory inconsistency and food safety issues identified.

It is recommended state and federal food regulators be made more aware of the Australian seaweed processing industry, as this would enable regulators working in different jurisdictions to collaborate on the identified regulatory issues and assist the growth of the industry.

Industry should also be provided with clarity on:

- The limits and controls on beach collection of seaweed in Australia, as there are inconsistent regulations for collecting seaweed

- The differing definitions (i.e. food processors vs primary production) and requirements contained in different sections of the *Australia New Zealand Food Standards Code*

- Which business types need to operate under a written food safety program.

Further work should be undertaken to identify potential controls at processing to reduce excessive iodine content in the processed seaweed. Future research projects could investigate:

- The iodine content of different species and different parts of the plant
- The ideal seaweed plant age at harvest
- The ideal environmental conditions at harvest
- The impact of rainfall in the harvest area
- The ideal rinsing water temperature and time.
- Blanching seaweed before drying.

The food safety program (contained in this report) and the HACCP plans and food safety purchasing guide (complementary to this report) developed as part of this project should be promoted for use by industry.

Consideration should also be given to the future development of a certifiable standard specific to seaweed-based food products that covers food safety hazard identification and controls.

Introduction

Australia is a net importer of seaweed in this global growth market. Imports into Australia in 2017-18 approached $40 million, of which 85% was for human consumption. There is potential for the Australian seaweed industry to have $10 million gross value of production by 2027. Currently, however, there is only a small number of Australian seaweed processors producing food products, either as bulk wholesale ingredients or finished retail-ready products, using land-grown or wild-collected seaweeds.

China is the world's largest supplier of seaweed products, supplying 60% of global production, of which 2% is wild harvested. Indonesia ranks second, followed by the Philippines and South Korea. The South Pacific islands grow approximately 500 different species of sea vegetables, of which at least 100 are edible, but each country in the region only consumes about 8-10 different species.

In 2019, there were more than 36 recalls/import alerts for seaweed-based foods worldwide and Australia instigated 50% of these recalls/alerts. These recalls indicate potential food safety hazards within seaweed-based food products, but almost no research has been undertaken on seaweed species in the southern hemisphere, especially in the South Pacific.

To meet existing Australian food safety regulations, food processing businesses must implement written food safety programs. But to do so, the processor must identify all potential food safety hazards, and then put in place processes to control them.

This project builds on the work undertaken for AgriFutures Australia by Dr Pia Winberg, who authored the 2017 report *Best Practices for the emerging Australian seaweed industry* (Winberg, 2017). It is hoped this project can encourage greater consideration of the food safety aspects of the diverse range of seaweed species available for human consumption.

The project scope covers identifying potential food safety hazards in seaweed-based human food production systems and developing two example food safety programs, but does not cover seaweed production for animal feed or the production of seaweed for alginate, carrageenan or agar.

Two seaweed products were considered: land-grown sea lettuce, harvested and processed to dried granules for use as an ingredient in processed food; and beach-collected, wild-grown golden kelp, processed to dried flakes for use as an ingredient in processed food.

The management system documentation developed will assist industry with achieving commercial third-party hazard analysis critical control point (HACCP) certification.

Objectives

The primary objective of this project was to develop a food safety program for the Australian seaweed processing industry specifically covering seaweed for human consumption. The program was required to meet market, industry stakeholder and consumer food safety standards and requirements, and be the basis of a readily adoptable program that seaweed processors can implement. It was also intended the food safety program would provide guidance to regulators and industry.

Methodology

The project objective was achieved by undertaking the following six major activities:

1. **Conduct a literature review**

   The literature review involved researching the known food safety issues in the seaweed sector and reviewing current regulation to identify potential food safety hazards for seaweed species currently under commercial production within Australia.

2. **Conduct a regulatory review covering the processing of seaweed/aquatic plants**

   The regulatory review focused on state and federal food safety and seaweed regulations so as to inform the food safety plan for the sector. Beach collection legislation and contamination limits were also reviewed.

3. **Undertake stakeholder identification, engagement and awareness**

   A stakeholder analysis identified key stakeholders as a mechanism to facilitate awareness of and engagement with project. A webinar with industry stakeholders, including a number of interested overseas parties, was held. A stakeholder communications report was documented as a standalone report, and a database of seaweed industry contacts was developed. Preliminary project findings have been presented at two conferences, in Australia and the US, and at the time of writing four more conference presentations have been planned (Australia and overseas) to communicate project findings.

4. **Develop a food safety program that covers seaweed receival, processing and dispatch, considering several process types**

   HACCP plans/food safety programs were developed for two industry case studies processing different seaweed species (land-grown *Ulva* spp. Ulvophyceae and wild-collected golden kelp (*Ecklonia radiata*) into food products. The HACCP plans/food safety programs document the product specifications; process steps to identify significant food safety hazards; risk assessment of the process steps; critical control points and associated critical limits; monitoring criteria and records; expected corrective actions; a verification schedule; and a validation table.

5. **Field assessment of transport, delivery and processing of seaweed, to develop a process maps using current manufacturing practices with stakeholder review to approve the draft food safety program**

   Visits to growing, collecting and processing sites in southern NSW were undertaken for the two case studies. All aspects of the HACCP plans were reviewed. This included confirming and verifying each process step within the flow chart; identifying food safety hazards; reviewing implemented control measures; reviewing lab testing records; and reviewing equipment and documentation (procedures, forms and monitoring records).

6. **Develop food safety management system documentation**

   Worked examples of additional management procedures, policies, forms and schedules were then designed and documented. These documents are the basis of third-party HACCP certification and can assist a seaweed processor with achieving certification.

1. Potential food safety hazards in seaweeds for human consumption

Seaweeds are photosynthetic, non-flowering, plant-like organisms called macroalgae that live in the sea. They are classified into three major groups based on their dominant pigmentation: red (Rhodophyta), green (Chlorophyta), and brown (Phaeophyceae; phylum: Ochrophyta). Red seaweeds consist of about 6,000 species and brown seaweeds consist of about 1,750 species. Green seaweeds consist of about 1,200 species (Muñoz and Díaz, 2020).

Farmed brown seaweeds are often used for foods such as kombu soup and wakame salads. *Gracilaria* and *Kappaphycus/Eucheuma* are used as a soup ingredient for soups and as sushi wrapping (FAO, 2022). The following seaweed-based foods have been identified as being consumed in the South Pacific islands: raw salads, raw in coconut milk, blanched with sauces, dried and flaked used seasonings, raw in vinegar, and as the base for mayonnaise, cooked vegetables, soup, jellies, tea, lollies, sweet puddings and pie (Novaczek and Athy, 2001).

A literature review was undertaken of known food safety issues in the seaweed sector and a review of current regulation was conducted to identify potential food safety hazards for the seaweed species currently under commercial production in Australia. As part of the literature review, a search was undertaken using the Horizon Scan database to identify all government recalls and border rejections of seaweed-based food products. The search ranged from 2000 to 2022 and identified the following food safety issues, in order of magnitude:

- Iodine: **265** incidents across 2000-2022
- Inorganic arsenic: **64** incidents across 2000-2022
- United States import refusals: **35** across 2002-2021, including labelling failure, processing failure, 'filth' and unauthorised colours
- Cadmium: **13** incidents across 2005-2020
- *Salmonella*: **11** incidents across 2011-2018.
- *E. coli* O7:H4: **3,000** school students and staff in Japan affected in 2020 (red seaweed salad)
- Chemical hazards: Nitrofurans, sulphites, benzopyrene and aluminium
- Unauthorised colours
- Unauthorised irradiation
- Microbiological organisms – listeria, mould and coliforms
- Allergens (undeclared) – soy, gluten and sesame
- Fraud – documentation (labelled as organic from North Korea in 2020) and species substitution (Vietnam in 2021).

Not all these issues represent actual food safety incidents, and some are a strong reflection of specific government regulations. The recalls/rejections from Australia (51 incidents) make up almost 10% of all incidents identified (546).

Banach *et al*., in their 2020 study of food safety hazards in the European seaweed chain, concluded there were 22 food safety hazards, ranked as major (4), moderate (5) and minor (13). Inorganic arsenic, cadmium, iodine and *Salmonella* were identified as major hazards (Banach *et al*., 2020a, 2020b).

The following hazards were identified as having data gaps and should be further risk assessed: pesticide residues, dioxins, polychlorinated biphenyls, brominated flame retardants, polycyclic aromatic hydrocarbons, pharmaceuticals, marine biotoxins, allergens and nanoplastics. Additional pathogenic microbiological hazards identified as needing consideration were norovirus and hepatitis E virus (Banach *et al*., 2020a, 2020b).

Microbiological hazards

The microbiological hazards of concern based on the Horizon Scan data were *Salmonella* spp., *E. coli* O7:H4 and *Listeria* monocytogenes, and in the review of the European seaweed chain were *Salmonella*, norovirus and hepatitis E (Banach *et al*., 2020a, 2020b).

Norovirus and other foodborne diseases stemming from humans handling the seaweed were the result of a lack of personal hygiene controls (FAO, 2022; Løvdal *et al*., 2021). During development of their HACCP plan, University of Connecticut researchers identified the following microbiological hazards: *Vibrio* spp., *Salmonella*, *E. coli* O157:H7, shigella, norovirus and hepatitis (Concepcion *et al*., 2020). These hazards were identified as coming from the harvest areas. *Salmonella, Vibrio* spp. and *E. coli* O157:H7 were identified as being of concern in Maine, US and were the result of human activities in the vicinity of the harvest areas (Barberi *et al*., 2020).

Haemorrhagic *E. coli* species differ across the world. In North America, *E. coli* O157:H7 dominates within the cattle industry but is then spread to fresh produce via water courses. It is likely that agricultural runoff is the source of this contamination in North American coastal waters. The *E. coli* species O111:H is found in Australia.

Other authors have identified seaweed as being a reservoir for *Vibrio* spp. (parahaemolyticus and vulnificus) in summer in Norway (Blikra *et al*., 2021), with presence of the pathogen dependant on the harvest water temperature. This indicates the warmer the harvest water temperature, the more likely it is that this pathogen could occur. Interestingly, both Løvdal *et al*. and Barberi *et al*. concluded bacterial count and species type in harvested seaweed did not always correlate to that in the water where the seaweeds grew.

Pathogens from harvest areas are potentially significant because the seaweed may be intended for use as a raw product for human consumption, without any additional processing step that would kill them off (Concepcion *et al*., 2020). Pathogens including *Vibrio* spp, *Salmonella* and *E. coli* can be killed through heating, but not all seaweed food products are heat treated to a high enough temperature (66 °C to kill *Salmonella*), even during the drying process. These pathogens must be considered as potential hazards for all seaweed grown in coastal seas, wild or farmed (Løvdal *et al*., 2021).

The pathogenic bacteria *Clostridium botulinum* occurs naturally in the marine and estuarine environment, and can become a highly dangerous toxin under specific circumstances. The circumstances require a lack of other competing bacterial populations and reduced oxygen. These circumstances can occur if seaweed products are raw and packaged in a modified/reduced-atmosphere package (e.g. vacuum packed). Products that have been effectively dried are usually considered shelf-stable and can be stored unrefrigerated. The key control is to ensure seaweed products have been dried to the point where live bacteria are killed (Concepcion *et al*., 2020; Løvdal *et al*., 2021).

Chemical hazards

The chemical hazards of concern based on the Horizon Scan data were iodine, inorganic arsenic, cadmium, nitrofurans, sulphites, benzopyrene, aluminium and undeclared allergens. In the review of the European seaweed chain, inorganic arsenic, cadmium and iodine were designated as major hazards, followed by pesticide residues, dioxins, polychlorinated biphenyls, brominated flame retardants, polycyclic aromatic hydrocarbons, pharmaceuticals, marine biotoxins and allergens as minor hazards (Banach *et al*., 2020).

There are considerable safety concerns related to potential adverse events associated with seaweed consumption, particularly given the variable and potentially dangerously high concentrations of iodine and heavy metals (including inorganic arsenic) in certain seaweeds (Holdt *et al*., 2011; Suleria *et al*., 2015). Heavy metals and chemicals from the environment are potentially significant food safety hazards because certain species of seaweeds exhibit a high affinity for accumulating heavy metals and other contaminants in their tissues (Concepcion *et al*., 2020).

There is little information is available on the toxic mineral composition of edible seaweeds. Thus, it is important for countries with edible seaweed production to investigate the presence of heavy metals in seaweeds grown under particular conditions and in certain environments (Muñoz *et al*., 2020). The time spent growing in the sea and the levels of heavy metals in the water should be considered (Ortega-Calvo *et al*. 1993; Smith *et al*., 2010). The types and concentration of metals found in seaweed vary and depend on species, collection time, growth phase and collection site (Se-Kwon Kim, 2011; Smith *et al*., 2010).

There is currently limited legislation to require food or supplement companies to disclose the mineral, heavy metal or iodine content of seaweed products, or to provide guidance on a safe portion size of certain whole seaweeds to prevent excessive consumption (Holdt *et al*., 2020; Suleria *et al*., 2015; FAO, 2018).

Arsenic is a naturally occurring element that can be introduced into food from natural sources and as a result of human activities. In general, brown algae have higher arsenic levels than red or green algae (Almela *et al*., 2002). International food regulatory agencies have issued warnings about the inorganic arsenic content of hijiki seaweed (*Sargassum fusiforme*). Food Standards Australia New Zealand (FSANZ) issued a similar warning in 2004 and border inspection requirements were tightened to target all shipments of hijiki seaweed. The warnings, however, do not apply to other edible seaweeds, such as arame (*Eisenia bicyclis*), nori (*Porphyra* spp.), kombu (*Laminaria* spp.) and wakame (*Undaria pinnatifida*). In 2010, 48 seaweed-based food samples were collected from retailers and tested by the NSW Food Authority. One dried seaweed product contained inorganic arsenic at the level of 38 mg/kg. The product has been withdrawn and is no longer imported into Australia (NSW Food Authority, 2010).

Phycotoxins are naturally occurring toxins in seaweed that occur within the harvest areas. These are produced by harmful microalgae species that can be present in seaweed harvest areas. The risk from these algae blooms is likely to increase with climate change-induced ocean conditions, such as higher temperatures and ocean acidification (FAO, 2022). Health problems related to the consumption of several *Gracilaria* species have been known to occur. These toxins are often heat-stable and even if seaweed is cooked/dried, the toxin will remain in the final product (Concepcion *et al*., 2020).

Allergenic reactions to consumption of seaweeds are known to have occurred, but currently no seaweed species is listed as an official allergen in any country (FAO, 2022; Novaczek, 2001). What is clear is that small crustaceans and molluscs co-exist and grow on seaweed during farming and in the wild (FAO 2022; Concepcion *et al*., 2020). Collectors of any seaweed grown in the sea must consider and control the hazard of attached crustaceans and molluscs.

The iodine content of seaweeds is highly variable and depends on factors such as species, plant area, stage of growth, season and location. Seaweeds can concentrate up to 30,000 times the iodine content of seawater. In general, the iodine content of brown seaweeds is greater than that of red or green seaweeds (Smyth, 2021; Marthe *et al*., 2019). In addition to their total iodine content, the bioavailability of the iodine and losses in cooking must be considered when determining iodine intake from seaweeds (Smyth, 2021).

European algae have higher iodine concentrations than analysed Asian algae. Significant differences were detected between the iodine content of European wakame algae and wakame algae from Asia. Kombu algae contain amounts of iodine higher than wakame algae (González *et al*., 2020). Almost all available published research has been undertaken on northern hemisphere species (Marthe *et al*., 2019).

In 2011, FSANZ published the results of a survey that investigated iodine levels in seaweed and seaweed-containing products (FSANZ, 2011). Iodine levels varied between red and brown seaweed, but were generally higher in brown seaweed. The iodine concentrations in wakame and nori seaweed were generally low. Some other dried seaweed types had high iodine levels and were considered unsafe for human consumption.

This survey was undertaken following a national food safety incident sparked by an increased number of reported human thyroid dysfunction cases (caused by high iodine intake). The cases were linked to consumption of a particular brand of soy beverage (Bonsoy) that contained a high level of iodine. The contamination occurred because of seaweed (kombu; *Laminaria* spp.) being added during manufacturing.

Physical hazards

Very little information was unearthed during the literature review regarding potential physical hazards. The only physical hazard discussed was that of nano/microplastics, defined as plastic particles smaller than five millimetres, which are now common throughout the marine environment. Such particles are prone to accumulate organic contaminants, which can be adsorbed into macroalgae, potentially introducing the particles and their associated contaminants into animals or humans. The possible implications of this, however, are not known (FAO, 2022; Duinker *et al*., 2016).

During development of the food safety program produced as part of this project, it was identified that physical contamination (sand, stones, shells, marine debris) is the most common form of food safety contamination in beach-collected seaweed.

2. Australian regulatory review

The regulatory review focused on Australian food safety programs and food contaminant regulations, as well as state government regulations for the beach collection of seaweed.

Australian food safety regulations

The general approach by even the most diligent state regulators can be summed up by an email received explaining why seaweed processors do not need to implement a written food safety program:

> Currently, producers of seaweed would not be required to be accredited or implement a food safety program (FSP) but must comply with the requirements of the Food Standards Code and the generic provisions of the *Primary Produce Act* (PPP).
>
> This state only requires FSPs for high-risk primary production and processing activities. The PPP activities … are the activities that are covered by Chapter 4 of the Food Standards Code. Further to this, under the state *Food Act* (regulated by Department of Health and local government), the only facilities that are required to have a FSP are the facilities that cater for vulnerable populations (nursing homes, childcare centres and hospitals).
>
> As the Department does not accredit these (seaweed) producers … producers would only need to show that they meet the requirements of the Food Standards Code [i.e. heavy metals compliance etc].
>
> Under the Marine Resources Act, we don't regulate use/end products of the beach-cast kelp collected, however we don't consider it suitable for human consumption as there are no limits on how fresh the harvested kelp is and we don't test chemical/element limits, although the individual businesses may. Most of the kelp is used to make fertiliser or mulch, or it is dried/granulated and exported for alginate.

The assumptions made are that seaweed businesses fall under the *Primary Production Act* and that no one is processing seaweed for human consumption, particularly for consumption within the state, despite a number of parties doing exactly that and openly selling product directly to consumers.

Understanding the definitions of "processors" and "primary producers" contained in the *Australia New Zealand Food Standards Code* is essential to identify which part of the Code is relevant for each business type. In the Code, section 3.2.1 states all food businesses, except for primary producers, require a written food safety program. Section 3.1.1 states that primary production does not include substantial transformation of the food, such as manufacturing. The conclusion is any food business manufacturing seaweed into food products for human consumption ***should*** have a written food safety program.

Under section 4.1.1 (the primary production chapter of the Code), the stated scope for that section includes processing, manufacturing, preparing, treating, preserving, packing and cooking. It also states that where a standard in this chapter provides that a person or business is required to comply, then that business must have and operate under a food safety management statement. The conclusion is that any food business that is "preparing, treating, preserving, packing and cooking" seaweed into food products for human consumption ***should*** have a written food safety management statement.

However, a key problem is that no part of section 4 includes seaweed growing, collecting or processing. Section 4.2.1 (seafood) specifically excludes edible seaweeds. The conclusion is then that seaweed businesses ***do not*** need a written food safety management statement.

There is a conflict between different parts of the Code on what constitutes "primary production" activities, and which business types need to operate under a written food safety program.

The specific requirements of a "food safety program" and a "food safety management statement" also differ. A food safety program is defined in section 3.2.1 as "a food safety program that satisfies the requirements of clause 5." Clause 5 requires that a food safety program must:

a) systematically identify the potential hazards that may be reasonably expected to occur in all food handling operations of the food business;

b) identify where, in a food handling operation, each hazard identified under paragraph (a) can be controlled and the means of control;

c) provide for the systematic monitoring of those controls;

d) provide for appropriate corrective action when that hazard, or each of those hazards, is found not to be under control;

e) provide for the regular review of the program by the food business to ensure its adequacy; and

f) provide for appropriate records to be made and kept by the food business demonstrating action taken in relation to, or in compliance with, the food safety program.

Under section 4, however, a food safety management statement is one that, at a minimum, has been approved or recognised by the relevant authority and is subject to ongoing verification activities by the business or person, and, if required by the authority, subject to ongoing verification activities by the relevant authority.

Australian food contaminate regulations

Australia has regulations for several seaweed chemical hazards identified in this project, including inorganic arsenic, cadmium and lead. Section 1.4.1 of the *Australia New Zealand Food Standards Code* (Contaminants and natural toxicants) lists the maximum levels for lead at 0.01 mg/kg and cadmium at 0.005 mg/kg, with cross-reference to Schedule 19 for the maximum allowable levels of contaminants and natural toxicants.

Schedule 19 lists the maximum allowable level of inorganic arsenic in seaweed as 1 mg/kg, and lists the maximum allowable levels of cadmium (0.1 mg/kg) and lead (0.1 mg/kg), but these limits are not specific to seaweed.

No regulation describes the maximum allowable level of iodine in Australian-produced seaweed, despite iodine levels in imported brown algae/seaweed vegetables being regulated. The maximum level of iodine in imported brown seaweed of the Phaeophyceae class is 1,000 mg/kg.

Australian regulations for the beach collection of seaweed

There is much inconsistency between state government and local government regulations regarding seaweed collection, with each set of regulations containing different collection limits and rules. Beach collection is not permitted in Queensland.

New South Wales

Marine vegetation collection for commercial purposes – information kit

You must obtain a permit from the NSW Department of Primary Industries to commercially harvest seaweed. Harvesting is limited to the species *Ecklonia radiata*, *Phyllospora comosa*, *Ulva intestinalis* and *Ulva lactuca*. Collection of any other species attached to the sea floor is prohibited. Up to 20 kg of beach-cast seaweed can be collected per day for personal use without a permit.

Tasmania

Seaweed Collection

No license is required when less than 100 kg per person of beach-cast seaweed is collected daily for personal use from beaches with public access. Collection of beach-cast seaweed in marine nature reserves is prohibited, as is the direct harvest of native seaweeds attached to the sea floor. Commercial harvesters must operate under a licence, of which there are 18 for beach-cast kelp.

South Australia

South Australian Beach-Cast Seagrass and Marine Algae Fishery Assessment

There are currently no limits to the amount of seaweed that can be collected for personal use from areas outside marine parks and reserves and areas that are not any intertidal rocky reef, from the high-water mark out to a water depth of two meters. For commercial harvest, an exemption must be obtained from the Primary Industries and Regions South Australia (PIRSA) Fisheries Division.

Victoria

Regulations are local government-based and differ from council to council. It is legal to collect small amounts (equating to few shopping bags' worth) of beach-cast seaweed for personal use. It is illegal to collect in marine parks and to the low tide level in areas adjacent to land-based parks, including coastal reserves.

Western Australia

Licences and Authorities

Collection licenses are required from both the Department of Parks and Wildlife and the Department of Fisheries for personal and commercial collection of live seaweed ("Other prescribed purposes" licence). Permission from the relevant land manager/s (e.g. local government authority) is also required. Dead beach-cast seaweed is not protected. If only dead seaweed is being collected, and it is not being removed from a marine reserve, then no license or authorisation is required.

Queensland

Seaweed is classified as a marine plant and is protected under the *Fisheries Act 1994*. Under the Planning Regulation 2017, seaweed collection must be undertaken in accordance with the relevant accepted development requirements (ADR) or under a development approval (assessable development).

Collecting seaweed for human consumption may comply with the ADR under the prescribed work type 1.16 For educational, research or monitoring work (See section 4.1 New work for a private purpose, page 9). The proposed collection would need to meet the requirements for accepted development as set out for work type 1.16, as well as the overall standards (section 3.3).

Queensland residents with questions on whether their proposed collection will comply with ADR requirements, or who want information on developing a seaweed aquaculture facility, should contact their nearest State Assessment and Referral Agency (SARA) office at the Department of State Development, Infrastructure, Local Government and Planning (DSDILGP) and request pre-lodgement advice.

Northern Territory

No regulations relating to the beach collection of seaweed in the Northern Territory are available.

3. Food safety plans

Australian food safety regulations use the terms “food safety program” and “food safety management statement”, and these have specific meanings. Within the food processing industry, however, the general term that is used is “HACCP plan”.

HACCP plans are based on 12 steps as outlined within the Codex Alimentarius document *General Principles of Food Hygiene: Good Hygiene Practices (GHPs) and the Hazard Analysis and Critical Control Point (HACCP) System CXC 1-1969*, updated in 2020 (Codex Alimentarius Commission, 2020). The 12 steps are:

- Assemble the HACCP team and identify scope
- Describe the product
- Identify intended use and users
- Construct flow diagram
- Onsite confirmation of flow diagram
- List potential hazards, conduct a hazard analysis and consider measure to control hazards
- Determine critical control points
- Establish validated critical limits for each critical control point
- Establish a monitoring system for each critical control point
- Establish corrective actions
- Validate the HACCP plan and establish verification procedures
- Establish documentation and recordkeeping

As part of this project, HACCP plans were developed for two industry case studies processing different Australian seaweed species – land-grown sea lettuce (*Ulva* spp. Ulvophyceae) and wild-collected golden kelp (*Ecklonia radiata*) – and their development followed the 12 steps (ICS, 2022a, 2022b). The HACCP plans/food safety programs document the product specifications; process steps to identify significant food safety hazards; risk assessment of the process steps; critical control points and associated critical limits; monitoring criteria and records; expected corrective actions; a verification schedule; and a validation table.

Visits to growing, collecting and processing sites in southern NSW were undertaken for the two case studies (Figure 1, Figure 2, Figure 3). All aspects of the HACCP plans were reviewed. This included confirming and verifying each process step within the flow chart; identifying food safety hazards; reviewing implemented control measures; reviewing lab testing results; and reviewing equipment and documentation (procedures, forms and monitoring records).

Food safety hazards identified during this process, and subsequent controls implemented by the case studies, are listed in Table 1.

Seaweed production process:
Land-grown sea lettuce

1. Nurse seaweed in tanks
2. Grow seaweed in tanks
3. Harvest seaweed by pump
4. Separate water and seaweed
5. Weigh seaweed into bins
6. Transport seaweed to processing site
7. Receive and weigh wet seaweed into bins
8. Mince seaweed
9. Load seaweed onto trays
10. Desiccate seaweed over six hours at 50 °C
11. Pelletise dried seaweed
12. Pack seaweed pellets into sealed buckets for ambient storage
13. Sell seaweed pellets as a bulk ingredient for food processors

Figure 1. Process used by an industry case study to process land-grown sea lettuce (*Ulva* spp. Ulvophyceae) for human consumption. Photos: Sea lettuce growing in tanks (step 2, top); seaweed being minced (step 8, bottom). Photos taken by Dr Pia Winberg.

Seaweed production process:
Hand-collected kelp

1. Collect kelp from beach
2. Place seaweed in baskets to drain
3. Transport seaweed to processing site
4. Inspect seaweed on a table
5. Dip seaweed in freshwater
6. Drain seaweed and transport to racks
7. Dry seaweed on racks
8. Remove seaweed from ranks and inspect
9. Pack seaweed into cartons
10. Mill dried seaweed
11. Collect seaweed flakes in buckets
12. Decant seaweed flakes into 4 kg drums
13. Store seaweed flakes in airtight drums
14. Pack seaweed flakes to order

Figure 2. Process used by an industry case study to process wild-collected golden kelp (*Ecklonia radiata*) for human consumption. Photos: Seaweed drying racks (step 7, top); beach collection of wild-grown seaweed (step 1, bottom). Photos taken by Clare Winkel.

Figure 3. Contaminants in collected seaweeds: marine stingers, sand, stones and shells (top); crustaceans and molluscs (bottom left); egg sacs (bottom right). Photos taken by Clare Winkel.

Table 1. Identified food safety hazards and implemented controls.

Food safety hazard	Implemented control
Allergens – crustaceans and molluscs	Seaweed washed in freshwater
Physical contamination – sand and marine debris	Seaweed washed in freshwater
Microbiological contamination – *Salmonella* and Staphylococcus aureus	Final product dried to water activity (a_w) below 0.83
Chemical contamination – naturally occurring iodine	Raw seaweed blanched prior to drying

Note: Growing seaweed in controlled tank conditions removes almost all known food safety hazards.

In both case studies, the absolute critical limit to ensure the microbiological food safety of the final products was a water activity (a_w) measurement of 0.83 (Løvdal *et al*., 2021). This is the level that will stop growth of the bacteria *Staphylococcus aureus*. This bacteria lives on the skin and hair of humans. It is very tolerant of low water levels and high salt levels. Once it has the right growth conditions, it can produce a toxin (chemical) that will not be killed or removed during any heating/cooling/drying process. Rather than trying to directly measure water activity, a series of critical limits more easily measured could collectively demonstrate that the dried product achieves an a_w level of 0.83 or lower.

These critical limits could include drying time, drying air temperature, humidity, velocity and thickness of the seaweed (Concepcion *et al*., 2020). But as can be seen from case study two, the drying time and temperature cannot be controlled easily, as it occurs outdoors on racks, not in a heat-controlled oven. Seaweed thickness can be highly variable as the raw material is beach-collected and wild-grown. This method of harvesting and drying is very traditional and sustainable. An alternative measurable critical limit was reviewed during the project, salt content of the dried but not milled product (step 6). After considerable review of the literature and consultation with international experts, it was concluded while higher salt content helps control bacterial growth, key food safety pathogens like *Salmonella* and *Staphylococcus aureus* need a very low a_w level to stop bacterial growth and prevent survival (Løvdal *et al*., 2021).

Case study one shows almost all identified food safety hazards with an environmental source (heavy metals, chemical residues, marine algae toxins, marine allergens, *Clostridium botulinum*, *Vibrio* spp. and dioxins) can be eliminated by growing seaweed in land-based tanks.

Lab testing of the iodine content of wild-collected seaweed showed highly variable results. As part of identifying potential food safety hazard controls, further testing of iodine levels in seaweed before and after several potential control measures (soaking in fresh water and blanching) was planned. This would validate the potential for these measures to reduce the iodine content in the final product. However, these trials and tests have not yet been undertaken as in the months prior to writing, opportunities to wild harvest were limited due to weather conditions and flooding in southern NSW.

Additionally, the following variables need to be considered to control iodine content in the final processed product (Banach *et al*., 2020a; Hoek-van den Hil *et al*., 2020; Marthe *et al*., 2019; Løvdal *et al*., 2021; FAO, 2022):

- Seaweed species, plant age at harvest and which parts of the plants are used
- Environmental conditions at harvest
- Rainfall in the harvest area
- Rinsing water temperature and time
- Blanching seaweed before drying.

Only two other seaweed HACCP plans were identified during this project, both developed in the US. One was developed by the University of Connecticut and designed for restaurant chefs using fresh sea-farmed seaweed, while the other was developed by the University of Alaska, Fairbanks and designed for people considering harvesting and processing wild-grown kelp species meeting federal regulations.

4. Food safety management system

In addition to meeting state and federal food safety regulation requirements, food processing companies that supply into mainstream retailers are required to implement additional processes and undergo annual audits by certification bodies. This is known as third-party certification.

The first level of third-party certification is HACCP certification. Despite there being an internationally recognised HACCP standard (Codex Alimentarius Commission, 2020), each certification body has its own documented HACCP standard for auditors to audit against.

If a food processor is supplying directly to a retailer or fast-food chain, it has to be audited against a higher-level food safety standard. These are often referred to as a Global Food Safety Initiative (GFSI)-benchmarked standard. There are numerous standards available internationally, however none are specifically designed for the seaweed sector.

The Brand Recognition Compliance Global Standard (BRCGS) standard does not include growing or harvesting seaweed within its scope. The Safe Quality Food (SQF) standard does include a module for aquaculture and another for food plant growing, but it is assumed that the aquaculture operation is growing animal-based seafood and the plants are growing on land in soil/hydroponically. The Food Safety System Certification (FSSC) 22000 standard does not cover growing/harvesting plants or aquaculture, but does cover general food manufacturing.

The only internationally auditable standard that has been developed for the seaweed sector is the Aquaculture Stewardship Council and Marine Stewardship Council (ASC-MSC) Seaweed Standard, which covers sustainability and social responsibility for wild-harvested and farm-grown seaweed production. It does not cover food safety hazard identification or controls.

With the existing standards in mind, this project has developed an example food safety management system manual for use within the seaweed processing sector. This manual, available on request to AgriFutures Australia, has been designed to help seaweed processors meet third-party HACCP certification. Each business, however, will need to review the specific requirements of the HACCP certification standard as issued by its chosen certification body, as each certification body has different requirements.

The manual provides information on relevant policies and includes the following procedures and forms to assist seaweed processors with becoming HACCP certified:

- Quality and food safety policy
- Organisation chart and job descriptions
- Management review procedure and meeting record
- Corrective action procedure, investigation form and register
- Approved supplier procedure
- Document control procedure
- Product identification and traceability procedure
- Customer complaints procedure
- Product recall procedure

- Staff training procedure, form and skills register
- Internal audit procedure and report
- Product assessment, sampling and testing procedure, and product assessment form
- Allergen management procedure
- Good hygiene procedure
- Calibration procedure and equipment schedule
- Pest control procedure
- Cleaning procedure and form
- Foreign object control procedure
- Equipment and maintenance procedure

International certification standards

SQF, FSSC 22000 and BRCGS are GFSI-benchmarked, internationally recognised, third-party audited food safety quality management systems.

Safe Quality Food

SQF Institute. (2020). *Food Safety Code: Aquaculture – Edition 9.* https://www.sqfi.com/wp-content/uploads/2020/11/20227FMIN_Aquaculture_v3-2-Final-w-links.pdf

SQF Institute. (2020). *Food Safety Code: Primary Plant Production – Edition 9.* https://www.sqfi.com/wp-content/uploads/2020/11/20227FMIN_PrimaryPlant_v3-2-Final-w-Links-1.pdf

Brand Recognition Compliance Global Standard

BRCGS. (2020). *Plant-Based Global Standard – Issue 1*. https://www.brcgs.com/store/global-standard-for-plant-based-issue-1/p-772/

This standard is suitable for food processing only, not growing or harvesting.

Food Safety System Certification 22000

FSSC 22000. (2020). *FSSC 22000 – Version 5.1*. https://www.fssc22000.com/scheme/scheme-documents-version-5-1/

Aquaculture Stewardship Council and Marine Stewardship Council

ASC-MSC. (2018). *ASC-MSC Seaweed (Algae) Standard*. https://www.asc-aqua.org/wp-content/uploads/2017/11/ASC-MSC-Seaweed-Algae-Standard-v1.01.pdf

This standard covers sustainability and social responsibility.

Implications for industry

The information obtained from the literature review, regulatory review and stakeholders, as well as during development of the food safety program, highlighted a number of implications regarding using seaweed for human consumption.

The literature review identified that pathogens from the harvest area are potentially significant because the seaweed may be intended for use as a raw product for human consumption, without an additional processing step that would kill them off. Pathogens of concern from the harvest area (*Vibrio* spp., *Salmonella*, haemorrhagic *E. coli* species, norovirus and hepatitis) are potentially significant and need to be considered as part of any system processing seaweed for human consumption.

Environmental contaminants are also potentially significant chemical hazards because certain seaweed species exhibit a high affinity for accumulating heavy metals and other contaminants in their tissues. Natural toxins from the harvest area have been responsible for health problems related to the consumption of several *Gracilaria* species. These toxins are often heat-stable and even if seaweed is heated, the toxin will remain in the final processed product.

Development of the two example HACCP plans identified some environmental food safety hazards identified in the literature are unlikely to be relevant within the Australian context. It was noted that the literature gives almost no consideration to southern hemisphere conditions, species and harvest locations. However, other hazards were identified, including potential microbial hazards, allergenic and physical contaminants.

There is a worldwide lack of knowledge of how and why iodine is absorbed by different species at very different rates, and the possible controls to minimise inconsistent iodine levels in raw products.

It was also noted that Codex is in the process of writing new standards for seaweed production (Codex Alimentarius Commission, 2021b). These would fall under “New food sources and production systems”, a broad term that includes seaweed, microalgae, edible insects, cell culture-based food products (meat, fish, dairy), plant-based protein alternatives and 3D-printed foods). A further standard is in development specifically for chemical hazards in seaweed (Codex Alimentarius Commission, 2021a)

Beach collection of seaweed is controlled at either a state government or local government level, and each set of regulations contains different daily take limits and rules. Beach collection is not permitted in Queensland. This means in certain states it is harder to set up a small seaweed-based food company. As a result, certain species of edible seaweeds that are readily growing in some states cannot be collected and processed into a food product, even though an Australian market exists and is being supplied with imported products.

There is much inconsistency even within federal regulations regarding the requirement to document food safety programs in the sector. Section 3.2.1 of the *Australia New Zealand Food Standards Code* states all food businesses, other than primary producers, must have a written food safety program. However, this conflicts with sections 4.1.1 and 4.2.1, which explicitly exclude seaweed growing, collecting or processing. Even the most proactive state regulators believe “most of the kelp is used to make fertiliser or mulch, or is dried/granulated and exported for alginate”, i.e. they are unaware of how many operators are collecting and processing seaweed for human consumption. This inconsistency makes it difficult for industry to know exactly what is required, and makes application of the law by state or local government officers problematic.

During development of a seaweed industry stakeholder database (more than 130 contacts from individual chefs to large corporations, researchers, regulators, seaweed collectors, seaweed processers

and seaweed sellers), it was identified that seaweed-based food products are being sold in Australia online, at retail stores, at markets, in restaurants, into food service and to food processors. The methods/activities being undertaken by stakeholders in the seaweed products for human consumption space include:

- Beach collection, drying and grinding of seaweed to create seaweed flakes that can be eaten as a condiment or used in other food. i.e. cheese, chocolate, pasta.
- Beach collection of seaweed by individuals who then use it as a fresh ingredient in their restaurants/food business or sell it onto other restaurants.
- Beach collection, drying/freezing and packaging of seaweed for retail sale.
- Beach collection, drying, and grinding of seaweed to create seaweed flakes that are exported to international processors to be used as alginate.
- Growing (in tanks), grinding and drying of seaweed to create seaweed powder that can be used in processed foods, such as pasta, chips, salts, crackers, snacks, breakfast cereal and nut coatings.
- Importation of dried and processed packaged products from overseas for online or retail sale.
- Importation of dried whole products from overseas, such as sea grapes from Vietnam, for rehydration to be used in salads.
- Purchasing of dried seaweed from other collectors for use in value-added products for retail sale.
- Purchasing parts of seaweed from large corporations (non-food seaweed processors) that do not use that part of the plant for further processing into flakes for retail sale.

It has also become obvious through communication with industry stakeholders, researchers and regulators that many parties do not need an example food safety plan but want a single document that outlines potential food safety hazards and controls for seaweed for human consumption. Such a publication will be produced as separate document to the example HACCP plans and the food safety management system manual developed as part of this project.

As part of this project, publications from across the world have been collated, in addition to a huge amount of reference material. These include publications produced by FAO, WHO and the United Nations; reports from European Union research projects; US state government guides and extension tools for industry; international certification standards; articles; and published scientific papers. These are diverse resources that would be useful for anyone working in this sector. The materials have been made available on Dropbox and can be accessed here.

Recommendations

It is important Australian seaweed industry participants consider the information in this report, as this will help them maintain food safety best practices when producing seaweed products for human consumption, even with the state of regulatory inconsistency and food safety issues identified.

It is recommended state and federal food regulators be made more aware of the Australian seaweed processing industry, as this would enable regulators working in different jurisdictions to collaborate on the identified regulatory issues and assist the growth of the industry.

Industry should also be provided with clarity on:

- The limits and controls on beach collection of seaweed in Australia, as there are inconsistent regulations for collecting seaweed
- The differing definitions (i.e. food processors vs primary production) and requirements contained in different sections of the *Australia New Zealand Food Standards Code*
- Which business types need to operate under a written food safety program.

Further work should be undertaken to identify potential controls at processing to reduce excessive iodine content in the processed seaweed. Future research projects could investigate:

- The iodine content of different species and different parts of the plant
- The ideal seaweed plant age at harvest
- The ideal environmental conditions at harvest
- The impact of rainfall in the harvest area
- The ideal rinsing water temperature and time.
- Blanching seaweed before drying.

The food safety program (contained in this report) and the HACCP plans and food safety purchasing guide (complementary to this report) developed as part of this project should be promoted for use by industry.

Consideration should also be given to the future development of a certifiable standard specific to seaweed-based food products that covers food safety hazard identification and controls.

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Government sources

Australia New Zealand Food Standards Code

Section 1.4.1 Contaminants and natural toxicants
https://www.legislation.gov.au/Details/F2022C00972

Section 3.2.1 Food safety programs
https://www.legislation.gov.au/Details/F2011C00551

Section 4.1.1 Primary production and processing standards
https://www.legislation.gov.au/Details/F2012C00777

Section 4.2.1 Primary production and processing standard for seafood
https://www.legislation.gov.au/Details/F2012C00775

Schedule 19 Maximum levels of contaminants and natural toxicants
https://www.legislation.gov.au/Details/F2022C00979

Food Standards Australia New Zealand

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Appendices

Appendix 1. Australian suppliers selling seaweed products

Alg Seaweed: https://algseaweed.com/ (Australian and imported products)

Ashmore Foods: https://ashmorefoods.com.au/ (Australian products)

Dirty Inc: https://www.dirtyinc.com.au/ (Australian products)

Kelp Industry: http://www.kelpind.com.au/ (Australian products)

Kombu Cody: kombucody@gmail.com (Australian products)

Kai Ho/Sea Vegetables Tasmania: http://www.oceantreasure.com.au/ (Australian products)

Mystery Bay Kelp for Life: https://mbkforlife.com/ (Australian and imported products)

Phyco Health and Venus Shell Systems: https://www.phycohealth.com (Australian products)

Seacare: https://seacare.org.au/ (products available at Salamanca Market in Hobart)

Sea Drift Distillery: https://seadriftdistillery.com/ (Australian products)

Sea Health Products: https://www.seahealthproducts.com.au/ (Australian products)

Seaweed Enterprises Australia: https://www.seaperia.com/ (imported products)

South Coast Seaweed: https://southcoastseaweed.com.au/ (Australian products)

Sydney Seagrapes: https://sydneyseagrapes.com.au/ (imported products)

Taskelp: http://taskelp.com/ (Australian products)

Two Providers: https://www.twoprovidores.com.au/ (Australian and imported products)

Appendix 2. Seaweed-related publications

Articles, books, videos, websites and other material relevant to the Australian and international seaweed industry are listed below.

Horizon Scan

Horizon Scan is an online subscription database of every global food and packaging recall and border rejection for the past 10 years, and 21 years in the case of seaweed. Table 2 shows examples of the information available regarding identified food safety hazards for seaweed and algae.

Table 2. Issues concerning seaweed, algae and carrageenan

Date	Notified by	Issue	Country of origin	Company
4 June 2021	Australia	Import refusal for kelp due to iodine (1,900 mg/kg)	China	Fuzhou Hailin Food Co. Ltd
2 June 2021	Australia	Import refusal for dried seaweed due to iodine (2,100 mg/kg)	China	Jinqiang Food Factory
4 May 2021	United States	Import refusal for dried seaweed due to iodine (3,200 mg/kg)	Japan	Tohkon Co. Ltd
28 June 2021	Australia	Import refusal for dried seaweed due to iodine (4,700 mg/kg)	Republic of Korea	Jayoenwon Food Inc.
29 June 2021	Australia	Import refusal for dried seaweed due to iodine (4,800 mg/kg)	Vietnam	Viet San Food Co.

Australia and New Zealand

As part of this project, on 30 September 2021 a public webinar on seaweed food safety hazards was presented. The recording is available at https://vimeo.com/618887171

The book *Coastal Chef: Culinary Art of Seaweed & Algae in the 21st Century*, edited by Claudine Tinellis, is available at https://www.phycohealth.com/products/coastal-chef-cookbook

The book *How Wild Things Are*: *Cooking, Fishing and Hunting at the Bottom of the World* by Analiese Gregory is available through the publisher Hardie Grant at https://www.hardiegrant.com/au/publishing/bookfinder/book/how-wild-things-are-by-analiese-gregory/9781743796023

The book *New Zealand Seaweeds: An Illustrated Guide* by Wendy Nelson is available through the Museum of New Zealand at https://www.tepapa.govt.nz/about/te-papa-press/natural-history/new-zealand-seaweeds-illustrated-guide-0

https://smartseaweed.com/

http://seafoodstandards.com.au/wp-content/uploads/sites/12/2020/12/AS-5301-2020-Aquatic-Plant-Names-Standard.pdf

https://www.youtube.com/watch?v=qYnGAAU-05Y&feature=youtu.be&fbclid=IwAR3oC9ILA5wnnZHN1f1H3-d2KVEtNO6ddBPrTm7xtW8UDcfm4dOJfY4-cEE

https://www.abc.net.au/news/science/2021-09-16/black-summer-bushfires-smoke-iron-algae-bloom-phytoplankton/100460218

https://www.theguardian.com/world/2015/may/08/bonsoy-25m-settlement-over-tainted-soy-milk-approved-by-supreme-court

https://www.abc.net.au/news/2014-11-24/bonsoy-iodine-victims-on-track-for-share-of-25m-payout/5913218

https://www.mja.com.au/journal/2010/193/7/iodine-toxicity-soy-milk-and-seaweed-ingestion-associated-serious-thyroid

https://www.csiro.au/en/News/News-releases/2020/Million-dollar-Food-Planet-Prize-awarded-to-CSIRO-innovation

https://www.couriermail.com.au/news/queensland/bundaberg/gourmets-go-gaga-for-bundy-sea-grapes/news-story/cabc0fc2faafc59ea30d493820ec7a9a

https://www.sbs.com.au/food/article/2021/12/09/eat-your-sea-greens-three-edible-seaweeds-found-tasmania

https://www.sbs.com.au/food/article/2020/06/22/how-eating-seaweed-can-supercharge-your-health-and-save-our-oceans?cid=food:edm:foodhealth:relation:foodhealthedm:na:na

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https://www.australianseaweedinstitute.com.au/current-state-of-the-australian-seaweed-industry

https://www.abc.net.au/news/2022-02-27/can-you-eat-seaweed-off-the-beach/100858562

https://waateanews.com/2021/08/16/seaweed-bounty-waiting-to-be-tapped/

https://www.coretext.com.au/post/first-farmed-kelp-harvests-for-tasmania

https://www.theislanderonline.com.au/story/6905097/ki-selected-for-us-companys-million-dollar-seaweed-climate-project/

https://www.hakaimagazine.com/features/scotlands-seaweed-showdown/

https://www.stuff.co.nz/business/farming/aquaculture/300107377/moves-for-nzs-first-seaweed-farms-begin-in-hauraki-gulf

https://www.waikato.ac.nz/news-opinion/media/2020/new-tauranga-aquaculture-facility-set-to-harness-seaweeds-potential

https://www.nzor.org.nz/names/d3757581-590c-499b-8af6-a59f72bb6489

Europe

https://www.phycomorph.org/pegasus-phycomorph-european-guidelines-for-a-sustainable-aquaculture-of-seaweeds

https://packagingeurope.com/an-inside-look-at-notplas-edible-seaweed-based-packaging/?

https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12780-Towards-a-strong-and-sustainable-EU-Algae-sector

https://www.eumofa.eu/blue-bioeconomy-report-2020-edition-is-online

https://ec.europa.eu/oceans-and-fisheries/news/2021-eu-blue-economy-report-emerging-sectors-prepare-blue-economy-leading-part-eu-green_en

https://sifted.eu/articles/you-will-soon-be-eating-seaweed/

http://www.seaweedmanifesto.com/

https://www.foodnavigator.com/Article/2020/08/27/Attention-algae!-Food-agency-warns-against-carcinogenic-contamination-in-edible-seaweed.

https://www.weforum.org/agenda/2020/10/can-the-growth-of-aquaculture-restore-the-health-of-our-ocean/

https://www.newfoodmagazine.com/article/138260/food-safety-in-depth-focus/

North America

https://www.fisheries.noaa.gov/feature-story/global-study-sheds-light-valuable-benefits-shellfish-and-seaweed-aquaculture

https://seaweedcommons.org/blog/

https://seaweedhub.org/about-2/

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