Food Safety
AUTHORITY OF IRELAND

Report of the Scientific Committee
of the Food Safety Authority of Ireland

2020

Safety Considerations of Seaweed and Seaweed-derived Foods Available on the Irish Market

Report of the Scientific Committee
of the Food Safety Authority of Ireland

Safety Considerations of Seaweed and Seaweed-derived Foods Available on the Irish Market

Published by:

Food Safety Authority of Ireland
The Exchange, George's Dock, IFSC,
Dublin 1, D01 P2V6

T +353 1 817 1300
E info@fsai.ie

www.fsai.ie

ISBN: 978-1-910348-42-0

Table of Contents

List of Figures

List of Tables

Glossary

Additive	Substance added to food or feed for technological purposes
Aquaculture	Cultivation of water-based products such as seaweed
Benthic	Relating to, or occurring at the bottom of a body of water
Epiphytic	A plant that grows on another plant but derives its moisture and nutrients from the air and rain
Hazard	A chemical, biological or physical agent that can cause an adverse effect
Macroalgae	Seaweed
Peridinoid	Type of tabulation (i.e. pattern) formed by alveolae, in dinoflagellates
Risk	The potential for a particular hazard to cause an adverse effect
Thallus	The entire body of a seaweed

Acronyms

AI	adequate intake
As	arsenic
BfR	German Federal Institute for Risk Assessment
BIM	Bord Iascaigh Mhara
Cd	cadmium
CO_2	carbon dioxide
DAFM	Department of Agriculture, Food and the Marine
DW	dry weight
EFSA	European Food Safety Authority
et al.	abbreviation for *et alia*: and others
EU	European Union
FAO	Food and Agriculture Organization
FSAI	Food Safety Authority of Ireland
Hg	mercury
ICCIDD	International Council for the Control of Iodine Deficiency Disorders
km	kilometer
LOD	limit of detection
MeHg	methylmercury
ML	maximum level
Pb	lead
PCB	polychlorinated biphenyl
ppm	part per million
SCF	Scientific Committee on Food
spp.	species
THg	total mercury
TWI	tolerable weekly intake
UK	United Kingdom
UL	upper tolerable limit
UNICEF	United Nations Children's Fund
WHO	World Health Organization
µg	microgram
µm	micrometer

1. Executive summary

There are 570 known species of seaweed (macroalgae) that have been identified in the waters off the 3,000 km coastline of Ireland (Morrissey *et al*., 2001). Seaweed harvesting in Ireland is focused in the coastal counties of Donegal, Sligo, Mayo, Galway, Clare and Cork. Irish-grown seaweed is used predominantly in high-volume, low-value products including animal feed, food supplements, food additives, fertilisers and agricultural products. Approximately 1% of Irish-harvested seaweed is used to produce higher-value products (foods, cosmetics and pharmaceuticals), generating 30% of the industry's overall income (Walsh and Watson, 2012). It is estimated that Ireland produces 29,500 tonnes of seaweed per year (Norton *et al*., 2018).

Seaweed is a relatively underexplored source of human and animal nutrition, although there has been increased interest in recent years. Market research has indicated that the amount of seaweed-flavoured foods and drinks available in Europe increased by 7% between 2011 and 2015, mainly due to the perceived health benefits of seaweed (Mintel Press Office, 2016).

A number of chemical hazards have been associated with edible seaweed and are discussed in this report. The main areas of concern are linked to the relatively high iodine, cadmium and arsenic content of some seaweed species. There are also a number of biological hazards including marine biotoxins produced by opportunistic dinoflagellates, as well as potential physical hazards in the form of microplastics and nanoplastics (Banach *et al*., 2020).

The following recommendations may assist in ensuring the safe growth of seaweed use as or in food:

1. Explore ways to assess the consumption of seaweed in the Irish population.
2. The hazards associated with seaweed use as or in food that pose the greatest risk to consumer safety at present are iodine and certain metals. Surveillance and monitoring should continue at current levels and where appropriate, at enhanced levels, particularly for imported seaweed products.
3. If the current EU monitoring programme for iodine and metals concludes that there is a need, the FSAI should support the establishment of EU maximum limits and provide data collected on retail samples generated by the Marine Institute and third-level colleges.
4. Further data should be identified that may elucidate the extent and nature of the Irish market for wild-harvested seaweed.
5. As part of the emerging risks work carried out by the FSAI, monitoring of national and international data related to the presence of microplatics and nanoplastics in marine and freshwater environments should be undertaken. These data may help to clarify whether this persistent and ubiquitous pollutant could affect the safety of seaweed use in food.

6. The FSAI should explore the need for consumer advice to certain vulnerable groups.
7. Risks currently not associated with Irish waters (e.g. the dinoflagellate *Gambierdiscus toxicus* which causes ciguatera) should be monitored and reviewed in light of climate change.

2. Scope

This report provides an overview of the Irish seaweed industry, with an emphasis on food-related aspects including edible seaweed, food additives and animal feed. The consumption patterns of seaweed and seaweed-derived products in Ireland are also explored, with certain hazards and risks identified and recommendations put forward to ensure the continued safety of edible seaweed and seaweed products.

3. Background

3.1 Definition and classification of seaweed

Seaweed is a macroscopic, multicellular marine algae living attached to rocks or any hard substrate in coastal areas (Guiry, 2019c). In terms of taxonomic classification, seaweed is classified into three broad groups based on pigmentation (Díaz-Pulido and McCook, 2008):

- **Rhodophyta** (red algae) derived from the Greek '*rhodo*' which means 'red rose' and '*phyton*' meaning 'plant'. These algae are commonly known as red algae and their red colour is due to the pigments phycoerythrin and phycocyanin. Marine macroalgae within the division Rhodophyta are considered 'red seaweed'.
- **Phaeophyceae** (brown algae) is derived from the Greek '*phaios*' which means 'brown' or 'dark'; also previously classified as Phaeophyta. These algae are commonly known as brown algae and their colour is due to the dominance of the xanthophyll pigment fucoxanthin. Within the brown algae, species belonging to the Laminariales (e.g. *Laminaria digitata*, *Laminaria hyperborea*, *Saccharina latissima* and *Alaria esculenta*) are further denoted as 'kelp' and species within the Fucaceae (e.g. *Fucus* spp., *Ascophyllum nodosum* and *Pelvetia canaliculata*) are denoted as 'fucoids'; the former occupy low-intertidal to subtidal habitats and the latter are found along intertidal shores.
- **Chlorophyta** (green algae) derived from the Greek '*chloro*' which means 'green'. These are commonly called green algae and their green colour is due to the presence of chlorophylls a and b.

Many seaweed species can be found both in Ireland and worldwide (Table 1). Ireland has a relatively high number of native seaweed species, possibly due to its diverse coastline habitats and its latitude at 51–56 °N, which straddles both the northern limit for some warm-water seaweed species and the southern limit for some cold-water species (Morrissey *et al*., 2001).

Table 1 Seaweed diversity worldwide and in Ireland

Type of seaweed	Number of marine species	
	Worldwide[(a)]	Ireland[(b)]
Red	3 900–9 500	303
Brown	1 500–2 151	161
Green	>800–1 597	80
Total	**6 200–13 248**	**544**

(a) Extracted from (Díaz-Pulido and McCook, 2008), (b) Extracted from (Guiry, 2012)

A number of seaweed species are of commercial value to the Irish industry (Table 2).

Table 2 Commercially harvested seaweed species in Ireland

Type of seaweed	Scientific name	Common name(s)
Red seaweed	*Chondrus crispus*	Irish moss, Carrageen moss
	Mastocarpus stellatus	False Irish moss, False carrageen moss
	Palmaria palmata	Dulse, Dillisk
	Porphyra and *Pyropia* spp. (7 species)	Nori
Brown seaweed	*Alaria esculenta*	Badderlocks, Dabberlocks, Winged kelp, Atlantic wakame
	Ascophyllum nodosum	Knotted wrack, Rockweed
	Fucus serratus	Toothed wrack, Serrated wrack
	Fucus vesiculosus	Bladder wrack
	Himanthalia elongata	Sea spaghetti
	Laminaria digitata	Kelp, Kombu, Oarweed
	Laminaria hyperborea	Tangle, Cuvie
	Saccharina latissima	Sugar kelp
Green seaweed	*Codium fragile*	Sponge seaweed
	Ulva spp.	Sea lettuce

3.2 Seaweed industry

3.2.1 In Ireland

The Irish seaweed industry is primarily involved with the sustainable harvesting of wild-grown *Ascophyllum nodosum*, while the cultivation of seaweed is still at an early phase of development (Jansen *et al*., 2019; Murphy *et al*., 2013).

The use of seaweed by industries involved with human nutrition, pharmaceuticals and cosmetics has added to its traditional uses which were in animal feed and alginate products (Mac Monagail and Morrison, 2020). This has resulted in an increase in the number of seaweed producers and microbusinesses, marketers and artisanal retailers specialising in the production and packaging of raw materials and finished products in Ireland (Delaney *et al*., 2016).

There are more than 40 companies involved with farming and processing seaweed in Ireland, making products such as plant strengtheners, soil nutrients, animal health or nutrition products and cosmetics (BIM, 2020). Farmed seaweed output in 2018 was 40 tonnes and worth approximately

€40,000 (BIM, 2019). Seaweed worth €37 million (77,000 tonnes) was exported from Ireland in 2018 and in the same year, 58,000 tonnes of seaweed worth €9 million was imported into Ireland for reprocessing and for the export market (BIM, 2020).

3.2.2 Worldwide

The global seaweed industry is estimated to be worth >6 billion US dollars each year, of which approximately 85% comprises food products. Seaweed extracts (carrageen, agar and alginates) account for 40% of the global hydrocolloid market in terms of food (FAO, 2018). The largest producing countries (2012-2017) of wild seaweed species (mainly brown and red algae) are indicated in Table 3.

Table 3 Global production (2012-2017) of wild seaweed by some of the leading producers

Wild seaweed production (tonnes) by country						
Country	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Ireland[(a)]	29 500	29 500	29 500	29 500	29 500	29 500
Chile	436 035	517 929	417 331	345 704	329 707	415 463
China	257 640	283 010	245 550	261 770	231 707	203 490
France	41 229	69 126	58 512	19 110	55 041	39 072
Indonesia	7 641	17 136	70 514	48 740	41 194	46 919
Japan	98 514	84 498	91 601	94 084	80 721	69 800
Norway	140 998	154 150	154 230	147 391	169 407	164 820
Total	**1 011 557**	**1 155 349**	**1 067 238**	**946 299**	**937 277**	**969 064**

Extracted from (FAO, 2019b) unless otherwise stated. (a) Extracted from (Norton *et al*., 2018)

Some of the countries from around the world that produced seaweed via aquaculture between 2012 and 2017 are indicated in Table 4 (FAO, 2019b). The seaweed species produced globally were mainly *Undaria pinnatifida*, *Gracilaria* spp., *Saccharina japonica* and *Eucheuma* spp. and in Ireland were *Alaria esculenta* and *Palmaria palmata*.

Table 4 Global production (2012-2017) of seaweed via aquaculture

Aquaculture seaweed production (tonnes) by country						
Country	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Ireland[a]	9	42	70	70	50	41
China	13 943 804	14 690 271	15 021 571	15 619 125	16 500 798	17 533 590
France[b]	504	304	510	490	500	-
Indonesia	6 514 854	9 298 474	10 076 992	11 269 341	11 050 301	9 746 100
Japan	440 754	418 365	373 908	400 180	391 208	406 500
Philippines	1 751 071	1 558 378	1 549 576	1 566 361	1 404 519	1 415 321
South Korea	992 283	1 131 326	1 087 048	1 197 125	1 351 248	1 761 224
Total	23 643 279	27 097 160	28 109 675	30 052 692	30 698 624	30 862 776

Extracted from (FAO, 2019b) unless otherwise stated. (a) Extracted from (BIM, 2019) (b) Extracted from (FAO, 2019a)

In 2005, global seaweed production was estimated at 14.7 million tonnes, of which wild harvest contributed more than 1.2 million tonnes and the aquaculture sector accounted for an estimated 13.5 million tonnes (marine: 13.4 million tonnes; freshwater: 53,157 tonnes; brackish water: 46,729 tonnes). However, by 2015, total seaweed production had doubled to 30.4 million tonnes, of which 1.1 million tonnes was produced by wild harvest and 29.4 million tonnes came from the aquaculture sector (FAO, 2018).

3.3 Seaweed production

3.3.1 Cultivation

Seaweed cultivation usually involves a two-step process: the collection of fertile material for the induction of spore release (typically undertaken indoors), followed by the spraying of propagules onto a suitable substrate (net/string) which are allowed to develop before deployment in the sea (Edwards and Watson, 2011).

Cultivation methods have been adapted for each species and location in order to ensure optimal growth. The suitability of a seaweed cultivation area can be influenced by environmental factors (light and nutrient availability); the potential for damage by storms, grazers or epiphytes; and the practicalities of harvesting (Radulovich *et al*., 2015). Bord Iascaigh Mhara (BIM) has led a seaweed development programme in Ireland since 2004, working with industry and researchers to develop appropriate cultivation methods for brown seaweed (*Laminaria digitata, Alaria esculenta* and *Saccharina latissima*) and more recently, red seaweed (*Palmaria palmata* and *Porphyra umbilicalis*).

In Ireland, the Aquaculture Licensing Section of the Aquaculture and Foreshore Management Division of the Department of Agriculture, Food and the Marine (DAFM) coordinates the processing and monitoring of licences for the cultivation of seaweed. A substantial number of new licences were granted in 2018 and 2019 for seaweed cultivation (BIM, 2020).

The cultivation of *Laminaria digitata*, *Saccharina latissima, Alaria esculenta* and *Palmaria palmata* in Ireland takes place at licensed marine sites using longlines. Sites deemed suitable for mussel farming on longlines are usually considered to be suitable for seaweed farming on longlines also. Requirements include suitable water depth, sufficient shelter from winter storms, good water flow and quality, sufficient distance from other enterprises such as farming, fishing and navigation traffic (BIM, 2016).

3.3.2 Seaweed harvesting

A licence from the DAFM is required for the collection or removal of seaweed in Ireland, unless it relates to small amounts for personal use. Exceptions can be made where there is an inherited right to seaweed collection from a foreshore in a privately owned estate (folio rights).

Seaweed harvesting can be manual or mechanical. Manual harvesting includes foraging and hand harvesting (cutting by hand using a sickle or similar tool) and while it is more labour intensive, it has less impact on the environment (Irish Wildlife Trust, 2017). Mechanical harvesting can be achieved using a number of methods including a Scoubidou (a boat with a hook-like structure that uproots seaweed), a cutting dredge (iron structure that is dragged along the seabed) or a suction cutter (plants are pulled into a cutter via suction). Seaweed harvesting in Ireland is mostly achieved using manual harvesting methods. Mechanical harvesting is more common in other countries and may have negative impacts on the marine environment through the physical processes involved or the sheer scale of the harvest.

3.3.3 Processing

Edible seaweed is subjected to different types of processing depending on the raw materials available, the traditions of a country and the intended use of the seaweed. Typically, after collection the harvest is washed using seawater or fresh water in order to reduce the levels of contaminating material (Barbier *et al*., 2019). Hand sorting for quality control may be carried out and the seaweed is then dried. If used for consumption (chopped, mixed, or softened), processed seaweed prepared under the appropriate conditions can possess a nutritional value similar to the fresh product. However, the biochemical composition and nutritional value (Bocanegra *et al*., 2009) and associated microbial communities (Ihua *et al*., 2019) of the intermediate or end product can be affected by the type of processing.

3.3.4 Drying

Fresh seaweed biomass can comprise upwards of 80% water (BIM, 2020). Drying reduces the water activity of a seaweed, which in turn restricts microbial growth as well as chemical and enzymatic degradation (Barbier *et al*., 2019). The different strategies used for drying can have varying impacts on the nutritional quality of seaweed (Chan *et al*., 1997). Traditional seaweed drying in the open air is only suitable for small-scale operations and can compromise the hygiene of a product, particularly if the product is intended for use in the food industry.

For seaweed-based food products in Ireland, the most common commercial drying methods involve the use of dehumidifiers or fans (no heating) over a 24–36-hour period. However, such drying methods are labour and energy intensive and only suitable for smaller operations (Walsh and Watson, 2012). For larger-scale production, automated convection and rotary driers have been utilised and include heating, which can affect the nutritional value of seaweed (Kadam *et al*., 2015). Alternative drying technologies include infrared, microwave and superheated steam drying to improve energy efficiency and product quality (Barbier *et al*., 2019). However, these are likely to be cost-effective only for high-value, low-volume products.

3.3.5 Storage

Seaweed can be stored in a number of different ways (e.g. a 1:1 mixture of water and glycerine) that may help to protect compositional and nutritional integrity (Kadam *et al*., 2015). However, drying is the most common method of seaweed preservation that helps to stabilise the biochemical and nutritional content of the biomass. Some studies have focused on the stability and integrity of the nutritional content of seaweed (Paull and Chen, 2008).

3.4 Seaweed uses

3.4.1 Food (edible seaweed)

Seaweed is sometimes referred to as a sea vegetable when used as food. The main seaweed species consumed in Ireland are *Palmaria palmata* (dulse), *Chondrus crispus* (Irish moss), *Mastocarpus stellatus* (false Irish moss), varieties of kelp (*Laminaria* spp., *Saccharina latissima* and *Alaria esculenta*) and wracks (*Fucus* spp.) (The Heritage Council, 2008).

The consumption of seaweed as food throughout the world dates back centuries in some coastal communities (FAO, 2018; Morrissey *et al*., 2001). Seaweed is a staple part of some Asian diets (e.g. Japan, China and South Korea) and more recently has become a feature in the diets of western regions including the United States and Europe (Dawczynski *et al*., 2007).

Edible seaweed species (Table 5) are available to consumers in a variety of forms, including fresh, dry, powdered and flaked (Buschmann *et al*., 2017) and can be added to many dishes such as tartars, beer and traditional Japanese foods (Mesnildrey *et al*., 2012).

Table 5 Edible seaweed species

Type of seaweed	Scientific name[a]	Common name(s)[b]
Red seaweed	*Chondrus crispus**	Irish moss, Carrageen moss
	Gracilaria verrucosa	Ceylon moss
	Lithothamnium spp.*	Maërl
	*Palmaria palmata**	Dulse, Dillisk
	Porphyra and *Pyropia* spp. (7 species)*	Nori
Brown seaweed	*Alaria esculenta**	Badderlocks, Dabberlocks, Winged kelp, Atlantic Wakame
	*Fucus vesiculosus**	Bladder wrack
	Himanthalia elongata	Sea spaghetti
	Laminaria digitata	Kelp, Kombu, Oarweed
	*Saccharina japonica**	Kombu
	*Saccharina latissima**	Sugar kelp
	Undaria pinnatifida	Wakame
Green seaweed	*Enteromorpha* (*Ulva* spp.)*	Hallow-green nori
	Ulva spp.*	Sea lettuce

(a) Extracted from (Mesnildrey *et al*., 2012). (b) Extracted from (Guiry, 2019a,b,c). *Occurs in Irish waters.

3.4.1.1 Nutritional value of edible seaweed

The addition of seaweed and seaweed extracts to foods has been reported to show potential beneficial effects by enhancing satiety and reducing the postprandial absorption rates of glucose and lipids in acute human feeding studies (Brownlee *et al*., 2012).

Seaweed species contain a range of proteins, minerals, lipids and fibre which can vary in concentration depending on the species, time of collection, habitat and environmental conditions (Stengel *et al.,* 2011). Some seaweed species are reported to have a protein content comparable to beef on a weight-for-weight basis (Cherry *et al*., 2019). Red seaweed and green seaweed have been shown to have a higher protein content than brown seaweed and have comparable protein content to vegetables such as soybeans (Burtin, 2003).

The fat content of seaweed is generally low (1–5% of the dry matter) and has been found to be highest in winter and lowest in summer (Madden *et al*., 2012). Seaweed contains considerable concentrations of polysaccharides, many of which cannot be digested by humans and therefore considered as dietary fibres and possible prebiotics (O'Sullivan *et al*., 2010). Brown seaweed contains alginate, laminarin and fucoidan polysaccharides; some groups of red seaweed contain agar or carrageenan, while some green seaweed contains ulvan, xylan and cellulose.

The vitamin and mineral content of seaweed can vary depending on the type of seaweed, different parts of the thallus, geographical location and environmental factors such as seasonality. Minerals such as calcium, magnesium, phosphorus, potassium, sodium and iron have been found in high concentrations in certain species of edible seaweed, including *Palmaria palmata, Undaria pinnatifida, Laminaria* spp. and *Ulva* spp. (Kumar *et al*., 2008). High zinc levels have been reported in some red seaweed species from Ireland (Stengel *et al.,* 2004). The most notable mineral in seaweed is iodine (Nitschke and Stengel, 2015), with some species of brown seaweed containing up to 1,000 times the level of iodine found in marine fish like cod.

Edible seaweed can also be a valuable source of vitamins C, E and B12. The average vitamin C content of green seaweed and brown seaweed is between 500 and 3,000 mg/kg of dry matter, with red algae containing around 100 to 800 mg/kg (Watanabe *et al*., 1999). On average, brown seaweed contains higher levels of vitamin E compared to green and red seaweed (Burtin, 2003).

3.4.2 Food supplements

The FSAI must be notified of food supplements being placed on the Irish market and has received a number of supplement notifications that include different seaweed species, mostly brown seaweed (*Ascophyllum* spp., *Fucus* spp., *Laminaria* spp., *Undaria pinnatifida* and *Macrocystis pyrifera*).

3.4.3 Food additives

Hydrocolloids are polysaccharides with a high molecular weight (Barbier *et al*., 2019) and some are used as thickening, emulsifying, gelling and stabilising agents (Saha and Bhattacharya, 2010). Several species of red seaweed and brown seaweed are used in the production of primary hydrocolloids such as agars, alginates and carrageenans.

Carrageenan (E 407) and processed *Eucheuma* seaweed (E 407a) are examples of EU-authorised food additives. Other food additives based on seaweed include alginic acid (E 400) and the alginates: sodium (E 401), potassium (E 402), ammonium (E 403) and calcium (E 404), propane 1,2-diol alginate (E 405); agar (E 406) and algal carotenes (E 160(a) iv). All additives undergo a safety assessment prior to authorisation in the EU. Phlorotannins (from brown seaweed) are being explored as natural alternatives to synthetic preservatives within the food industry due to their reported high antioxidant activity (Kirke *et al*., 2017).

3.4.4 Seaweed extracts

Seaweed extracts have a wide range of food and non-food applications:

- Agar is extracted from red seaweed, some species of which occur in Europe, such as *Gelidium* spp. and *Gracilaria* spp. Agar is used in culture media for microbiological analyses, as a solid media for electrophoresis, as a thickening agent (food additive) in food and an alternative to animal gelatine in food.
- Alginates are extracted from seaweed species that include the European species *Ascophyllum nodosum* and *Laminaria* spp. Alginates are used in the food and feed industries as stabilisers and colouring agents, as well as in wastewater treatment and waterproofing in the textile industry.
- Carrageenans are extracted from a group of red seaweed species that include the European species *Chondrus crispus* and *Mastocarpus stellatus*, although most production is based on carageenophytes such as warm-water species (*Eucheuma* spp. and *Kappaphycus* spp.). They are primarily used as food additives for their technological functions (thickening, gelling and stabilising) in a wide range of foodstuffs, including dairy products (Barbier *et al*., 2019; Mesnildrey *et al*., 2012).

- Phycoerythrin is a protein-based pigment found in red seaweed and cyanobacteria and is currently used in biotechnology applications (immunofluorescence dye), with the potential for use as a red fluorescent colourant in the food industry (Fleurence *et al*., 2018).

Agars, alginates and carrageenans are currently not produced in Ireland.

3.4.5 Seaweed as animal feed

In the past, farm animals along coastal areas consumed seaweed that had been washed ashore. In more recent times, animal feed containing seaweed ingredients has become commercially available. Potential advantages to using seaweed rather than terrestrial plants as a protein source for animals include the relative ease of cultivation, a higher photosynthetic efficiency and generally faster growth and reproduction rates (García-Vaquero, 2018). Some potential benefits reported in the literature to be associated with the incorporation of seaweed into animal diets include:

- Improvement in poultry health, productivity and egg quality (Kulshreshtha *et al*., 2014)
- Benefits to the digestive health, locomotion and the immune system (Ememe and Ememe, 2017)
- Improvements in the fatty acid content of ewe's milk (Caroprese *et al*., 2016)
- Temporary reduction in methane production from cattle (Barbier *et al*., 2019).

3.4.6 Seaweed-based agrochemicals

The agricultural use of seaweed in Ireland was historically confined to coastal areas. Research since the 1950s has facilitated an increase in seaweed components being refined into liquid extracts and used as fertiliser (Guiry and Blunden, 1991). These fertilisers can be spread on the soil as micro balls, as powder or pulverised in liquid form (Mesnildrey *et al*., 2012). In Ireland, three types of agrochemicals are produced from seaweed: seaweed meal (Guiry and Blunden, 1991), liquid seaweed extracts obtained from *Ascophyllum nodosum* and maërl from *Phymatolithon purpureum* and *Lithothamnion corallioides* (Guiry, 2019c).

3.4.7 Other seaweed applications

Seaweed has other possible applications:

- Pharmaceutical: Several bioactive seaweed substances including fucoidans, lectins, β-carotene, fucoxanthin, astaxanthin and eicosapentaenoic acid are reported to possess a range of health-related properties (Appendix 1) (Qin, 2018).

- Skincare: Seaweed contains vitamins, minerals, iodine, polysaccharides and proteins which are used in the manufacture of skincare products. Macroalgae are generally used in the cosmetics industry as emulsifiers, stabilisers and colouring agents (Barbier *et al*., 2019).
- Biofuel: The rapid growth rate and relatively high sugar content of some seaweed species make them a suitable candidate for biofuel production (Kadam *et al*., 2015).
- Ecosystem management: Seaweed is a photosynthetic algae that can absorb dissolved CO_2 and inorganic nutrients.
- Bioaccumulation and bio-indicator: Seaweed capacity as a bioaccumulator and bio-indicator has been extensively explored (Barbier *et al*., 2019).

4. Seaweed consumption and market data

Seaweed as a dietary source of nutrition in Europe has traditionally been restricted to countries and regions with significant coastlines such as Ireland, Wales and Brittany. However, seaweed has attracted wider consumer interest more recently (Nitschke and Stengel, 2016). In a report commissioned by BIM (BIM, 2015), Ecovia Intelligence (formerly known as Organic Monitor) observed that the European market for sea vegetables was estimated at a wholesale value of approximately €24 million in 2013. France had the largest consumer market, followed by the UK, Germany and Spain; taken all together representing 80% of European sea vegetable revenues. The same report found that the market for sea vegetables was growing by approximately 7-10% per annum.

Nori (*Porphyra* spp*.* and *Pyropia* spp*.*) are the dominant edible seaweed species in Europe, with 288 tonnes sold in Europe in 2013, most of which was imported from Japan, China and South Korea. Traditionally, demand for nori has come from catering and food service companies that used nori, wakame and kombu in Japanese and Asian cuisine. The UK is the largest market for nori in Europe (BIM, 2015).

Dulse (*Palmaria palmata*) is the second most popular seaweed product, with sales close to 70 tonnes in 2013. With imports comprising just 10% of the total sales volume, the biggest producer (and consumer) of dulse in Europe is France (BIM, 2015).

Atlantic wakame (*Alaria esculenta*) sales in Europe were close to 64 tonnes in 2013, with approximately 50% being imported. Spain is the leading producer of Atlantic wakame in Europe, followed by the Netherlands and France. Spain is the biggest market because of the large volumes going into food processing, although other significant markets include the UK and France (BIM, 2015).

Sugar kelp (*Saccharina latissima*) sales were estimated at approximately 50 tonnes in 2013, more than half of which was imported. France has the largest consumer market, accounting for 40% of the total, followed by the UK and Spain (BIM, 2015).

The main seaweed species consumed in Ireland are *Palmaria palmata* (dulse), *Chondrus crispus* (Irish moss), *Mastocarpus stellatus* (false Irish moss) varieties of kelp (*Laminaria* spp., *Saccharina latissima* and *Alaria esculenta*) and wracks (*Fucus* spp.) (The Heritage Council, 2008).

5. Hazards and risks associated with the consumption of seaweed and products derived from seaweed

Although the many edible species of seaweed themselves are not generally considered to pose a risk to human safety (Cheney, 2016), there are several potential safety risks associated with the consumption of seaweed, including the natural presence of chemical, biological and physical contaminants.

5.1 Chemical risks

5.1.1 Iodine

Iodine is an essential nutrient for mammals and is required for the synthesis of thyroid hormones. Thyroid hormones play an important role in energy-yielding metabolism and in the expression of genes that impact on many physiological functions, including embryogenesis and growth, as well as the development of neurological and cognitive functions (EFSA, 2014). Iodine deficiency can lead to significant health issues such as dysfunction or enlargement of the thyroid gland (Roleda *et al*., 2018). In 2014, the European Food Safety Authority (EFSA) established Dietary Reference Values for iodine, which are presented as Adequate Intake (AI) in Table 6. The World Health Organization (WHO), the United Nations Children's Fund (UNICEF) and the International Council for the Control of Iodine Deficiency Disorders (ICCIDD) recommend a slightly higher iodine intake of 250 µg/day for pregnant women (WHO, 2007).

Iodine is primarily acquired by humans through the consumption of foods such as marine products, eggs, dairy products and iodised salt (EFSA, 2017a). Various species of seaweed have strong bioadsorption and bioaccumulation capacities, with the result that their mineral content can be 10–100 times higher than that of terrestrial vegetables (Circuncisão *et al*., 2018).

Table 6 Adequate and tolerable upper intake levels of iodine (EFSA, 2017a)

Age	Adequate Intake (AI) (µg/day)	Upper Tolerable Limit (UL) (µg/day)*
7–11 months	70	–
1–3 years	90	200
4–6 years	90	250
7–10 years	90	300
11–14 years	120	450
15–17 years	130	500
≥18 years	150	600
Pregnant and lactating women	200	600

* These ULs do not apply to Iodine Deficiency Disease populations as they are more sensitive to iodine exposure, or to individuals who are being treated with iodine under medical supervision.

Excessive iodine intake can alter the normal function of the thyroid gland (Scientific Committee on Food, 2002) and can lead to thyroiditis and thyroid papillary cancer (National Institutes of Health, 2019). The Scientific Committee on Food (SCF) noted that the UL is not a threshold of toxicity and may be exceeded for short periods without an appreciable risk to the health of the individuals concerned. The SCF also concluded that ingestion of iodine-rich algal products, particularly dried products, can result in dangerously excessive iodine intakes.

A total diet study carried out in Ireland between 2012 and 2014 (FSAI, 2016c) estimated the average intake of iodine for adults at between 147 and 153 µg/day. The above-average (97.5th percentile) daily intake was estimated to fall between 354 and 359 µg/day. For children, the average intake ranged from 162 to 167 µg/day and above-average intake ranged from 363 to 368 µg/day. Iodine was detected in 60% of all foods analysed. Dairy products were the most important contributors of iodine to the diet of adults and children, contributing 73% and 85% to the overall dietary intake respectively. The results of this study indicate that the Irish population is generally not likely to experience over- or under-exposure to iodine in the diet. In comparison, average iodine intake in Japan is 1–3 mg/day, mainly due to the regular consumption of edible seaweed (Roleda *et al*., 2018).

Oceans are the richest source of bioavailable iodine, which can be present as inorganic iodate (IO_3^-) and iodide (I^-), with total iodine concentrations averaging 50–65 µg/L (Roleda *et al*., 2018). Seaweed bioaccumulates iodine, with particular kelp species (*Laminaria* spp.) being some of the richest natural sources (Nitschke and Stengel, 2015). The iodine content of seaweed varies significantly (Appendix 2) and can be species-specific (Roleda *et al*., 2018). Even within a particular seaweed species, the iodine concentration can vary between the different parts of the thallus such as the blade, mid, stipe and holdfast (Nitschke and Stengel, 2015).

Kelps (e.g. *Laminaria hyperborea* and *Laminaria digitata*) may contain relatively high quantities of iodine (Nitschke and Stengel, 2015). Members of the order Fucales and phylum Rhodophyta retain iodine at levels approximately one order of magnitude lower than kelps. Analyses of green macroalgae (phylum Chlorophyta) showed iodine concentrations about 100 times lower than those present in the order Laminariales. Other factors such as location, season, physiological stress and/or the size/age of the specimens have also been reported to influence iodine concentration (Nitschke and Stengel, 2015).

Edible seaweed is rarely consumed raw and undergoes processing (Figure 1) including washing, dehydration, rehydration and cooking/boiling, all of which can affect the iodine content. The potential exposure of humans to excess iodine via seaweed consumption strongly depends on post-harvest processing procedures (Nitschke and Stengel, 2016). Results of a recent study suggest that ingested iodine may have low bioavailability (<30%) and moderate bioaccessibility (48–82%) (Domínguez-González *et al.,* 2017).

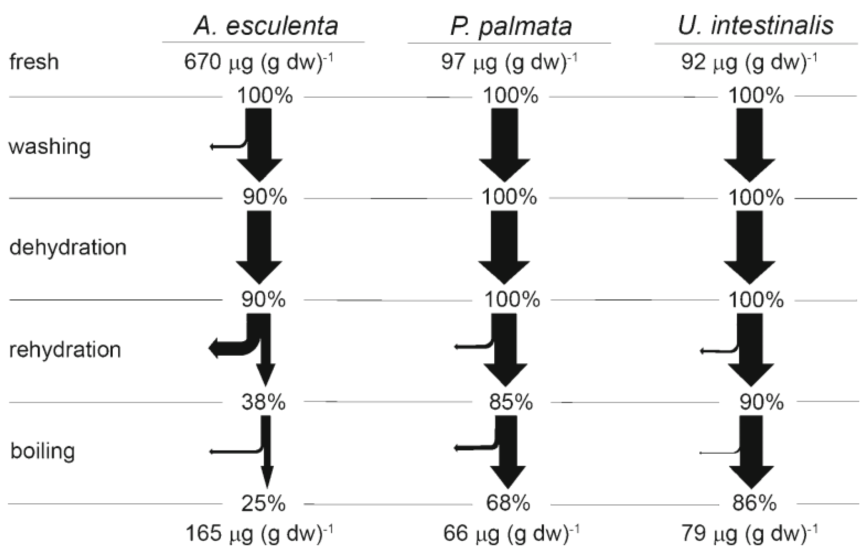

Figure 1 Iodine loss during processing

Source: (Nitschke and Stengel, 2016)

Ireland does not have established legislative limits for iodine content in seaweed.

The maximum permitted level of iodine in France is set at 2 mg/g dry weight for all species of edible seaweed (ANSES, 2018). In contrast, Germany recommends a maximum concentration of 20 mg/kg of iodine in dried seaweed for consumption and a maximum daily uptake of 500 µg/day (BfR, 2004).

France advises that seaweed and seaweed-derived products should not be consumed by (1) people with thyroid dysfunction, heart disease or kidney failure, (2) those taking medication containing iodine or lithium and (3) pregnant or breastfeeding women (ANSES, 2018).

5.1.2 Metals

Some metals are essential micronutrients, with metabolic roles as enzyme cofactors, enzyme activators and structural protein stabilisers (Hänsch and Mendel, 2009). All metals are toxic at certain concentrations and sometimes the difference between beneficial and toxic levels can be very small. Different seaweed species can accumulate and concentrate essential and non-essential metals from their environments. Using seaweed as a biomonitor for metal pollution, the Irish coastline was found to be a relatively clean environment despite the anticipated effects of population growth (Morrison *et al*., 2008).

The uptake of metals by seaweed can be achieved through electrostatic attraction with the surface, or via active uptake in which metal ions are transported across the cell membrane into the cytoplasm (Sánchez-Rodríguez *et al*., 2001). Metal accumulation in seaweed is influenced by: (i) environmental parameters (dissolved concentrations in water, water salinity, season, temperature, pH, light, nutrient concentrations and oxygen); (ii) the capacity of seaweed to accumulate metals; (iii) the structural differences between seaweed species (Trifan *et al*., 2015) and (iv) the interaction between all of these factors (Besada *et al*., 2009).

In humans, metal toxicity can negatively affect the brain, lungs, kidney, liver, blood composition and other organs. Long-term exposure can lead to progressive physical, muscular and neurological degenerative diseases. *In utero* metal exposure can cause neurological, developmental and endocrine disorders in infants (Caserta *et al*., 2013). Repeated long-term exposure to some metals may even be associated with certain cancers (Jaishankar *et al*., 2014).

Maximum levels (MLs) of arsenic, cadmium and lead in various foodstuffs are established under Commission Regulation (EC) No 1881/2006. Currently, MLs are not established for these metals in seaweed, except for the MLs for food supplements consisting exclusively or mainly of seaweed or products derived from seaweed. Commission Recommendation (EU) 2018/464 stipulates that Member States, in collaboration with food and feed business operators, should monitor the presence of arsenic, cadmium, iodine, lead and mercury in seaweed, halophytes and products based on seaweed during 2018, 2019 and 2020. The data gathered are to be provided to EFSA and will be used to assess whether the contribution of arsenic, cadmium, iodine, lead and mercury from seaweed and halophytes to the total exposure of these substances would necessitate the establishment of MLs for arsenic, cadmium and lead for these commodities, or the amendment of the maximum residue limit (MRL) for mercury from algae and prokaryotic organisms, or any action to be taken related to the exposure to iodine from these products.

5.1.2.1 Mercury

Limited information is available in the literature with respect to the content of total mercury (THg) and methylmercury (MeHg) in edible seaweed (Appendix 3). Mercury concentration in seaweed is influenced by environmental parameters, including the uptake capacity of the seaweed and seasonal variation. It is not clear whether post-harvest processing of seaweed can lower the mercury content.

Excessive human exposure to mercury is associated with a broad spectrum of adverse health effects, including damage to the central nervous system, kidneys and possibly the cardiovascular system (FSAI, 2016c). Epidemiological studies in exposed human populations, as well as toxicological studies in animals have shown a range of neurological disturbances, including impaired learning and brain damage (FSAI, 2016c). The EFSA Panel on Contaminants in the Food Chain concluded that the developing brain should be considered the most sensitive target organ for MeHg toxicity (EFSA, 2004). Currently in Ireland and the EU, there are no regulatory limits set for mercury in edible seaweed. EFSA has established a tolerable weekly intake (TWI) for MeHg of 1.3 µg/kg body weight and a TWI for inorganic mercury of 4 µg/kg body weight, both expressed as mercury (EFSA, 2012). The Joint Food and Agriculture Organization/World Health Organization Expert Committee on Food Additives (JECFA) established a provisional TWI for MeHg of 1.6 µg/kg body weight and for inorganic mercury of 4 µg/kg body weight (WHO, 2011).

5.1.2.2 Arsenic

Arsenic exists in organic and inorganic forms, with the latter considered a highly toxic Class I carcinogen (IARC, 2004). Long-term exposure to low levels of inorganic arsenic is associated with adverse health effects such as skin lesions, cancer, developmental toxicity, cardiovascular diseases, neurotoxicity and diabetes (Cherry *et al*., 2019).

Arsenic is a naturally occurring chemical element in the earth’s crust and is widely distributed throughout the environment (air, water and land). Of global concern is the relatively high concentration of arsenic in groundwater. Although there are regional hotspots, the levels of arsenic in Irish ground water are not universally elevated (McGrory *et al*., 2017). Routine monitoring by the Marine Institute as part of the national programme for coastal water shows that total arsenic levels in seawater and biota do not vary greatly (0.5–2 µg/L) around the coast of Ireland (Ronan *et al*., 2017). Fish and seafood are the main dietary sources of arsenic, contributing more than 50% of the daily intake of arsenic (EFSA, 2009b). The predominant form of arsenic found in fish is arsenobetaine, a non-toxic organoarsenic.

Seaweed can contain high levels of total arsenic, while inorganic arsenic levels are generally low, with the exception of brown seaweed species (Appendix 4). A greater level of total arsenic in brown seaweed relative to green and red seaweed is associated with a higher alginic acid content in the class Phaeophyceae (Duinker *et al*., 2016). Most arsenic in seaweed is in the form of arsenosugars, typically bonded to glycerol, sulfonate or phosphate (Marine Institute, 2015). Arsenosugars have been shown to resist degradation in the stomach and are metabolised in the gastrointestinal tract to at least 12 different metabolites of unknown toxicity (Cherry *et al*., 2019). Arsenolipids such as arsenic-containing hydrocarbons have been shown to be as cytotoxic as inorganic arsenic (Meyer *et al*., 2015), while the toxicology of other commonly occurring arsenolipids (arsenic-containing phospholipids) in seaweed has not been established (Ronan *et al*., 2017).

Hijiki (*Hizikia fusiforme*) has been found to contain relatively high concentrations (>60 mg/kg) of inorganic arsenic (FSAI, 2016a). The potential risk of arsenic poisoning due to hijiki consumption has led to recommendations regarding its safe consumption (FSA, 2004; FSAI, 2015). Significant levels of total arsenic were found in two species of brown algae sampled from the Irish coast: *Laminaria digitata* (49.4–114 µg/g dry weight) and *Ascophyllum nodosum* (64 µg/g dry weight) (Ronan *et al*., 2017). Processing and cooking of *Porphyra* spp. and hijiki can alter the inorganic arsenic content (Laparra *et al*., 2003). Japanese traditional washing and soaking with water before cooking hijiki can reduce the total arsenic content by 60% (Hanaoka *et al*., 2001). The JECFA concluded that washing or soaking seaweed and discarding the water before cooking can reduce the levels of arsenic, especially inorganic arsenic (WHO, 2011).

Ireland's Health (Arsenic and Lead in Food) Regulations, 1972 (Statutory Instrument No. 44 of 1972) stipulate that any edible seaweed or product containing edible seaweed may contain arsenic in a proportion exceeding one part per million (ppm), where such arsenic is naturally present in that edible seaweed or is in that product by reason of the edible seaweed content.

5.1.2.2.1 Arsenic in animal feed

Ascophyllum nodosum has a history of use as a supplement in livestock feed and is the primary algal species used for the production of animal feed globally (Mac Monagail *et al*., 2017; Makkar *et al*., 2016). The ability of seaweed to bioaccumulate metals from the surrounding seawater (García-Seoane *et al*. 2018; Morrison *et al*., 2008) and particularly the presence of elevated levels of arsenic in certain species of brown seaweed (Mac Monagail and Morrison, 2019; Taylor *et al*.;

2017; Ratcliff *et al*., 2016; Francesconi, 2010) has raised concerns regarding their safe use in animal feed. A level of uncertainty surrounds the potential risk from arsenic in animal feed produced with seaweed, given that most arsenic in seaweed is present in organic forms (Almela *et al.,* 2006; Chávez-Capilla *et al.*, 2016), the toxicity of which is still unclear (Feldmann and Krupp, 2011). However, a recent study indicates that there is a negligible risk of human exposure to arsenic through the consumption of products (milk, beef, chicken and eggs) from animals reared on a diet supplemented with *Ascophyllum nodosum* (Mac Monagail *et al., 2*018)*.* A series of methylation steps which occurs within the gut of the animal, plus high excretion rates in both humans and animals results in a low biotransfer of arsenic from *Ascophyllum nodosum* (Mac Monagail and Morrison, 2019; Mac Monagail *et al*., 2018).

EU Directive 2002/32/EC established a maximum total arsenic content of 40 mg/kg dry weight (relative to feed with a moisture content of 12%) in seaweed meal and feed materials derived from seaweed. The responsible operator must perform analysis to demonstrate that the content of inorganic arsenic is lower than 2 ppm.

5.1.2.3 Lead

Lead is not considered a typical contaminant in seaweed and measurable levels can be linked to a point source (van Netten *et al*., 2000). The limited information available on the content of lead in different seaweed species (Appendix 5) does not suggest that lead is a widespread contaminant and therefore the risk of human exposure through the consumption of seaweed is considered to be low. However, more data regarding lead content in seaweed and seaweed consumption are required in order to better assess the true extent of that risk.

Lead is a cumulative poison primarily affecting the kidneys, hematopoietic and nervous systems. Long-term exposure to lead may cause damage to bodily systems (reproductive, immune and nervous) and to the kidneys (FSAI, 2016c). Short-term exposure to high levels of lead has been associated with brain damage, paralysis (lead palsy), anaemia and gastrointestinal symptoms. Infants and young children are more vulnerable to the toxic effects of lead than adults as they absorb it more readily. Like mercury, lead crosses the placental barrier and accumulates in the foetus where it can hinder intellectual development in young children (FSAI, 2016c). Organic and inorganic lead are considered possible carcinogens in humans (IARC, 2006).

It is not clear if processing affects lead content in seaweed, although some species of conventionally cultivated seaweed have been shown to have a slightly elevated lead concentration (0.08 μg/g dry weight) compared to their organically cultivated counterparts (0.05 μg/g dry weight) (Rubio *et al*., 2017). There is no EU or Irish legislative limit currently set for lead in seaweed used as food and feed. France was the first European country to establish a specific regulation concerning the lead content (<5 µg/g) of fresh and dried seaweed for human consumption (Mabeau and Fleurence, 1993).

5.1.2.4 Cadmium

Cadmium is a toxic contaminant which can enter the food chain as a result of human-related activities. It is poorly absorbed into the body and slowly excreted, having a half-life of 10–20 years. Most of the cadmium in the body is retained in the liver and kidneys and the principal toxic effect is its kidney toxicity (FSAI, 2016c). Cadmium has been categorised as a Class 1 human carcinogen (IARC, 2012). The risk of human exposure to cadmium via seaweed consumption can be high as it may bioaccumulate in some seaweed species. EFSA has established a TWI of 2.5 µg/kg body weight (EFSA, 2009a).

It is not clear whether processing has any effect on the cadmium content of seaweed. However, organically cultivated seaweed has been shown to contain lower levels (0.13 µg/g dry weight) relative to conventionally cultivated seaweed (0.28 µg/g dry weight) (Rubio *et al*., 2017).

Commission Regulation (EC) No 1881/2006 sets a maximum limit for cadmium in food supplements containing seaweed and seaweed-derived products at 3 mg/kg wet weight. France has set a maximum limit for cadmium in edible seaweed of 0.5 µg/g dry weight (Mabeau and Fleurence, 1993).

A wide variation in cadmium content can be observed between the various seaweed species (Appendix 6 and Appendix 7). The highest cadmium content (62 µg/g dry weight) was found in green algae (*Ulva lactuca*) which was dried and ground (Kamala-Kannan *et al*., 2008). In red seaweed, the highest cadmium content (3.10 µg/g dry weight) was found in *Porphyra umbilicalis* (Besada *et al*., 2009). Among brown seaweed, the highest cadmium content (10.03 µg/g dry weight) was reported in *Fucus vesiculosus* (Giusti, 2001).

5.1.3 Pesticides

Pesticides such as organophosphates, carbamates and pyrethroids have been associated with the aquaculture industry and are known to be neurotoxic (García-Rodríguez *et al*., 2012; Moreno *et al*., 2007). Agrochemicals, including herbicides and pesticides also have the potential to enter the marine environment through run-off and leaching from agricultural use (Sapkota *et al*., 2008). A multi-residue analytical baseline survey for pesticide monitoring could help to establish the risk (if any) posed to human health by contaminated seaweed.

5.1.4 Radioactive material

Radioactivity in the environment can be naturally occurring or associated with human activity (e.g. nuclear power plants, nuclear processing facilities or nuclear accidents). The presence of naturally occurring ^{210}Polonium is the most common cause of radiation exposure through the consumption of marine foodstuffs (McMahon *et al*., 2005). Other naturally occurring radionuclides associated with seaweed include ^{7}Beryllium, ^{234}Thorium and ^{228}Radon (Ishikawa *et al*., 2004). Artificial radionuclides that have the potential to contaminate the environment from medical or scientific waste such as ^{131}Iodine are relatively short-lived and their contribution to the marine environment is not considered significant. However, artificial radionuclides resulting from nuclear weapons testing in the 1950s and 1960s (^{3}Hydrogen, ^{14}Carbon, ^{90}Strontium, ^{137}Caesium, ^{238}Plutonium, ^{239}Plutonium and ^{240}Plutonium) were widely dispersed and persist in the environment (McMahon *et al*., 2005).

Once present in the environment, these radionuclides are available for uptake by plants and animals through which they can make their way into the food chain (McMahon *et al*., 2005). The ability of seaweed to concentrate the very low levels of radionuclides in the marine environment is one of the reasons for its suitability in biomonitoring programmes for radioactive discharges (Goddard and Jupp, 2001).

Concentrations of radionuclides in seaweed have been shown to vary depending on the season, species or specific events such as a radiological incident. Radionuclides are a potential hazard for edible seaweed that is harvested in an area following a nuclear accident, such as the 2011 Fukushima incident in Japan (Banach *et al*., 2020). Council Regulation (Euratom) 2016/52 sets out the maximum permitted levels of radioactive contamination of food and feed following a nuclear accident or any other radiological emergency.

The levels of radionuclides in Irish cultivated seaweed are low and are not considered a significant health risk (McMahon *et al*., 2005).

5.1.5 Persistent organic pollutants

Persistent organic pollutants are organic, lipid-soluble pollutants including dioxins and polychlorinated biphenyls (PCBs). Some of these persistent xenobiotics are considered to be endocrine disrupters and carcinogens (Carvalho *et al*., 1999). Most seaweed species have a low lipid content and therefore a low concentration of fat-soluble pollutants (Duinker *et al*., 2016). Dioxins and PCBs can be found in some species of seaweed (*Undaria* spp. and *Ecklonia* spp.), especially in areas of high industrial pollution (Banach *et al*., 2020). *Ulva* spp. grown in contaminated sites have been observed to concentrate PCBs which can then be transferred up the food chain (Cheney *et al*., 2014).

5.2 Biological risks

5.2.1 Dinoflagellate toxins

Dinoflagellates (class Dinophyceae) are protists (unicellular eukaryotes) propelled by two dimorphic flagella (Faust and Gulledge, 2002). Some dinoflagellates produce chemicals that can be extremely toxic, even at low doses (Wang, 2008). Population blooms of toxin-producing dinoflagellates, including 'red-tide-forming' organisms can lead to large-scale fish deaths. Certain toxins produced by dinoflagellates have long been associated with human illnesses such as paralytic shellfish poisoning, neurotoxic shellfish poisoning, diarrhetic shellfish poisoning and ciguatera (Carty and Parrow, 2014; Baden, 1983). Some dinoflagellates are considered to be epiphytic and grow in close association with seaweed, while others are benthic and are associated with sediment material such as coral rubble, sand and organic detritus (Vila *et al*., 2001).

As an example, *Prorocentrum lima* is a coastal or estuarine dinoflagellate species which can be found globally and can attach to the surface of red and brown macroalgae (Faust and Gulledge, 2002).

Ciguatera fish poisoning is a human disease caused by the ingestion of marine finfish that are contaminated with polyether toxins (ciguatoxins and maitotoxins, among others). Ciguatera poisoning can cause gastrointestinal and neurological disorders and can sometimes be fatal. The dinoflagellate *Gambierdiscus toxicus* causes ciguatera poisoning and can be found attached to the surface of seaweed which is consumed by herbivorous fish. Consumption of those herbivorous fish then exposes the consumer to ciguatera poisoning (Vila *et al*., 2001). *G. toxicus* can be found in tropical waters but not usually in Irish waters and so the only real risk to Irish consumers comes from fresh or frozen imported contaminated seaweed (FSAI, 2016b). This may change in the future however, if global warming facilitates the expansion of *G. toxicus* into Irish waters.

The peridinoid dinoflagellate *Vulcanodinium rugosum* is the only known producer of pinnatoxins, members of the cyclic imine group of marine toxins. These marine toxins are most commonly associated with filter feeders such as shellfish (Rhodes *et al*., 2010) in the warm or temperate waters off Australia, New Zealand, Japan, the Mexican Pacific and Hawaii (de la Iglesia *et al*., 2014). However, pinnatoxins have also been associated with a seaweed (*Saccharina latissima*) in cold Norwegian waters, possibly linked to the presence of dinoflagellates attached to the surface of the seaweed. The level of the pinnatoxin identified was 10 to 100-fold lower than that reported in shellfish and so consumption of this seaweed is currently not considered to pose a significant safety risk (de la Iglesia *et al*., 2014). EFSA was unable to determine the risk associated with the consumption of shellfish containing pinnatoxins due to the limited toxicological and exposure data available (EFSA, 2010).

5.2.2 Cyanobacteria

Cyanobacteria are photosynthetic bacteria that can be found in all bodies of water. The dried biomass of *Arthrospira* spp. (spirulina) is an established food ingredient. However, some cyanobacteria can be toxic to the hepatic, neurological, gastrointestinal and integumentary systems, while also having embryo-lethal, teratogenic, mutagenic and tumour-promoting activities (Kubickova *et al*., 2019). Although many toxic species of cyanobacteria are found in freshwater systems, highly toxic marine species have also been identified (Osborne *et al*., 2001). EFSA has identified the epiphytic growth of filamentous cyanobacteria on edible seaweed as a potential emerging issue (EFSA, 2017b).

5.2.3 Pathogenic microorganisms

Microbial contamination can occur during the growth, harvesting, processing or storage of seaweed and a certain level of official control monitoring is carried out in Ireland each year (Appendix 8). Bacterial communities belonging to the Proteobacteria and Firmicutes phyla are usually the most abundant on seaweed surfaces. The surface of seaweed contains an exopolysaccharide layer (secreted organic substances) which, under the right conditions facilitates the attachment and growth of microbial communities. Seaweed-associated microorganisms also have an ecological function in the morphogenesis and growth of seaweed (Singh and Reddy, 2014), but the role of edible seaweed as reservoirs for pathogenic microorganisms is not well understood.

A study of an edible red seaweed (*Palmaria palmata*) collected off the coast of Northern Ireland did not reveal the presence of human gastrointestinal pathogens such as *Escherichia coli* O157, *Salmonella* spp., *Listeria monocytogenes*, *Staphylococcus aureus*, *Vibrio* spp. or *Campylobacter* spp. (Moore *et al*., 2002).

The authors of a number of studies have concluded that coastal seaweed could act as a year-round reservoir for diverse *Vibrio parahaemolyticus* populations (Mahmud *et al*., 2008; Mahmud *et al*., 2007; Mahmud *et al*., 2006). They observed that *V. parahaemolyticus* occurrence has a positive correlation with water temperature, observing an abundance in seaweed that was at least 50 times greater during the summer (20–29 °C) compared to the winter (10–18 °C). Even though *Vibrio*-associated foodborne infections have been observed sporadically in Ireland, there have not been any incidents demonstrably connected to the consumption of seaweed. The *Vibrio* genus is relatively sensitive to heating and drying processes and therefore is unlikely to survive routine food production processes. However, the consumption of fresh or fresh-frozen seaweed could pose a risk (Mahmud *et al*., 2008; Mahmud *et al*. 2007; Mahmud *et al*., 2006).

The risks posed by other pathogenic organisms, including bacterial spore formers (e.g. *Clostridium* and *Bacillus* spp.) have not been evaluated to a significant extent.

Norovirus associated with food and water causes a significant number of acute gastroenteritis incidents worldwide each year (Lee *et al*., 2015). Certain molluscs, crustaceans, fruits and vegetables are the foods most commonly associated with norovirus illness, especially when they are consumed raw (Kusumi *et al*., 2017). A number of norovirus outbreaks were linked to seaweed consumption in South Korea in 2012 (Park *et al*., 2015), in Japan in 2017 (Kusumi *et al*., 2017) and in Norway in 2019 (RASFF, 2019, Reference: 2019.3003). Norovirus contamination of seaweed is also considered an emerging risk (EFSA, 2017b).

5.2.4 Allergens

Seaweed is not known to pose a significant allergenic risk to consumers (Miyake *et al*., 2006). However, due to the marine origin, it is possible that edible seaweed could carry debris from fish, molluscs and crustaceans, constituting a relatively minor and indirect allergenic risk.

5.3 Physical risks: Microplastics

Microplastics are highly persistent in the environment and have been accumulating in different ecosystems for some time (Andrady, 2011). Due to its mass production, widespread use and the speed at which it accumulates in various habitats, plastic has become the most common type of marine litter worldwide (Bhattacharya *et al*., 2010).

EFSA has defined microplastics as a "heterogeneous mixture of differently shaped materials referred to as fragments, fibres, spheroids, granules, pellets, flakes or beads, in the size range of 0.1–5,000 µm" (EFSA, 2016). Microplastics (particles and fibres) in the marine environment may be introduced in their originally manufactured size of micro- or nano-sized particles, or result from the fragmentation of larger plastic debris (EFSA, 2016). In the marine environment, microplastics have been detected in a large variety of zooplanktonic organisms; invertebrates such as crustaceans and bivalves; as well as vertebrates such as fish, seabirds and marine mammals (Bouwmeester *et al*., 2015).

Microplastics have been shown to absorb organic and inorganic contaminants from their environments and therefore can act as vehicles for industrial or environmental chemical contaminants (EFSA, 2016). Some of these possibly harmful chemical contaminants include styrene, toxic metals, phthalates, bisphenol A, PCBs and polycyclic aromatic hydrocarbons (Barboza *et al*., 2018).

While there are relatively few studies addressing the presence of microplastics in seaweed, *in vitro* evidence suggests that at least one brown seaweed (*Fucus vesiculosus*) can retain suspended microplastics on its surface at levels correlating with the concentration in the surrounding water (Gutow *et al*., 2016). Seaweed has been shown to efficiently accumulate additives (e.g. phthalates) from microplastics that can adhere to the seaweed surface. However, more data are needed before a conclusion can be reached on the actual risk to consumers or the wider environment (Gutow *et al*., 2016).

In humans, only microplastics smaller than 150 μm may translocate across the gut epithelium, causing systemic exposure. The absorption of these microplastics is expected to be limited (≤0.3%) and only the smallest particles (<1.5 μm) may penetrate deep into organs (EFSA, 2016).

There is currently no legal limit set for microplastics and nanoplastics as contaminants in food. EFSA estimates that the presence of microplastics in food would have a minimal effect on the overall human exposure to additives or contaminants (EFSA, 2016). In addition, the WHO has also anticipated that the potential for additives to leach from microplastics will be relatively small and depend on a variety of factors such as the relative size of the particle, the mass of chemicals accumulated, the gastrointestinal residence time of the particle and the relative level of contamination within the gut (WHO, 2019). However, there are considerable gaps in the available data and capabilities required in order to carry out a meaningful risk assessment on the presence of microplastics and nanoplastics in food and the environment.

6. Conclusions

Due to its geographical location and the number of different seaweed species found along an extensive coastline, Ireland seems to be a suitable location for seaweed production and processing. However, while reliable quantitative data for wild-harvested seaweed are not available, the amount of aquaculture-produced seaweed in Ireland seems insignificant when compared to the major seaweed-producing countries. Seaweed produced in Ireland is primarily wild harvested and destined mainly for the export market. Seaweed is a significant component in the diets of some Asian countries, but currently only comprises a minor proportion of the western diet. The Irish market for food and feed containing or consisting of seaweed is relatively small (niche market) compared to the overall food and feed market in Ireland. Therefore, there is currently a low potential for exposure of the general Irish population to any possible risks that may be associated with Irish-grown seaweed. However, the level of risk may be higher for those who frequently consume Irish seaweed and seaweed products, or those who consume imported seaweed grown or processed in other countries.

Seaweed growth and development is strongly dependent on the nutritional content of the water in which it is grown as well as local environmental conditions. Seaweed is generally low in fat content and can be a valuable source of certain micronutrients when consumed as or in a food. A considerable number and variety of hydrocolloids and polysaccharides can be found in seaweed, which forms the basis for the additive functions (i.e. thickeners, gelling agents, etc.) of seaweed or seaweed extracts in food.

A number of chemical, biological and physical hazards are associated with seaweed when used as food or feed. Due to the ability of seaweed to bioaccumulate certain minerals and metals from the growth environment, chemical hazards pose the greatest risk to human health. However, the level of risk posed by such hazards varies with the type of seaweed and can be mitigated by certain post-harvest physical processing in some cases. Iodine can be obtained from certain foods including seaweed and is an essential dietary mineral that is critical to a number of normal physiological functions. However, iodine can also be found in certain brown seaweed species at levels at which it can pose a safety risk. The amount of iodine in seaweed can be reduced by washing or cooking the raw harvested material. As with iodine, certain metals (mercury, lead, cadmium and arsenic) with no known biological function in humans can bioaccumulate in seaweed. The presence of some, but not all of these metals in seaweed can also be reduced by processes like washing or cooking. Regulatory limits or EFSA-tolerable intake levels apply to some metals in food.

Acknowledging the increasing importance of seaweed in the diet of some EU Member States, the European Commission deemed it necessary in 2018 to assess whether the contribution of arsenic, cadmium, iodine, lead and mercury from seaweed to the total exposure of these substances would necessitate regulatory measures. Member States were asked to collect occurrence data for arsenic, cadmium, iodine, lead and mercury in different seaweed species, halophytes and products based on seaweed to support a dietary exposure assessment (EC, 2018).

Other chemical hazards include environmental pollutants such as PCBs, dioxins and pesticide residues, but these are not exclusive to food made with seaweed. Such pollutants can enter marine and freshwater systems as a result of their direct use in aquaculture and agriculture, or as contaminating by-products of industrial processes.

Seaweed can be associated with certain biological hazards including dinoflagellate toxins (e.g. ciguatoxins and pinnatoxins) as well as cyanobacteria and pathogenic microorganisms. However, along with physical hazards like microplastics and nanoplastics, there are currently insufficient data available to suggest that these contaminants pose a significant risk to consumers in general through the consumption of seaweed or seaweed-based foods.

7. Recommendations

Although there is some potential for growth, the size of the Irish seaweed industry as it relates to food production is relatively small when compared to the overall food industry in Ireland. The following recommendations may assist in ensuring the safe growth of seaweed use as or in food:

1. Explore ways to assess the consumption of seaweed in the Irish population.
2. The hazards associated with seaweed use as or in food that pose the greatest risk to consumer safety at present are iodine and certain metals. Surveillance and monitoring should continue at current levels and where appropriate, at enhanced levels, particularly for imported seaweed products.
3. If the current EU monitoring programme for iodine and metals concludes that there is a need, the FSAI should support the establishment of EU maximum limits and provide data collected on retail samples generated by the Marine Institute and third-level colleges.
4. Further data should be identified that may elucidate the extent and nature of the Irish market for wild-harvested seaweed.
5. As part of the emerging risks work carried out by the FSAI, monitoring of national and international data related to the presence of microplastics and nanoplastics in marine and freshwater environments should be undertaken. These data may help to clarify whether this persistent and ubiquitous pollutant could affect the safety of seaweed use in food.
6. The FSAI should explore the need for consumer advice to vulnerable groups.
7. Risks currently not associated with Irish waters (e.g. the dinoflagellate *Gambierdiscus toxicus* which causes ciguatera) should be monitored and reviewed in light of climate change.

8. References

Akcali I and Kucuksezgin F (2011) A biomonitoring study: Heavy metals in macroalgae from eastern Aegean coastal areas. *Marine Pollution Bulletin,* 62(3), 637–645.

Almela C, Algora S, Benito V, Clemente MJ, Devesa V, Súñer MA, Vélez D and Montoro R (2002) Heavy metal, total arsenic, and inorganic arsenic contents of algae food products. *Journal of Agricultural and Food Chemistry,* 50(4): 918–923.

Almela C, Clemente MJ, Vélez D and Montoro R (2006) Total arsenic, inorganic arsenic, lead and cadmium contents in edible seaweed sold in Spain. *Food and Chemical Toxicology,* 44(11): 1901–1908.

Almela C, Laparra JM, Vélez D, Barberá R, Farré R and Montoro R (2005) Arsenosugars in raw and cooked edible seaweed: characterization and bioaccessibility. *Journal of Agricultural and Food Chemistry,* 53(18): 7344–7351.

Andrady AL (2011) Microplastics in the marine environment. *Marine Pollution Bulletin,* 62(8): 1596–1605.

ANSES, French Agency for Food, Environmental and Occupational Health & Safety (2018) *OPINION of the French Agency for Food, Environmental and Occupational Health & Safety on the risk of excess iodine intake from the consumption of seaweed in foodstuffs.* Maisons-Alfort. Available at: https://www.anses.fr/en/system/files/NUT2017SA0086EN.pdf

Baden DG (1983) Marine Food-Borne Dinoflagellate Toxins. *International Review of Cytology,* 82: 99–150.

Banach JL, Hoek-van den Hil EF and van der Fels-Klerx HJ (2020) Food safety hazards in the European seaweed chain. *Comprehensive Reviews in Food Science and Food Safety,* 19(2): 332–364.

Barbier M, Charrier B, Araujo R, Holdt SL, Jacquemin B and Rebours C (2019) *PEGASUS - Phycomorph European Guidelines for a Sustainable Aquaculture of Seaweeds, COST Action FA1406.* Roscoff, France: PEGASUS. Available at: http://www.phycomorph.org/pegasus-phycomorph-european-guidelines-for-a-sustainable-aquaculture-of-seaweeds

Barboza LGA, Vethaak AD, Lavorante BRBO, Lundebye AK and Guilhermino L (2018) Marine microplastic debris: An emerging issue for food security, food safety and human health. *Marine pollution bulletin,* 133: 336–348.

Besada V, Andrade JM, Schultze F and González JJ (2009) Heavy metals in edible seaweeds commercialised for human consumption. *Journal of Marine Systems,* 75(1–2): 305–313.

BfR (2004) *Health risks linked to high iodine levels in dried algae.* BfR Opinion No. 026/2007. Berlin: Federal Institute for Risk Assessment. Available at: https://mobil.bfr.bund.de/cm/349/health_risks_linked_to_high_iodine_levels_in_dried_algae.pdf

Bhattacharya P, Lin S, Turner JP and Ke PC (2010) Physical Adsorption of Charged Plastic Nanoparticles Affects Algal Photosynthesis. *The Journal of Physical Chemistry C,* 114(39): 16556–16561.

Bikker P, van Krimpen MM, van Wikselaar P, Houweling-Tan B, Scaccia N, van Hal JW, Huijgen WJJ, Cone JW and López-Contreras AM (2016) Biorefinery of the green seaweed *Ulva lactuca* to produce animal feed, chemicals and biofuels. *Journal of Applied Phycology,* 28(6): 3511–3525.

BIM (2015) *The European Market for Sea Vegetables.* Bord Iascaigh Mhara. Available at: http://www.bim.ie/media/bim/content/publications/The,European,Market,for,Sea,Vegetables,-,2015.pdf

BIM (2016) *Report on BIM Seaweed Development Programme 2016*. Bord Iascaigh Mhara. Available at: http://www.bim.ie/media/bim/content/publications/aquaculture/BIM-Seaweed-Development-Programme-2016.pdf

BIM (2019) *National Seafood Survey: Aquaculture Report 2019*. Bord Iascaigh Mhara. Available at: http://www.bim.ie/media/bim/content/publications/aquaculture/BIM-National-Seafood-Survey-Aquaculture-Report-2019.pdf

BIM (2020) Scoping a seaweed biorefinery concept for Ireland: Report for Bord Iascaigh Mhara, http://www.bim.ie/media/bim/content/publications/aquaculture/BIM-Scoping-a-seaweed-biorefinery-concept-for-Ireland.pdf

Bocanegra A, Bastida S, Benedí J, Ródenas S and Sánchez-Muniz FJ (2009) Characteristics and nutritional and cardiovascular-health properties of seaweeds. *Journal of Medicinal Food,* 12(2): 236–258.

Bonanno G and Orlando-Bonaca M (2018) Chemical elements in Mediterranean macroalgae. A review. *Ecotoxicology and Environmental Safety,* 148: 44–71.

Bouwmeester H, Hollman PCH and Peters RJB (2015) Potential Health Impact of Environmentally Released Micro- and Nanoplastics in the Human Food Production Chain: Experiences from Nanotoxicology. *Environmental Science & Technology,* 49(15): 8932–8947.

Brownlee I, Fairclough A, Hall A and Paxman J (2012) The potential health benefits of seaweed and seaweed extract. In: VH Pomin (ed.) *Seaweed: ecology, nutrient composition and medicinal uses.* Hauppauge, New York: Nova Science Publishers. pp. 119–136.

Burtin P (2003) Nutritional value of seaweeds. *Electronic Journal of Environmental, Agricultural and Food Chemistry,* 2(4): 498–503.

Buschmann AH, Camus C, Infante J, Neori A, Israel Á, Hernández-González MC, Pereda SV, Gomez-Pinchetti JL, Golberg A, Tadmor-Shalev N and Critchley AT (2017) Seaweed production: overview of the global state of exploitation, farming and emerging research activity. *European Journal of Phycology,* 52(4): 391–406.

Caliceti M, Argese E, Sfriso A and Pavoni B (2002) Heavy metal contamination in the seaweeds of the Venice lagoon. *Chemosphere,* 47(4): 443–454.

Caroprese M, Ciliberti MG, Marino R, Santillo A, Sevi A and Albenzio M (2016) Polyunsaturated fatty acid supplementation: effects of seaweed *Ascophyllum nodosum* and flaxseed on milk production and fatty acid profile of lactating ewes during summer. *Journal of Dairy Research,* 83(3): 289–297.

Carty S and Parrow MW (2014) Dinoflagellates. In: JD Wehr, RG Sheath and JP Kociolek (eds.) *Freshwater Algae of North America - Ecology and Classification* (2nd edn.). Amsterdam; Boston: Academic Press. pp. 773–807.

Carvalho FP, Villeneuve JP and Cattini C (1999) The determination of organochlorine compounds and petroleum hydrocarbons in a seaweed sample: results of a world-wide intercomparison exercise. *TrAC Trends in Analytical Chemistry,* 18(11): 656–664.

Caserta D, Graziano A, Lo Monte G, Bordi G and Moscarini M (2013) Heavy metals and placental fetal-maternal barrier: a mini-review on the major concerns. *European Review for Medical and Pharmacological Sciences,* 17(16): 2198–2206.

Chan JCC, Cheung PCK and Ang PO (1997) Comparative Studies on the Effect of Three Drying Methods on the Nutritional Composition of Seaweed *Sargassum hemiphyllum* (Turn.) C. Ag. *Journal of Agricultural and Food Chemistry*, 45(8): 3056–3059.

Chávez-Capilla T, Beshai M, Maher W, Kelly T and Foster S (2016) Bioaccessibility and degradation of naturally occurring arsenic species from food in the human gastrointestinal tract. *Food Chemistry,* 212: 189–197.

Cheney D (2016) Toxic and Harmful Seaweeds. In: I Levine and J Fleurence (eds.) *Seaweed in Health and Disease Prevention* (1st edn.). Amsterdam; Boston: Academic Press. pp. 407–421.

Cheney D, Rajic L, Sly E, Meric D and Sheahan T (2014) Uptake of PCBs contained in marine sediments by the green macroalga *Ulva rigida*. *Marine Pollution Bulletin,* 88(1–2): 207–214.

Cherry P, O'Hara C, Magee PJ, McSorley EM and Allsopp PJ (2019) Risks and benefits of consuming edible seaweeds. *Nutrition Reviews,* 77(5): 307–329.

Circuncisão AR, Catarino MD, Cardoso SM and Silva AMS (2018) Minerals from macroalgae origin: health benefits and risks for consumers. *Marine Drugs,* 16(11): 400.

Cofrades S, López-López I, Bravo L, Ruiz-Capillas C, Bastida S, Larrea MT and Jiménez-Colmenero F (2010) Nutritional and antioxidant properties of different brown and red Spanish edible seaweeds. *Food Science and Technology International,* 16(5): 361–370.
Dawczynski C, Schubert R and Jahreis G (2007) Amino acids, fatty acids, and dietary fibre in edible seaweed products. *Food Chemistry,* 103(3): 891–899.
de la Iglesia P, del Río V and Diogène J (2014) The sugar kelp *Saccharina latissima* is a potential source of the emerging toxin, Pinnatoxin-G, in cold waters. *16th International Conference on Harmful Algae*, 27–31 October, Wellington, New Zealand.
Delaney A, Frangoudes K and Li SA (2016) Society and seaweed: understanding the past and present. In: I Levine and J Fleurence (eds.) *Seaweed in Health and Disease Prevention* (1st edn.). Amsterdam; Boston: Academic Press. pp. 7–40.
Diaz-Pulido G and McCook L (2008) Environmental Status: Macroalgae (Seaweeds). In: A. Chin (ed.) *The State of the Great Barrier Reef On-line*. Townsville, Australia: Great Barrier Reef Marine Park Authority. Available at: http://www.gbrmpa.gov.au/__data/assets/pdf_file/0019/3970/SORR_Macroalgae.pdf
Domínguez-González MR, Chiocchetti GM, Herbello-Hermelo P, Vélez D, Devesa V and Bermejo-Barrera P (2017) Evaluation of iodine bioavailability in seaweed using in vitro methods. *Journal of Agricultural and Food Chemistry,* 65(38): 8435–8442.
Duinker A, Sunde Roiha I, Amlund H, Dahl L, Lock EJ, Kögel T, Måge A and Tore Lunestad B (2016) *Potential risks posed by macroalgae for application as feed and food - a Norwegian perspective.* Bergen, Norway: National Institute of Nutrition and Seafood Research (NIFES).
EC (2018) *Commission Recommendation (EU) 2018/464 of 19 March 2018 on the monitoring of metals and iodine in seaweed, halophytes and products based on seaweed*: European Commission Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32018H0464.
Edwards M and Watson L (2011) *Aquaculture explained: Cultivating* Laminaria digitata*.* Bord Iascaigh Mara.
EFSA (2004) Opinion of the Scientific Panel on Contaminants in the Food Chain on a request from the Commission related to mercury and methylmercury in food. *EFSA Journal,* 34: 1–14.
EFSA (2009a) Cadmium in food - Scientific opinion of the Panel on Contaminants in the Food Chain. *EFSA Journal*, 980: 1–139.
EFSA (2009b) Scientific Opinion on Arsenic in Food. *EFSA Journal*, 7(10): 1351.
EFSA (2010) Scientific Opinion on marine biotoxins in shellfish – Cyclic imines (spirolides, gymnodimines, pinnatoxins and pteriatoxins). *EFSA Journal*, 8(6): 1628.
EFSA (2012) Scientific Opinion on the risk for public health related to the presence of mercury and methylmercury in food. *EFSA Journal,* 10(12): 2985.
EFSA (2014) Scientific Opinion on Dietary Reference Values for iodine. *EFSA Journal,* 12(5): 3660.
EFSA (2016) Presence of microplastics and nanoplastics in food, with particular focus on seafood. *EFSA Journal,* 14(6): 4501.
EFSA (2017a) Dietary Reference Values for nutrients Summary report. *EFSA Supporting Publications,* 14(12): e15121E.
EFSA (2017b) EFSA's Activities on Emerging Risks in 2016. *EFSA Supporting Publications*, 14(11): 1336E.
Ememe M and Ememe C (2017) Benefits of Super Food and Functional Food for Companion Animals. In: V. Waisundara and N. Shiomi (eds.) *Superfood and Functional Food: An Overview of Their Processing and Utilization*. London, UK: Intech Open. pp. 309–322.
FAO (2018) *The global status of seaweed production, trade and utilization.* Rome, Italy: Globefish Research Programme Vol. 124. Available at: http://www.fao.org/3/CA1121EN/ca1121en.pdf
FAO (2019a) Profils des pêches et de l'aquaculture par pays: La République Française. Available at: http://www.fao.org/fishery/facp/FRA/fr

FAO (2019b) *FAO yearbook. Fishery and Aquaculture Statistics 2017/FAO annuaire. Statistiques des pêches et de l'aquaculture 2017/FAO anuario. Estadísticas de pesca y acuicultura 2017.* Rome, Italy: FAO. Available at: http://www.fao.org/3/ca5495t/CA5495T.pdf

Faust MA and Gulledge RA (2002) Identifying harmful marine dinoflagellates. *Contributions from the United States National Herbarium*, 42: 1–144.

Feldmann J and Krupp EM (2011) Critical review or scientific opinion paper: arsenosugars--a class of benign arsenic species or justification for developing partly speciated arsenic fractionation in foodstuffs? *Analytical and Bioanalytical Chemistry,* 399(5): 1735–1741.

Fleurence J, Morançais M and Dumay J (2018) Seaweed proteins. In: RY Yada (ed.) *Proteins in Food Processing* (2nd edn.). Cambridge, UK: Woodhead Publishing. pp. 245–262.

Francesconi KA (2010) Arsenic species in seafood: origin and human health implications. *Pure and Applied Chemistry,* 82(2): 373–381.

FSA (2004) *Annual Report of the Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment.* London, UK: Food Standards Agency. Available at: https://cot.food.gov.uk/sites/default/files/cot/cotsection.pdf.

FSAI (2015) Consumption of Hijiki Seaweed. Available at: https://www.fsai.ie/faq/hijiki_seaweed.html

FSAI (2016a) *Report of the Scientific Committee of the Food Safety Authority of Ireland: Metals of Toxicological Importance in the Irish Diet.* Dublin: Food Safety Authority of Ireland.

FSAI (2016b) *Report of the Scientific Committee of the Food Safety Authority of Ireland: The Occurrence of Marine Biotoxins and Risk of Exposure to Seafood Consumers in Ireland.* Dublin: Food Safety Authority of Ireland.

FSAI (2016c) *Report on a Total Diet Study carried out by the Food Safety Authority of Ireland in the period 2012 – 2014.* Dublin: Food Safety Authority of Ireland.

FSANZ (2013) *Survey of inorganic arsenic in seaweed and seaweed-containing products available in Australia.* Available at: https://www.foodstandards.gov.au/science/surveillance/pages/surveyofinorganicars5773.aspx

Ganesan AR, Tiwari U and Rajauria G (2019) Seaweed nutraceuticals and their therapeutic role in disease prevention. *Food Science and Human Wellness,* 8(3): 252–263.

García-Rodríguez D, Cela-Torrijos R, Lorenzo-Ferreira RA and Carro-Díaz AM (2012) Analysis of pesticide residues in seaweeds using matrix solid-phase dispersion and gas chromatography–mass spectrometry detection. *Food Chemistry,* 135(1): 259–267.

García-Salgado S, Quijano MA and Bonilla MM (2012) Arsenic speciation in edible alga samples by microwave-assisted extraction and high performance liquid chromatography coupled to atomic fluorescence spectrometry. *Analytica Chimica Acta,* 714: 38–46.

García-Seoane R, Fernández JA, Villares R and Aboal JR (2018) Use of macroalgae to biomonitor pollutants in coastal waters: Optimization of the methodology. *Ecological Indicators,* 84: 710–726.

García-Vaquero M (2018) Seaweed Proteins and Applications in Animal Feed. In: M Hayes (ed.) *Novel Proteins for Food, Pharmaceuticals and Agriculture: Sources, Applications and Advances*. Hoboken, New Jersey: John Wiley & Sons, Ltd. pp. 139–161.

Giusti L (2001) Heavy metal contamination of brown seaweed and sediments from the UK coastline between the Wear river and the Tees river. *Environment International,* 26(4): 275–286.

Goddard CC and Jupp BP (2001) The radionuclide content of seaweeds and seagrasses around the coast of Oman and the United Arab Emirates. *Marine Pollution Bulletin,* 42(12): 1411–1416.

Guiry MD (2012) *A catalogue of Irish seaweeds.* Gantner Books.

Guiry MD (2019a) *Enteromorpha intestinalis* (Linnaeus) Nees 1820. AlgaeBase: National University of Ireland, Galway. Available at: https://www.algaebase.org/search/species/detail/?species_id=37

Guiry MD (2019b) *Gracilaria verrucosa* (Hudson) Papenfuss, nom. rejic. 1950*.* AlgaeBase: National University of Ireland, Galway. Available at: https://www.algaebase.org/search/species/detail/?species_id=2479
Guiry MD (2019c) The Seaweed Site: information on marine algae. Available at: http://www.seaweed.ie/
Guiry MD and Blunden G (eds.) (1991) *Seaweed resources in Europe: uses and potential.* Chichester: John Wiley & Sons, Ltd.
Gutow L, Eckerlebe A, Giménez L and Saborowski R (2016) Experimental Evaluation of Seaweeds as a Vector for Microplastics into Marine Food Webs. *Environmental Science & Technology,* 50(2): 915–923.
Hanaoka K, Yosida K, Tamano M, Kuroiwa T, Kaise T and Maeda S (2001) Arsenic in the prepared edible brown alga hijiki, *Hizikia fusiforme. Applied Organometallic Chemistry,* 15(6): 561–565.
Hänsch R and Mendel RR (2009) Physiological functions of mineral micronutrients (Cu, Zn, Mn, Fe, Ni, Mo, B, Cl). *Current Opinion in Plant Biology,* 12(3): 259–266.
Harding G, Dalziel J and Vass P (2018) Bioaccumulation of methylmercury within the marine food web of the outer Bay of Fundy, Gulf of Maine. *PLoS ONE,* 13(7): e0197220.
Hwang YO, Park SG, Park GY, Choi SM and Kim MY (2010) Total arsenic, mercury, lead, and cadmium contents in edible dried seaweed in Korea. *Food Additives and Contaminants: Part B,* 3(1): 7–13.
IARC (2004) Tobacco Smoke and Involuntary Smoking. *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, No. 83.* Lyon, France: International Agency for Research on Cancer.
IARC (2006) Inorganic and Organic Lead Compounds. *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, No. 87*. Lyon, France: International Agency for Research on Cancer.
IARC (2012) Arsenic, Metals, Fibres, and Dusts. *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, No. 100 C*. Lyon, France: International Agency for Research on Cancer.
Ihua MW, Guihéneuf F, Mohammed H, Margassery LM, Jackson SA, Stengel DB, Clarke DJ and Dobson ADW (2019) Microbial population changes in decaying *Ascophyllum nodosum* result in macroalgal-polysaccharide-degrading bacteria with potential applicability in enzyme-assisted extraction technologies. *Marine Drugs,* 17(4): 200.
Irish Wildlife Trust (2017) *The Irish Wildlife Trust Seaweed Harvesting Policy.* Available at: https://iwt.ie/wp-content/uploads/2017/09/IWT-Seaweed-Harvesting-Policy.pdf
Ishikawa Y, Kagaya H and Saga K (2004) Biomagnification of ^{7}Be, ^{234}Th, and ^{228}Ra in marine organisms near the northern Pacific coast of Japan. *Journal of Environmental Radioactivity,* 76(1–2): 103–112.
Jaishankar M, Tseten T, Anbalagan N, Mathew BB and Beeregowda KN (2014) Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary Toxicology*, 7(2): 60–72.
Jansen HM, Tonk L, van der Werf A, van der Meer I, van Tuinen S, van der Burg S, Veen J, Bronswijk L and Brouwers E (2019) *Development of Offshore Seaweed Cultivation: food safety, cultivation, ecology and economy: Synthesis report 2018*. Yerseke, Netherlands: Wageningen Marine Research.
Kadam SU, Álvarez C, Tiwari BK and O'Donnell CP (2015) Processing of seaweeds. In: BK Tiwari and DJ Troy (eds.) *Seaweed Sustainability: Food and Non-Food Applications*. Amsterdam; Boston: Academic Press. pp. 61–78.
Kamala-Kannan S, Batvari BPD, Lee KJ, Kannan N, Krishnamoorthy R, Shanthi K and Jayaprakash M (2008) Assessment of heavy metals (Cd, Cr and Pb) in water, sediment and seaweed (*Ulva lactuca*) in the Pulicat Lake, South East India. *Chemosphere,* 71(7): 1233–1240.
Kirke DA, Smyth TJ, Rai DK, Kenny O and Stengel DB (2017) The chemical and antioxidant stability of isolated low molecular weight phlorotannins. *Food Chemistry,* 221: 1104–1112.

Kubickova B, Babica P, Hilscherová K and Šindlerová L (2019) Effects of cyanobacterial toxins on the human gastrointestinal tract and the mucosal innate immune system. *Environmental Sciences Europe,* 31.
Kulshreshtha G, Rathgeber B, Stratton G, Thomas N, Evans F, Critchley A, Hafting J and Prithiviraj B (2014) Feed supplementation with red seaweeds, *Chondrus crispus* and *Sarcodiotheca gaudichaudii*, affects performance, egg quality, and gut microbiota of layer hens. *Poultry Science,* 93(12): 2991–3001.
Kumar CS, Ganesan P, Suresh PV and Bhaskar N (2008) Seaweeds as a source of nutritionally beneficial compounds – a review. *Journal of Food Science and Technology,* 45(1): 1–13.
Kusumi E, Tanimoto T, Hosoda K, Tsubokura M, Hamaki T, Takahashi K and Kami M (2017) Multiple norovirus outbreaks due to shredded, dried, laver seaweed in Japan. *Infection Control and Hospital Epidemiology,* 38(7): 885–886.
Laparra JM, Vélez D, Montoro R, Barberá R and Farré R (2003) Estimation of arsenic bioaccessibility in edible seaweed by an in vitro digestion method. *Journal of Agricultural and Food Chemistry,* 51(20): 6080–6085.
Lee SG, Cho HG and Paik SY (2015) Molecular epidemiology of norovirus in South Korea. *BMB Reports,* 48(2): 61–67.
Lee SM, Lewis J, Buss DH, Holcombe GD and Lawrance PR (1994) Iodine in British foods and diets. *The British Journal of Nutrition,* 72(3): 435–446.
Mabeau S and Fleurence J (1993) Seaweed in food products: biochemical and nutritional aspects. *Trends in Food Science & Technology,* 4(4): 103–107.
Mac Monagail M and Morrison L (2019) Chapter Nine – Arsenic speciation in a variety of seaweeds and associated food products. *Comprehensive Analytical Chemistry*, 85: 267–310.
Mac Monagail M and Morrison L (2020) The seaweed resources of Ireland: a twenty-first century perspective. *Journal of Applied Phycology*, 32: 1287–1300.
Mac Monagail M, Cornish L, Morrison L, Araújo R and Critchley AT (2017) Sustainable harvesting of wild seaweed resources. *European Journal of Phycology,* 52(4): 371–390.
Mac Monagail M, Cummins E, Bermejo R, Daly E, Costello D and Morrison L (2018) Quantification and feed to food transfer of total and inorganic arsenic from a commercial seaweed feed. *Environment International,* 118: 314–324.
Madden M, Mitra M, Ruby D and Schwarz J (2012) Seasonality of selected nutritional constituents of edible Delmarva seaweeds. *Journal of Phycology,* 48(5): 1289–1298.
Mæhre HK, Malde MK, Eilertsen KE and Elvevoll EO (2014) Characterization of protein, lipid and mineral contents in common Norwegian seaweeds and evaluation of their potential as food and feed. *Journal of the Science of Food and Agriculture,* 94(15): 3281–3290.
Mahmud ZH, Kassu A, Mohammad A, Yamato M, Bhuiyan NA, Nair GB and Ota F (2006) Isolation and molecular characterization of toxigenic *Vibrio parahaemolyticus* from the Kii Channel, Japan. *Microbiological Research,* 161(1): 25–37.
Mahmud ZH, Neogi SB, Kassu A, Mai Huong BT, Jahid IK, Islam MS and Ota F (2008) Occurrence, seasonality and genetic diversity of *Vibrio vulnificus* in coastal seaweeds and water along the Kii Channel, Japan. *FEMS Microbiology Ecology,* 64(2): 209–218.
Mahmud ZH, Neogi SB, Kassu A, Wada T, Islam MS, Nair GB and Ota F (2007) Seaweeds as a reservoir for diverse *Vibrio parahaemolyticus* populations in Japan. *International Journal of Food Microbiology,* 118(1): 92–96.
Makkar HPS, Tran G, Heuzé V, Giger-Reverdin S, Lessire M, Lebas F and Ankers P (2016) Seaweeds for livestock diets: a review. *Animal Feed Science and Technology,* 212: 1–17.
Malea P, Chatziapostolou A and Kevrekidis T (2015) Trace element seasonality in marine macroalgae of different functional-form groups. *Marine Environmental Research,* 103: 18–26.
Malea P, Haritonidis S and Kevrekidis T (1995) Metal content of some green and brown seaweeds from Antikyra Gulf (Greece). *Hydrobiologia,* 310(1): 19–31.
Marine Institute (2015) *Arsenic in Irish marine macroalgae - implications for industry.* Available at: https://oar.marine.ie/bitstream/handle/10793/1094/Arsenic %20in %20Marine

%20Macroalgae-Implications %20for %20Industry %20Oct %202015.pdf?sequence=1&isAllowed=y

Maulvault AL, Anacleto P, Barbosa V, Sloth JJ, Rasmussen RR, Tediosi A, Fernandez-Tejedor M, van den Heuvel FHM, Kotterman M and Marques A (2015) Toxic elements and speciation in seafood samples from different contaminated sites in Europe. *Environmental Research,* 143: 72–81.

Mayer AMS, Rodríguez AD, Taglialatela-Scafati O and Fusetani N (2017) Marine Pharmacology in 2012-2013: Marine Compounds with Antibacterial, Antidiabetic, Antifungal, Anti-Inflammatory, Antiprotozoal, Antituberculosis, and Antiviral Activities; Affecting the Immune and Nervous Systems, and Other Miscellaneous Mechanisms of Action. *Marine Drugs,* 15(9): 273.

McGrory ER, Brown C, Bargary N, Williams NH, Mannix A, Zhang C, Henry T, Daly E, Nicholas S, Petrunic BM, Lee M and Morrison L (2017) Arsenic contamination of drinking water in Ireland: a spatial analysis of occurrence and potential risk. *Science of The Total Environment,* 579: 1863–1875.

McMahon CA, Long S, Ryan TP, Fegan M, Sequeira S, Dowdall A, McKittrick L, Wong J, Hayden E, Murray M, Colgan PA and Pollard D (2005) *Radioactivity Monitoring of the Irish Marine Environment 2002.*

McSheehy S and Szpunar J (2000) Speciation of arsenic in edible algae by bi-dimensional size-exclusion anion exchange HPLC with dual ICP-MS and electrospray MS/MS detection. *Journal of Analytical Atomic Spectrometry,* 15(1): 79–87.

Mesnildrey L, Jacob C, Frangoudes K, Reunavot M and Lesueur M (2012) *Seaweed industry in France. Report Interreg program NETALGAE.* Rennes, France: AGROCAMPUS OUEST. Available at: https://hal-agrocampus-ouest.archives-ouvertes.fr/hal-00840572/document

Meyer S, Raber G, Ebert F, Taleshi MS, Francesconi KA and Schwerdtle T (2015) Arsenic-containing hydrocarbons and arsenic-containing fatty acids: Transfer across and presystemic metabolism in the Caco-2 intestinal barrier model. *Molecular Nutrition & Food Research,* 59(10): 2044–2056.

Mintel Press Office (2016) Seaweed-flavoured food and drink launches increased by 147% in Europe between 2011 and 2015. Available at: https://www.mintel.com/press-centre/food-and-drink/seaweed-flavoured-food-and-drink-launches-increased-by-147-in-europe-between-2011-and-2015

Miyake Y, Sasaki S, Ohya Y, Miyamoto S, Matsunaga I, Yoshida T, Hirota Y, Oda H and The Osaka Maternal And Child Health Study Group (2006) Dietary intake of seaweed and minerals and prevalence of allergic rhinitis in Japanese pregnant females: baseline data from the Osaka Maternal and Child Health Study. *Annals of Epidemiology,* 16(8): 614–621.

Moore JE, Xu J and Millar BC (2002) Diversity of the microflora of edible macroalga (*Palmaria palmata*). *Food Microbiology,* 19(2–3): 249–257.

Moreno DV, Ferrera ZS and Rodríguez JJS (2007) SPME and SPE comparative study for coupling with microwave-assisted micellar extraction in the analysis of organochlorine pesticides residues in seaweed samples. *Microchemical Journal,* 87(2): 139–146.

Morrison L, Baumann HA and Stengel DB (2008) An assessment of metal contamination along the Irish coast using the seaweed *Ascophyllum nodosum* (Fucales, Phaeophyceae). *Environmental Pollution,* 152(2): 293–303.

Morrison L, Chen B, Brombach CC, Krupp E and Corns W (2015) Mercury speciation in commercially important seaweeds using liquid chromatography cold vapour atomic fluorescence spectrometry (SPE-HPLC-CV-AFS). *International Conference on Mercury as a Global Pollutant*, 15 June, Jeju, South Korea.

Morrissey J, Kraan S and Guiry M (2001) *A guide to commercially important seaweeds on the Irish coast*. Dublin: Bord Iascaigh Mhara/Irish Sea Fisheries Board. Available at: https://www.academia.edu/1864462/A_guide_to_commercially_important_seaweeds_on_the_Irish_coast

Murphy F, Devlin G, Deverell R and McDonnell K (2013) Biofuel production in Ireland—an approach to 2020 targets with a focus on algal biomass. *Energies,* 6(12): 6391–6412.

National Institutes of Health (2019) Iodine: Fact Sheet for Health Professionals. Bethesda, Maryland: U.S. Department of Health and Human Services – National Institutes of Health. Available at: https://ods.od.nih.gov/factsheets/Iodine-HealthProfessional/

Nitschke U and Stengel DB (2015) A new HPLC method for the detection of iodine applied to natural samples of edible seaweeds and commercial seaweed food products. *Food Chemistry,* 172: 326–334.

Nitschke U and Stengel DB (2016) Quantification of iodine loss in edible Irish seaweeds during processing. *Journal of Applied Phycology,* 28(6): 3527–3533.

Norton D, Hynes S and Boyd J (2018) *Valuing Ireland's Coastal, Marine and Estuarine Ecosystem Services.* Environmental Protection Agency. Available at: http://www.epa.ie/pubs/reports/research/water/Research_Report_239.pdf

O'Sullivan L, Murphy B, McLoughlin P, Duggan P, Lawlor PG, Hughes H and Gardiner GE (2010) Prebiotics from marine macroalgae for human and animal health applications. *Marine Drugs,* 8(7): 2038–2064.

Ortega-Calvo JJ, Mazuelos C, Hermosin B and Saiz-Jimenez C (1993) Chemical composition of *Spirulina* and eukaryotic algae food products marketed in Spain. *Journal of Applied Phycology,* 5: 425–435.

Osborne NJT, Webb PM and Shaw GR (2001) The toxins of *Lyngbya majuscula* and their human and ecological health effects. *Environment International,* 27(5): 381–392.

Park JH, Jeong HS, Lee JS, Lee SW, Choi YH, Choi SJ, Joo IS, Kim YR, Park YK and Youn SK (2015) First norovirus outbreaks associated with consumption of green seaweed (*Enteromorpha* spp.) in South Korea. *Epidemiology and Infection,* 143(3): 515–521.

Paull RE and Chen NJ (2008) Postharvest handling and storage of the edible red seaweed *Gracilaria. Postharvest Biology and Technology,* 48(2): 302–308.

Pétursdóttir ÁH, Blagden J, Gunnarsson K, Raab A, Stengel DB, Feldmann J and Gunnlaugsdóttir H (2019) Arsenolipids are not uniformly distributed within two brown macroalgal species *Saccharina latissima* and *Alaria esculenta. Analytical and Bioanalytical Chemistry,* 411(19): 4973–4985.

Phaneuf D, Côté I, Dumas P, Ferron LA and LeBlanc A (1999) Evaluation of the contamination of marine algae (seaweed) from the St. Lawrence River and likely to be consumed by humans. *Environmental Research,* 80(2): S175–S182.

Qin Y (2018) Applications of bioactive seaweed substances in functional food products. In: Y Qin (ed.) *Bioactive Seaweeds for Food Applications: Natural Ingredients for Healthy Diets* (1st edn.). Amsterdam; Boston: Academic Press. pp. 111–134.

Radulovich R, Neori A, Valderrama D, Reddy CRK, Cronin H and Forster J (2015) Farming of seaweeds. In: BK Tiwari and DJ Troy (eds.) *Seaweed Sustainability: Food and Non-Food Applications.* Amsterdam; Boston: Academic Press. pp. 27–59.

RASFF (2019) Foodborne outbreak suspected to be caused by norovirus (G II) in frozen seaweed salad from China, via Denmark (Reference: 2019.3003). Rapid Alert System for Food and Feed. Available at: https://webgate.ec.europa.eu/rasff-window/portal/?event=SearchForm&cleanSearch=1

Ratana-Arporn P and Chirapart A (2006) Nutritional Evaluation of Tropical Green Seaweeds *Caulerpa lentillifera* and *Ulva reticulata. Kasetsart Journal - Natural Sciences,* 40: 75–83.

Ratcliff JJ, Wan AHL, Edwards MD, Soler-Vila A, Johnson MP, Abreu MH and Morrison L (2016) Metal content of kelp (*Laminaria digitata*) co-cultivated with Atlantic salmon in an Integrated Multi-Trophic Aquaculture system. *Aquaculture,* 450: 234–243.

Rhodes L, Smith K, Selwood A, McNabb P, van Ginkel R, Holland P and Munday R (2010) Production of pinnatoxins by a peridinoid dinoflagellate isolated from Northland, New Zealand. *Harmful Algae,* 9(4): 384–389.

Roleda MY, Skjermo J, Marfaing H, Jónsdóttir R, Rebours C, Gietl A, Stengel DB and Nitschke U (2018) Iodine content in bulk biomass of wild-harvested and cultivated edible seaweeds: Inherent variations determine species-specific daily allowable consumption. *Food Chemistry,* 254: 333–339.

Romarís-Hortas V, García-Sartal C, Barciela-Alonso MdC, Domínguez-González R, Moreda-Piñeiro A and Bermejo-Barrera P (2011) Bioavailability study using an in-vitro method of iodine and bromine in edible seaweed. *Food Chemistry,* 124(4): 1747–1752.
Ronan JM, Stengel DB, Raab A, Feldmann J, O'Hea L, Bralatei E and McGovern E (2017) High proportions of inorganic arsenic in *Laminaria digitata* but not in *Ascophyllum nodosum* samples from Ireland. *Chemosphere,* 186: 17–23.
Rose M, Lewis J, Langford N, Baxter M, Origgi S, Barber M, MacBain H and Thomas K (2007) Arsenic in seaweed—forms, concentration and dietary exposure. *Food and Chemical Toxicology,* 45(7): 1263–1267.
Rubio C, Napoleone G, Luis-González G, Gutiérrez AJ, González-Weller D, Hardisson A and Revert C (2017) Metals in edible seaweed. *Chemosphere,* 173: 572–579.
Saha D and Bhattacharya S (2010) Hydrocolloids as thickening and gelling agents in food: a critical review. *Journal of Food Science and Technology,* 47(6): 587–597.
Sánchez-Rodríguez I, Huerta-Diaz MA, Choumiline E, Holguín-Quiñones O and Zertuche-González JA (2001) Elemental concentrations in different species of seaweeds from Loreto Bay, Baja California Sur, Mexico: implications for the geochemical control of metals in algal tissue. *Environmental Pollution,* 114(2): 145–160.
Sapkota A, Sapkota AR, Kucharski M, Burke J, McKenzie S, Walker P and Lawrence R (2008) Aquaculture practices and potential human health risks: current knowledge and future priorities. *Environment International,* 34(8): 1215–1226.
SCF (2002) *Opinion of the Scientific Committee on Food on the tolerable upper intake level of iodine*, Bruxelles: Scientific Committee on Food of European Commission. Available at: https://ec.europa.eu/food/sites/food/files/safety/docs/sci-com_scf_out146_en.pdf.
Schiener P, Black KD, Stanley MS and Green DH (2015) The seasonal variation in the chemical composition of the kelp species *Laminaria digitata*, *Laminaria hyperborea*, *Saccharina latissima* and *Alaria esculenta. Journal of Applied Phycology,* 27(1): 363–373.
Singh RP and Reddy CRK (2014) Seaweed-microbial interactions: key functions of seaweed-associated bacteria. *FEMS Microbiology Ecology,* 88(2): 213–230.
Smith JL, Summers G and Wong R (2010) Nutrient and heavy metal content of edible seaweeds in New Zealand. *New Zealand Journal of Crop and Horticultural Science,* 38(1): 19–28.
Stengel DB, Connan S and Popper ZA (2011) Algal chemodiversity and bioactivity: sources of natural variability and implications for commercial application. *Biotechnology Advances,* 29(5): 483–501.
Stengel DB, Macken A, Morrison L and Morley N (2004) Zinc concentrations in marine macroalgae and a lichen from western Ireland in relation to phylogenetic grouping, habitat and morphology. *Marine Pollution Bulletin,* 48(9–10): 902–909.
Taboada C, Millán R and Míguez I (2010) Composition, nutritional aspects and effect on serum parameters of marine algae *Ulva rigida. Journal of the Science of Food and Agriculture,* 90(3): 445–449.
Taylor V, Goodale B, Raab A, Schwerdtle T, Reimer K, Conklin S, Karagas MR and Francesconi KA (2017) Human exposure to organic arsenic species from seafood. *Science of The Total Environment,* 580: 266–282.
Taylor VF and Jackson BP (2016) Concentrations and speciation of arsenic in New England seaweed species harvested for food and agriculture. *Chemosphere,* 163: 6–13.
Teas J, Pino S, Critchley A and Braverman LE (2004) Variability of iodine content in common commercially available edible seaweeds. *Thyroid,* 14(10): 836–841.
The Heritage Council (2008) *Ireland's coastline seaweed.* Kilkenny, Ireland: The Heritage Council. Available at: https://www.heritagecouncil.ie/content/files/irelands_coastline_seaweed_2008_4mb.pdf
Trifan A, Breabăn IG, Sava D, Bucur L, Toma CC and Miron A (2015) Heavy metal content in macroalgae from Roumanian Black Sea. *Revue Roumaine de Chimie,* 60(9): 915–920.
van Netten C, Hoption Cann SA, Morley DR and van Netten JP (2000) Elemental and radioactive analysis of commercially available seaweed. *Science of The Total Environment,* 255(1–3): 169–175.

Vila M, Garcés E and Masó M (2001) Potentially toxic epiphytic dinoflagellate assemblages on macroalgae in the NW Mediterranean. *Aquatic Microbial Ecology,* 26(1): 51–60.

Walsh M and Watson L (2012) *A Market Analysis towards the Further Development of Seaweed Aquaculture in Ireland.* Bord Iascaigh Mhara. Available at: http://www.seaweed.ie/irish_seaweed_contacts/doc/A %20Market %20Analysis %20towards %20the %20Further %20Development %20of %20Seaweed %20Aquaculture %20in %20Ireland.pdf

Wang DZ (2008) Neurotoxins from Marine Dinoflagellates: A Brief Review. *Marine Drugs,* 6(2): 349–371.

Watanabe F, Takenaka S, Katsura H, Masumder SA, Abe K, Tamura Y and Nakano Y (1999) Dried green and purple lavers (Nori) contain substantial amounts of biologically active vitamin B(12) but less of dietary iodine relative to other edible seaweeds. *Journal of Agricultural and Food Chemistry,* 47(6): 2341–2343.

WHO (2007) *Assessment of iodine deficiency disorders and monitoring their elimination - a guide for programme managers* (3rd edn.). Geneva, Switzerland: World Health Organization. Available at: https://apps.who.int/iris/bitstream/handle/10665/43781/9789241595827_eng.pdf

WHO (2011) Evaluation of certain contaminants in food: seventy-second report of the Joint FAO/WHO Expert Committee on Food Additives. *WHO Technical Report Series, No. 959*. Geneva, Switzerland: World Health Organization. Available at: https://apps.who.int/iris/bitstream/handle/10665/44514/WHO_TRS_959_eng.pdf?sequence=1&isAllowed=y

WHO (2019) *Microplastics in drinking-water.* Geneva, Switzerland: World Health Organization. Available at: https://apps.who.int/iris/bitstream/handle/10665/326499/9789241516198-eng.pdf?ua=1

Zhao Y, Shang D, Ning J and Zhai Y (2012) Arsenic and cadmium in the marine macroalgae (*Porphyra yezoensis* and *Laminaria japonica*) - forms and concentrations. *Chemical Speciation & Bioavailability,* 24(3): 197–203.

Appendix 1 Macroalgae compounds with pharmacological activity

Species		Drug class	Compound	Location	Pharmacological activity
Cymathaere triplicata		Nervous system	Cymatherelactone	USA	Voltage-gated sodium channel inhibition
Cystoseira usneoides		Anti-inflammatory	Cystodione A	Spain	Radical-scavenging and macrophage TNF-α inhibition *in vitro*
Ecklonia cava		Anti-inflammatory	6,6'-Bieckol	South Korea; USA	Macrophage TNF-α and IL-6 expression inhibition
		-	Dieckol	South Korea	Inhibition of melanin synthesis
Ishige foliacea		Antidiabetic	Apo-9'-fucoxanthinone	South Korea	Increased glucose uptake in rat myoblast cells
			Octaphlorethol A		Glucose transporter 4 increase
Sargassum spp.	*S. patens*	Antidiabetic	Phloroglucinol	Japan	Suppression of hydrolysis of amylopectin by human salivary and pancreatic α-amylase
	S. micracanthum	Antioxidant	Sargassumol	South Korea	Potent ABTS radical scavenging activity
	S. vulgare	Antiviral	Octaphlorethol A	Brazil	Human herpes simplex virus 1 and 2 inhibition
	S. muticum	Anti-inflammatory	Astaxanthin	South Korea	Macrophage TNF-α, IL-6 and 12 expression inhibition
	S. hemiphyllum	Glucose metabolism	Fucoxanthin	-	Exhibits α-amylase and α-glucosidase inhibitory activity and enhances insulin release *in vitro*
Undaria pinnatifida		Lipid metabolism	Fucoxanthin	Japan	Inhibits hepatic and adipocytic lipogenesis, modulating lipolysis in liver
				Mexico	Control of adipogenesis; inhibition of G6PDH, acetyl-CoA carboxylase, and fatty acid synthase
Fucus spp.	*F. distichus*	Glucose metabolism	-	USA	Inhibition of α-amylase and α-glucosidase
	F. vesiculosus	Glucose metabolism	Polyphenol	USA	Inhibition of α-glucosidase
Ascophyllum nodosum		Glucose metabolism	Fucoidan	UK	Inhibition of hepatic α-amylase

Species	Drug class	Compound	Location	Pharmacological activity
Kappaphycus alvarezii	Lipid metabolism	Polyphenol	-	Antioxidant activity
Gelidium amansii	Lipid metabolism	Polyphenol and flavonoid	South Korea	Downregulation of adipogenesis and lipogenesis, decrease in total cholesterol and triglyceride levels
Neorhodomela aculeata	Antiviral	*Sargassum vulgare* glycolipid	South Korea	Human rhinoviruses 2 and 3 inhibition
Laurencia dendroidea	Antiprotozoal	*Neorhodomela aculeata* metabolites	Brazil	*Trypanosoma cruzi* inhibition
***Callophycus* spp.**	Antibacterial	Elatol	Fiji, USA	*Staphylococcus aureus* and *Enterococcus faecalis* inhibition
Polyopes lancifolia	Glucose metabolism	Bromophenol	-	Exhibits α-glucosidase-inhibitory activity
Caulerpa racemosa	Antifungal	Caulerprenylol B	China	*Candida glabrata* and *Cryptococcus neoformans* inhibition
Ulva lactuca	Antioxidant	Fatty acid	USA	Antioxidant-response element activator
	-	Caulerpine	Brazil	Spasmolytic effect on guinea pig ileum
Unspecified	Anti-inflammatory	Bromophycoic acids A and E	Italy	Macrophage cytokine inhibition
	Antibacterial	Chrysophaentins	Spain; USA	Gram-negative and Gram-positive bacterial inhibition

TNF: tumor necrosis factor; IL: interleukine; ABTS: 2,2′-Azino-bis(3-ethylbenzthiazoline-6-sulphonic acid; G6PDH: glucose-6-phosphate dehydrogenase; Acetyl-CoA: acetyl coenzyme A.

Source: Ganesan *et al*. (2019) and Mayer *et al*. (2017).

Appendix 2 Average iodine content in different seaweed species

Species		Common name	Location	Sample type		Iodine content (µg/g)		Ref.
						Fresh weight	Dry weight	
Palmaria palmata		Dulse	Ireland	Whole thallus		71	442	1
				Wild seaweed		-	97	2
			Norway	Wild seaweed		-	72–293	3, 8
			Gulf of Maine, USA	Whole seaweed		-	72 ±23	4
			Spain	Commercial sample		-	77.3 ±8.69	5
			Canada	Wild seaweed		-	173 ±190	6
			UK	Commercial sample		-	44.1	7
Chondrus crispus		Irish moss	Ireland	Whole thallus		79 ±34	296 ±136	1
***Porphyra* spp.**	***P. umbilicalis***	Nori or purple laver	Ireland	Freeze-dried and ground to fine powder		9 ±1	56 ±6	1
	P. tenera		UK	Commercial sample		-	4.3–25	7
			Japan	-		-	17–185	9
			Japan	Sheet		-	16 ±2	4
	P. linearis		Spain	Commercial sample		-	43.2 ±3.73	5
	Not specified		Canada	Wild seaweed		-	31.7 ±33.4	6
			New Zealand	Wild seaweed		-	64 ±21	10
				Commercial sample		-	45.03	
Ecklonia bicyclis		Arame	Namibia	Whole seaweed		-	586 ±56	4
			UK	Commercial sample		-	706	7
			Japan	-		-	600	9
Fucus vesiculosus		Bladderwrack	Ireland	Thallus part	Meristematic tip	99 ±30	509 ±160	1

Species		Common name	Location	Sample type		Iodine content (µg/g)		Ref.
						Fresh weight	Dry weight	
					Mid	155 ±47	583 ±75	
			Norway	Commercial sample		-	732	9
			Norway	Wild seaweed			130	3
			Gulf of Maine, USA	Whole seaweed			276 ±82	4
			Canada	Wild seaweed			226 ±96	6
Hizikia fusiforme		Hiziki/hijiki	Japan	Whole seaweed		-	629 ±153	4
			UK	Commercial sample			391	7
			Japan				436	9
Laminaria spp.	*L. digitata*	Oarweed	Ireland	Thallus part	Blade	1099 ±239	5762 ±1669	1
					Meristem	1252 ±392	7097 ±1704	
					Stipe	1920 ±441	10 203 ±2589	
					Holdfast	994 ±117	3340 ±212	
			Norway	Wild seaweed		-	3100	3
			Scotland	Wild seaweed		-	6531 ±1590	11
			Gulf of Maine, USA	Whole seaweed		-	1862 ±520	4
							1997 ±563	
							2984 ±910	
			Iceland	Granules			8165 ±373	
	Not specified	Kombu	Washington, USA	Commercial sample		-	1350 ±362	
	L. japonica (Saccharina japonica)		Japan			-	2110	9
			UK				2660	7
		Sugar kelp	Spain	Commercial sample		-	6138 ±313.7	5

Species	Common name	Location	Sample type		Iodine content (µg/g)		Ref.
					Fresh weight	Dry weight	
Saccharina latissima		Ireland	Thallus part	Blade	1002 ±152	3341 ±265	1
				Meristem	817 ±297	3579 ±1435	
				Stipe	1132 ±345	5149 ±1595	
				Holdfast	1426 ±444	6130 ±1576	
		Norway and France	Cultivated seaweed		-	1556–7208	8
		Canada	Wild seaweed		-	238	9
		Scotland			-	2782 ±1760	11
	Kelp	Norway	Kelp tablets		-	815	9
		UK	Kelp granules		-	67	7
Ascophyllum nodosum	Rockweed	Ireland	Thallus part	Upper shore	235 ±50	772 ±153	1
					227 ±24	785 ±57	
				Lower shore	193 ±50	662 ±199	
					168 ±20	608 ±54	
		Gulf of Maine, USA	Whole seaweed		-	646 ±392	4
		Canada	Wild seaweed		-	482 ±168	6
Himanthalia elongata	Sea spaghetti	Spain	Commercial sample		-	116 ±22.62	5
		Ireland	Reproductive part of thallus		24 ±3	135 ±21	1
Fucus serratus	Serrated wrack	Ireland	Thallus part	Meristematic tip	320 ±77	1530 ±462	1
				Mid	275 ±180	999 ±673	
Undaria pinnatifida	Wakame	Spain	Commercial sample		-	305.6 ±42.39	5
		Tasmania	Tablets			22 ±1	4
			Powder			32 ±4	

Species		Common name	Location	Sample type	Iodine content (µg/g)		Ref.
					Fresh weight	Dry weight	
				Whole seaweed		41 ±14	
			Japan	Whole seaweed		42 ±17	
			New Zealand	Wild seaweed	-	171 ±28 [a] 100.67	10
			Japan	Commercial sample	-	60–102	9
			UK	-	-	104–217	7
Alaria spp.	*A. marginata*	Winged kelp	Canada	Wild seaweed	-	151	9
	A. esculenta		Norway and France	Cultivated seaweed	-	180–1070	8
			Norway	Wild seaweed	-	220	3
			Ireland		-	670	2
			Scotland		-	815 ±420	11
			Gulf of Maine, USA	Whole seaweed	-	110 ±30 431 ±104	4
Ulva spp.	*U. rigida*	Sea lettuce	Spain	Commercial sample	-	65.6 ±2.11	5
				Wild seaweed	-	8	12
	U. intestinalis		Norway		-	130	3
					-	92	2
			Ireland	Whole seaweed	9 ±1–14 ±2	63 ±3–79 ±4	1
	U. lactuca		Norway	Wild seaweed	-	21	3
			Canada		-	482 ±168	6
	U. stenophylla		New Zealand	Wild seaweed	-	27 ±12[a]	10
	U. reticulata		Thailand	Wild seaweed	-	11.24	13
***Enteromorpha* spp.**		Green nori, aonori	Canada	Wild seaweed	-	22.7 ±6.8	6

Species		Common name	Location	Sample type	Iodine content (µg/g)		Ref.
					Fresh weight	Dry weight	
***Codium* spp.**	***Codium fragile***	Sponge seaweed	Ireland	Whole seaweed	3 ±1	41 ±13	1

± indicates standard deviation (mean, ±SD); [a] indicates standard error (mean, ±SE); - indicates not reported.

References: (1) Nitschke and Stengel, 2015; (2) Nitschke and Stengel, 2016; (3) Mæhre *et al*., 2014; (4) Teas *et al*., 2004; (5) Romarís-Hortas *et al*., 2011; (6) Phaneuf *et al.*, 1999; (7) Lee *et al*., 1994; (8) Roleda *et al*., 2018; (9) van Netten *et al*., 2000; (10) Smith *et al*., 2010; (11) Schiener *et al*., 2015; (12) Taboada *et al*., 2010; (13) Ratana-Arporn and Chirapart, 2006.

Appendix 3 Average mercury content in different seaweed species

Species		Common name	Location	Mercury (Hg) content (µg/g dry weight)	Ref.
Palmaria palmata		Dulse	Spain	≤0.01	1
			Canada	<0.05	2
			Norway	0.006–0.007	3
Chondrus crispus		Irish moss	Spain	0.006–0.007	1
***Porphyra* spp.**	***P. tenera***	Nori or purple laver	Spain	0.014 ±0.002	1
				≤0.01	
			Japan	0.24–0.44	4
	P. umbilicalis		Spain	0.08–0.03	3
	Not specified		Canada	<0.05	2
			Korea	0.006	5
			New Zealand	0.01–0.03 ±0.02	6
Ecklonia bicyclis		Arame	Spain	≤0.03–0.04 ±0.003	1
				0.02–0.04	3
			Japan	<0.05	4
Fucus vesiculosus		Bladderwrack	Spain	0.03 ±0.006	1
			Canada	<0.05	2
			Norway	1.08	4
			Norway	0.01	7
			Gulf of Maine	THg and MeHg: <0.001[a]	8
			Ireland	THg and MeHg: <0.01	9
Hizikia fusiforme		Hiziki/Hijiki	Spain	0.03 ±0.003	1

Species		Common name	Location	Mercury (Hg) content (µg/g dry weight)	Ref.
				≤0.02	
				0.03 ±0.003	
				0.01–0.05	3
			Japan	0.32	4
***Laminaria* spp.**	***L. digitata***	Oarweed	Norway	THg: 0.02 MeHg: <0.01	10
				0.006	7
			Ireland	THg: 0.04 MeHg: <0.01	9
	L. japonica (Saccharina japonica)	Kombu	Spain	0.03 ±0.005	1
				0.03 ±0.004	
				0.001–0.005	3
			Japan	0.40	4
	Saccharina latissima	Sugar kelp	Canada	<0.05	4
			Norway	THg: 0.03 MeHg: <0.01	10
	Not specified	Kelp	Norway	0.24	4
Ascophyllum nodosum		Rockweed	Canada	<0.05	2
			Gulf of Maine, USA	THg and MeHg: <0.001[a]	8
			Ireland	THg and MeHg: <0.01	9
Himanthalia elongata		Sea spaghetti	Spain	0.008–0.01	3
Undaria pinnatifida		Wakame	Spain	0.01 ±0.001	1
				0.02 ±0.003	
				0.01 ±0.001	

Species		Common name	Location	Mercury (Hg) content (µg/g dry weight)	Ref.
				0.01–0.05	3
			Japan	<0.05–0.24	4
			New Zealand	0.03 ±0.01	6
Alaria marginata		Winged kelp	Canada	<0.05	4
Alaria esculenta			Norway	<0.005	7
***Ulva* spp.**	***U. pertusa***	Sea lettuce	Spain	0.01 ±0.002	1
	U. lactuca		Ireland	0.01	11
			Norway	0.005	7
	U. intestinalis		Norway	0.01	7
	U. rigida		Spain	0.018–0.019	3
	Not specified		Korea	0.005	5
	U. stenophylla		New Zealand	0.10 ±0.03	6
***Enteromorpha* spp.**		Green nori, aonori	Spain	0.02 ±0.004	1
			Canada	<0.05	2
***Codium* spp.**	***C. fragile***	Sponge seaweed	Mediterranean	26.1 ±0.23	12
	C. vermilara		Mediterranean	0.13 ±0.10	

± indicates standard deviation (mean, ±SD); [a] indicates wet weight.

References: (1) Almela *et al*., 2002; (2) Phaneuf *et al*., 1999; (3) Besada *et al*., 2009; (4) van Netten *et al*., 2000; (5) Hwang *et al*., 2010; (6) Smith *et al*., 2010; (7) Mæhre *et al*., 2014; (8) Harding *et al*., 2018; (9) Morrison *et al*., 2015; (10) Maulvault *et al*., 2015; (11) Bikker *et al*., 2016; (12) Bonanno and Orlando-Bonaca, 2018.

Appendix 4 Average arsenic content in different seaweed species

Species		Common name	Location	Arsenic (As), µg/g dry weight (mean ±SD)		Ref.
				Total As	Inorganic As	
Palmaria palmata		Dulse	Spain	7.56 ±0.02	0.44 ±0.6	1
			USA	12.1	<LOD	2
				8.95 ±4.80	0.06 ±0.11	3
			Canada	9.4 ±3.0	-	4
			Norway	10	-	5
				9–12	0.05	6
			Brittany, France	5.3	1.9	7
			Japan	12.6	0.595	8
Chondrus crispus		Irish moss	Spain	23.2–25.5	0.217–0.225	9
				12.7	0.357	8
				16.1	0.842	
			USA	12.13 ±0.97	0.07 ±0.08	3
				6.10	0.06	
***Porphyra* spp.**	***P. umbilicalis***	Nori or purple laver	USA	20.73	0.12	
			Spain	28.9–49.5	0.132–0.338	9
				34.5	0.23	8
				25 ±3	-	10
			Japan	14 ±2	-	10
			Brittany, France	5.4	3	7
	P. tenera		Spain	23.7 ±0.5	0.57 ±0.04	1

Species		Common name	Location	Arsenic (As), µg/g dry weight (mean ±SD)		Ref.
				Total As	Inorganic As	
				28.3 ±0.5	0.19 ±0.02	
				30 ±1	0.314 ±0.005	
			Japan	23.2–24.1	0.16–0.28	8
				29	-	11
	Not specified		USA	17.8	<LOD	2
				19.4 ±4.2	0.03 ±0.01	
			UK	24 ±5.32	<0.3	12
			Spain	33.60 ±0.68	-	13
				33.28 ±0.79	-	
				27.19 ±1.58	-	
				26.43 ±0.29	-	
			Canada	19.0 ±4.2	-	4
			Australia	-	0.11 ±0.03	14
			South Korea	13.05	-	15
Ecklonia bicyclis		Arame	Spain	27.9–34.1	0.041–0.170	9
				30.01 ±0.1	0.15 ±0.06	1
				23.8 ±0.5	0.17 ±0.02	
				29 ±1	0.185 ±0.005	
			USA	41.6	<LOD	2
			Japan	20.12 ±10.11	0.43 ±0.51	8
			Japan	31	-	11
			USA	41.6	<LOD	2

Species		Common name	Location	Arsenic (As), µg/g dry weight (mean ±SD)		Ref.
				Total As	Inorganic As	
Fucales	**Not specified**	-	Spain	8.4	3.3	7
Fucus vesiculosus		Bladderwrack	Spain	50.0 ±0.3	0.34 ±0.04	1
			USA	28.89 ±2.16	0.06 ±0.04	3
				32.76 ±3.73	<LOD	
			Canada	31.6 ±7.8	-	4
			Norway	20	-	11
			Norway	41	-	5
			France	36 ±2	11 ±1	10
			Unknown	40.4	0.29	8
Hizikia fusiforme		Hiziki/hijiki	Spain	128 ±5	88 ±6	1
				141 ±6	85 ±6	
				115 ±12	83 ±5	
				103.73 ±7.41	13.2 ±0.7	13
				56.24 ±3.51	23.2 ±0.2	
				50.23 ±0.66	-	
				131.61 ±4.72	8.65 ±0.43	
				94.42 ±0.86	41.7 ±0.1	
				31.84 ±0.25	-	
				103–147	32.1–69.5	9
			Japan	88	-	11
			Iceland	35.6	-	16
			UK	108.6 ±8.8	77.4 ±8.8	12

Species		Common name	Location	Arsenic (As), µg/g dry weight (mean ±SD)		Ref.
				Total As	Inorganic As	
				5.4 ±3.7	11 ±6.1 (wet weight)	
				-	3 ±2.2	
			Japan	72 ±1	50.3 ±0.4	10
				54	34	7
				45	22	
				109.6 ±24.03	73.4 ±23.3	8
***Laminaria* spp.**	***L. digitata***	Oarweed	Japan	65.7	0.251	8
			USA	106.73	<LOD	3
				50.38 ±11.91	8.32 ±7.67	
			Norway	64	-	5
				73–107	0.1–7.7	6
			Ireland	59–114	30–62	17
				49.4–89.6	-	18
				51	9.2	17
				75.2	12.4	
				88.2	22.8	
				88	38.4	
				89.4	44	
			Norway	41 ±19	20 ±1	19
			France	92 ±2	77 ±3	10
	Not specified	Unknown	Spain	39.6	0.47	8
			Japan	48.3	0.14	

Species		Common name	Location	Arsenic (As), µg/g dry weight (mean ±SD)		Ref.
				Total As	Inorganic As	
			Spain	8.4	3.3	7
			Brittany, France	134	62	
			Iceland	30	18	
	Not specified	Kombu	Spain	51.7–68.3	0.052–0.443	9
			UK	50 ±23.73	<0.3	12
				0.30 ±0.29	<0.3 (wet weight)	
				-	<0.01	
			USA	45.5	<LOD	2
				51.2 ±11.6	<LOD	
			Australia	-	0.21 ±0.07	14
	L. japonica (Saccharina japonica)		Spain	47 ±1	0.297 ±0.001	1
				53 ±1	0.254 ±0.005	
			Japan	116	1.44	8
				104	0.23	
			Japan	29	-	11
	Saccharina latissima	Sugar kelp	Canada	76.2	-	
			Norway	43	0.39	19
				61–66	0.03–0.07	6
			Iceland	117 ±9	-	16
				116 ±6	-	
				114 ±28	-	
				127 ±6	-	

Species	Common name	Location	Arsenic (As), µg/g dry weight (mean ±SD)		Ref.
			Total As	Inorganic As	
			53 ±5	-	
		USA	43.5	<LOD	2
			0.08	<LOD	
		Norway	17	-	11
		South Korea	23.26	-	15
Ascophyllum nodosum	Rockweed	USA	23.14 ±6.82	0.08 ±0.03	3
			23.68 ±4.33	0.06 ±0.08	
			2.29	0.08	
			5.76	0.58	
		Canada	23.0 ±5.8	-	4
		Ireland	64 ±20	<1% of Ast	17
Himanthalia elongata	Sea spaghetti	Spain	18 ±2	2.0 ±0.1	10
		Spain	32.9–36.7	0.166–0.245	9
			23.6	<LOD	8
			31.2	0.202	
			21.3	<LOD	
		Brittany, France	3.6	2.4	7
Undaria pinnatifida	Wakame	USA	34.7 ±15.8	<LOD	2
			45.9	<LOD	
		Spain	32 ±1	0.15 ±0.10	1
			42 ±2	0.26 ±0.03	
			34.6 ±0.3	0.18 ±0.05	

Species		Common name	Location	Arsenic (As), µg/g dry weight (mean ±SD)		Ref.
				Total As	Inorganic As	
				42.1–76.9	0.045–0.346	9
				49.34 ±0.48	-	13
				49.51 ±0.70	-	
				0.71 ±0.03	-	
				47.42 ±0.02	-	13
				34.04 ±0.30	-	
				14.71 ±0.50	-	
			UK	35 ±4.6	<0.3	12
				0.42 ±0.58	<0.3 (wet weight)	
				-	<0.01	
			Japan	55	-	11
				20	-	
				5.6	4	7
				18 ±3	4.5 ±0.3	10
			Spain	27 ±3	2.2 ±0.1	
			Italy	70.0 ±33.0	-	20
			Japan	41.4	<LOD	8
				45.2	<LOD	
			Japan, Spain, South Korea	38.8 ±8.25	0.68 ±0.39	
***Alaria* spp.**	***A. marginata***	Winged kelp	Canada	39.5	-	11
	A. esculenta		USA	34.46 ±13.72	0.03 ±0.04	3
			Norway	48	-	5

Species		Common name	Location	Arsenic (As), µg/g dry weight (mean ±SD)		Ref.
				Total As	Inorganic As	
			Iceland	53 ±3	-	16
				43 ±4		
				116 ±6	-	
				102 ±2	-	
				93 ±4	-	
Ulva **spp.**	***U. rigida***	Sea lettuce	Spain	6.41–7.06	0.151–0.177	9
			Slovenia	1.35 ±0.07	-	20
			Syria	5.03 ±0.04	-	
			Greece	0.10–1.10	-	
				2.70 ±0.30	-	
				1.45 ±0.24	-	
	U. lactuca		Norway	7.9	-	5
			Syria	6.89 ±0.23	-	20
			Greece	2.20 ±0.20	-	
			USA	5.34	0.13	3
				4.13	1.00	
				14.65	1.06	
			Canada	6.0 ±2.4	-	4
			Norway	6–13	0.12	6
	U. intestinalis		Greece	1.90 ±0.10	-	20
				1.50 ±0.47	-	
	U. pertusa		Spain	5.17 ±0.05	0.36 ±0.06	1

Species		Common name	Location	Arsenic (As), µg/g dry weight (mean ±SD)		Ref.
				Total As	Inorganic As	
			Unknown	3.24	0.26	8
	Not specified		Greece	0.18–9.52	-	20
			South Korea	12.50	-	15
***Enteromorpha* spp.**		Green nori, aonori	Spain	2.3 ±0.1	0.37 ±0.07	1
			Canada	7.20 ±0.96	-	4
			Norway	4.9	-	5
			Slovenia	1.43 ±0.07	-	20
			Unknown	2.15	0.34	8
***Codium* spp.**	***C. fragile***	Sponge seaweed	Greece	4.25 ±0.49	-	20
				23.0 ±1.00	-	
				3.66	-	

- indicates not reported; <LOD: lower than detection limit; all values are expressed in dry weight unless otherwise specified.

References: (1) Almela *et al*., 2002; (2) Taylor *et al*., 2017; (3) Taylor and Jackson, 2016; (4) Phaneuf *et al*., 1999; (5) Mæhre *et al*., 2014; (6) Duinker *et al*., 2016; (7) McSheehy and Szpunar, 2000; (8) Almela *et al*., 2006; (9) Besada *et al*., 2009; (10) García-Salgado *et al*., 2012; (11) van Netten *et al*., 2000; (12) Rose *et al*., 2007; (13) Almela *et al*., 2005; (14) FSANZ, 2013; (15) Hwang *et al*., 2010; (16) Pétursdóttir *et al*., 2019; (17) Ronan *et al*., 2017; (18) Ratcliff *et al*., 2016; (19) Maulvault *et al*., 2015; (20) Bonanno and Orlando-Bonaca, 2018.

Appendix 5 Average lead content in different seaweed species

Species		Common name	Location	Lead (Pb), µg/g dry weight (mean ±SD)	Ref.
Palmaria palmata		Dulse	Spain	0.05 ±0.02	1
			Japan	1.52	2
			Spain	1.1 ±0.2	3
			Canada	0.84 ±0.83	4
Chondrus crispus		Irish moss	Spain	0.07	1
				0.348–0.720	2
				0.403–0.726	5
***Porphyra* spp.**	**Not specified**	Nori or purple laver	South Korea	0.71	6
			Spain	0.15 ±0.21	1
			New Zealand	0.98 ±0.36[a]	7
				0.41	
			Canada	0.67 ±0.71	4
	P. tenera		Japan	0.123	2
			Spain	0.31 ±0.06	3
				0.289 ±0.004	
				0.29 ±0.02	
			Japan	0.28	8
				0.14	
	P. umbilicalis		Spain	0.817	2
				<0.008–0.270	5
				<0.4	9

Species		Common name	Location	Lead (Pb), µg/g dry weight (mean ±SD)	Ref.
Ecklonia bicyclis		Arame	Japan	0.20 ±0.03	2
				<LOD	
				0.19 ±0.02	3
			Spain	0.15 ±0.08	3
				0.18 ±0.01	
			Japan	0.31	8
			Spain	0.029–0.096	5
Fucus vesiculosus		Bladderwrack	Unknown	0.898	2
			Spain	0.51 ±0.04	3
			Norway	0.38	8
			Canada	0.44 ±0.27	4
Hizikia fusiforme		Hiziki/hijiki	Japan	<LOD	2
				0.721 ±0.825	
			Spain	0.63 ±0.08	3
				0.89 ±0.15	
				0.53 ±0.06	
			Japan	0.16	8
			Spain	<0.008–0.531	5
***Laminaria* spp.**	***L. digitata***	Oarweed	Japan	0.106	2
			Scotland	0.33 ±0.21	10
	L. japonica (Saccharina japonica)	Kombu	Japan	<0.05	2
				0.22	8
			Spain	<LOD	3

Species		Common name	Location	Lead (Pb), µg/g dry weight (mean ±SD)	Ref.
			Spain	<0.008–0.460	5
	Saccharina latissima	Sugar kelp	Canada	<0.01	8
			Scotland	1.16 ±0.72	10
	Not specified	Unknown	Spain	0.07 ±0.05	1
			Japan	0.260	2
			Spain	<LOD	
	Not specified	Kelp	South Korea	0.669	6
Ascophyllum nodosum		Rockweed	Canada	0.16 ±0.11	4
			Ireland	0.118–2.114	11
Himanthalia elongata		Sea spaghetti	Spain	0.02 ±0.01	1
				0.146 ±0.045	2
				0.203–0.259	5
				<0.4	9
Undaria pinnatifida		Wakame	Spain	0.07 ±0.03	1
			Japan	<LOD	2
			Spain	0.113	
			South Korea	0.795	
				1.49 ±0.82	
				0.648	
			Spain	<LOD	3
			Japan	0.14	8
				0.21	
			Spain	<0.008–1.28	5

Species		Common name	Location	Lead (Pb), µg/g dry weight (mean ±SD)	Ref.
				1.05	9
			New Zealand	0.23 ±0.05[a]	7
				0.30	
***Alaria* spp.**	***A. marginata***	Winged kelp	Canada	0.64	8
	A. esculenta		Scotland	1.13 ±0.86	10
***Ulva* spp.**	***U. pertusa***	Sea lettuce	Unknown	<LOD	2
	Not specified		Spain	0.93 ±0.02	3
	U. intestinalis		South Korea	0.539	6
			Greece	4.61 ±1.18[a]	12
				3.06 ±0.66[a]	
	U. rigida		Spain	1.00–1.05	5
	U. stenophylla		New Zealand	1.83 ±0.99[a]	7
	U. lactuca		Ireland	0.956	13
			Canada	1.64 ±0.88	4
***Enteromorpha* spp.**		Green nori	Unknown	0.205	2
			Spain	1.33 ±0.03	3
			Canada	3.2 ±2.5	4
***Codium* spp.**	***C. bursa***	Sponge seaweed	Greece	11.5–34.5	14
	C. fragile		Turkey	2.02 ±0.08[a]	15
				6.96 ±1.39[a]	
			Greece	3.89 ±2.01[a]	12

[a] indicates standard error (mean ±SE).

References: (1) Rubio *et al*., 2017; (2) Almela *et al*., 2006; (3) Almela *et al*., 2002; (4) Phaneuf *et al*., 1999; (5) Besada *et al*., 2009; (6) Hwang *et al*., 2010; (7) Smith *et al*., 2010; (8) van Netten *et al*., 2000; (9) Cofrades *et al*., 2010; (10) Schiener *et al*., 2015; (11) Morrison *et al*., 2008; (12) Malea *et al*., 2015; (13) Bikker *et al*., 2016; (14) Malea *et al*., 1995; (15) Akcali and Kucuksezgin, 2011.

Appendix 6 Average cadmium content in different seaweed species

Species		Common name	Location	Cadmium (Cd) µg/g DW (mean ±SD)	Ref.
Palmaria palmata		Dulse	Spain	0.70 ±0.03	1
				0.16 ±0.11	2
			Canada	0.32 ±0.19	3
			Norway	0.48	4
Chondrus crispus		Irish moss	Spain	0.71–0.742	5
				0.29 ±0.03	2
***Porphyra* spp.**	***P. umbilicalis***	Nori or purple laver	Spain	0.253–3.10	5
				<0.4	6
	P. tenera		Spain	0.35 ±0.01	1
				0.18 ±0.02	
				0.38 ±0.01	
			Japan	0.27	7
				0.83	
	P. yezoensis		China	1.7–2.7	8
	P. leucosticta		Italy	0.1	9
	Not specified		Canada	0.29 ±0.09	3
			Spain	0.58 ±0.30	2
			South Korea	0.608	10
Ecklonia bicyclis		Arame	Spain	0.585–0.827	5
				0.75 ±0.01	1
				0.67 ±0.03	

Species		Common name	Location	Cadmium (Cd) µg/g DW (mean ±SD)	Ref.
				0.74 ±0.02	
			Japan	0.57	7
***Fucus* spp.**		Bladderwrack	Not specified	1.1	11
Fucus vesiculosus			Norway	1.2	4
			Spain	0.55 ±0.01	1
			Canada	1.40 ±0.69	3
			Norway	0.34	7
			England	0.02–10.03	12
Hizikia fusiforme		Hiziki/hijiki	Spain	0.988–2.50	5
				1.45 ±0.14	1
				1.46 ±0.02	
				1.0 ±0.1	
			Japan	2.3	11
				2.4	
				0.8	
***Laminaria* spp.**	***L. digitata***	Oarweed	Norway	0.1	4
				0.05	13
	***L. japonica* (*Saccharina japonica*)**	Kombu	Spain	0.15 ±0.02	1
				0.30 ±0.02	
				0.085–1.83	5
			China	0.45–0.80	8
			Japan	0.02	7
		Sugar kelp	Canada	2.80	7

Species		Common name	Location	Cadmium (Cd) µg/g DW (mean ±SD)	Ref.
	Saccharina latissima		Norway	0.13	13
	Not specified	Unknown	Spain	0.07 ±0.03	2
Ascophyllum nodosum		Rockweed	Canada	0.46 ±0.14	3
			Ireland	0.105–0.598	14
Himanthalia elongata		Sea spaghetti	Spain	0.310–0.326	5
				0.82 ±0.02	2
				<0.4	6
Undaria pinnatifida		Wakame	Italy	0.10	15
			Spain	0.267–4.82	5
				1.5 ±0.1	1
				0.13 ±0.03	
				1.9 ±0.1	
			Canada	0.71	7
				0.51	
			Spain	0.06 ±0.02	2
			Japan	0.6	11
				1.8	
				1.0	
***Alaria* spp.**	***A. marginata***	Winged kelp	Canada	0.45	7
	A. esculenta		Norway	3.4	4
***Enteromorpha* spp.**		Green nori, aonori	Mediterranean Sea	0.01–19.2	15
			Spain	0.03 ±0.01	1

Species		Common name	Location	Cadmium (Cd) µg/g DW (mean ±SD)	Ref.
			Canada	0.28 ±0.11	3
			Norway	0.12	4
Ulva spp.		Sea lettuce	Mediterranean Sea	0.01–11	15
Ulva spp.	*U. lactuca*	Sea lettuce	India	21.7–62	16
	U. lactuca		Canada	0.22 ±0.13	3
	U. lactuca		Norway	0.092	4
	U. lactuca		Ireland	0.257	17
	U. rigida		Spain	0.031–0.033	5
	U. rigida		Italy	0.2	9
	U. rigida		Greece	0.03 ±0.003[a]	18
	U. pertusa		Spain	0.17 ±0.01	1
	U. intestinalis		Greece	0.03 ±0.004[a]	18
	Not specified		South Korea	0.71	10
Codium spp.	*C. bursa*	Sponge seaweed	Greece	1.30–7.30	15
	C. bursa		Greece	0.05 ±0.03	15
	C. effusum		Slovenia	0.20	15
	C. vermilara		Slovenia	0.10	15
	C. vermilara		Croatia	0.30	15
	C. vermilara		Italy	0.19 ±0.07	15
	C. fragile		Turkey	14.9 ±0.65	15
	C. fragile		Greece	0.04 ±0.02[a]	18

[a] indicates standard error (mean, ±SE).

References: (1) Almela *et al*., 2002; (2) Rubio *et al*., 2017; (3) Phaneuf *et al*., 1999; (4) Mæhre *et al*., 2014; (5) Besada *et al*., 2009; (6) Cofrades *et al*., 2010; (7) van Netten *et al*., 2000; (8) Zhao *et al*., 2012; (9) Caliceti *et al*., 2002; (10) Hwang *et al*., 2010; (11) Ortega-Calvo *et al*., 1993; (12) Giusti, 2001; (13) Maulvault *et al*., 2015; (14) Morrison *et al*., 2008; (15) Bonanno and Orlando-Bonaca, 2018; (16) Kamala-Kannan *et al*., 2008; (17) Bikker *et al*., 2016; (18) Malea *et al*., 2015.

Appendix 7 Irish annual monitoring data – chemical

Seaweed product name	Cd (mg/kg)	Pb (mg/kg)	Hg (mg/kg)	As (mg/kg)	Iodine (mg/kg)
2017					
Seaweed	0.20	0.95	<0.05	-	-
Irish organic seaweed	0.20	0.18	<0.05	-	-
Irish sea vegetable	0.12	0.18	<0.05	-	-
Irish organic seaweed	0.17	0.16	<0.05	-	-
2018					
Seaweed	0.06	<0.02	<0.02	>4.00 (78.07)	575
Seaweed	0.34	0.25	<0.02	>4.00 (4.32)	374
Organic seaweed	0.19	0.51	<0.02	>4.00 (6.93)	155
Seaweed	0.23	0.85	<0.02	>4.00 (7.25)	58
Seaweed	0.16	>2.00	<0.02	>4.00 (5.34)	158
Seaweed	0.33	0.07	<0.02	3.78	186
Candy bar	0.07	0.03	<0.02	1.21	-
Candy bar	0.11	0.02	<0.02	0.44	-
Snack	0.02	<0.02	<0.02	0.31	-
Bread mix	0.06	<0.02	<0.02	0.47	-

- indicates not reported.

Source: Cork Public Analyst Laboratory and FSAI.

Appendix 8 Irish annual monitoring data – microbiology

Year	**2018**	**2017**	**2016**					**2014**	**2013**		**2012**			**2011**	
Seaweed product	**Wakame**	**Dillisk**	**Dillisk**	**Carrageen**	**Ginger seaweed salad**	**Sesame seaweed salad**		**Sea spaghetti**	**Sesame seaweed salad**	**Ginger seaweed salad**	**Dillisk**	**Carrageen**		**Kombu kelp**	**Atlantic wakame**
Sample origin	China	IRE	IRE	IRE	Non-EU	IRE	Non-EU	IRE	Non-EU	Non-EU	IRE	IRE	NS	NS	NS
Cooked status	Dried	Raw	NS	Dried	Raw	Pasteurised	Raw	Raw	Cooked	Cooked	Raw	Cooked-chilled	Cooked	Raw	Raw
ACC	-	-	-	-	-	-	-	-	<300 000	530 000	-	<1000*	<1000	<1000	180 000
***Bacillus* spp.**	-	-	-	-	-	-	-	-	-	-	-	-		<1000	<1000
Clostridium perfringens	-	-	-	-	-	-	-	-	<10	<10	-	<10	<10	<20	20
Coagulase-positive *Staphylococcus* spp.	-	-	-	-	-	-	-	-	<10	<10	-	<10	<10	<20	<20
Enterobacteriaceae	<100	-	-	-	-	-	-	-	<100	<100	-	-	<100	<100	<100
Escherichia coli	<10	<10	<10	-	<10	<10	<10		<10	<10	-	<10	<10	<10	<10
***Escherichia coli* O157**	-	-	-	Abs	-	-	-	-	-	-	-	-	-	-	-
***Escherichia coli* O26**	-	-	-	Abs	-	-	-	-	-	-	-	-	-	-	-
Escherichia coli* ungroupable *vt1* and *vt2		-	-	ND	-	-	-	-	-	-	-	-	-	-	-
***Listeria* spp.**	-	-	-	-	-	-	-	-	-	-	-	-	-	<20	<20
Listeria monocytogenes	<10	<10	<10	-	<10	<10	<10	ND	<10	<10	<10	<10	<10	-	-

Year	**2018**	**2017**	**2016**					**2014**	**2013**		**2012**			**2011**	
***Listeria* spp. (non-*monocytogenes*)**	<10	<10	<10	-	<10	<10	<10	-	-	-	<10	Abs	Abs	-	-
***Salmonella* spp.**	ND	Abs	Abs	-	Abs	Abs	Abs	-	-	ND	-	ND	ND	-	-

All units in Colony Forming Units per gram; ACC: Aerobic Colony Count at 30 °C/48 h (* indicates 37 °C/48 h); Abs: absent in 25 g; ND: not detected in 25 g; NS: not stated.

Source: Cork Public Analyst Laboratory and FSAI.

Appendix 9 Request for advice from the Scientific Committee

Topic Title: Risk Assessment of the safety of seaweed and seaweed derived foods available on the Irish market

Date Requested: 28th September 2018
Date Accepted: 14th December 2018
Target Deadline for Advice: 18 months from date of acceptance
Form of Advice required: Written report

Background/Context

Seaweed *(i.e. macroalgae, it refers to several species of macroscopic and multicellular marine algae that generally live attached to rock or any hard substrate)* are widely consumed across East Asia, particularly Japan, China and Korea, but not to any great extent in Europe. Seaweed can be collected from the wild but is now increasingly cultivated. Recently in Ireland seaweed has been attracting interest as a nutritional food source with some commercial products produced from or containing seaweed appearing on the market, typically in a dried form.

Seaweeds are rich in hydrocolloids such as alginates, carrageenan and agar and extracts of these are used in processed foods for texture and stability, particularly in low fat processed foods. As seaweed absorbs minerals from the sea, it is rich in certain minerals and trace elements. Calcium and iron tend to accumulate at higher levels in seaweed than in terrestrial plants and high levels of iodine are also found in various seaweeds (e.g. certain species of brown seaweed). There have been safety concerns raised about the consumption of certain seaweed in the diet.

In 2004 the German Federal Institute for Risk Assessment (BfR) warned of seaweed varieties containing high levels of iodine and recommended establishing safe upper iodine limits for seaweed products across the EU. In 2012 a Japanese study identified a positive association between seaweed consumption and the risk of thyroid cancer (especially for papillary carcinoma) in postmenopausal women. However, the association between high iodine intake and thyroid disease requires further study.

Additionally, certain seaweeds can accumulate heavy metals like arsenic, which is highly toxic in its inorganic form. A 2004 study carried out by the UK Food Standards Agency (FSA) found that hijiki seaweed (a non-European species) contained high levels of inorganic arsenic. As a result, the UK FSA advised consumers to avoid eating this variety of seaweed. Similar recommendations were made by the FSAI and Food Standards Australia New Zealand. In 2015, the Superior Health Council of Belgium conducted a risk assessment of the exposure to inorganic arsenic though the consumption of edible seaweeds. They also recommended that the consumption of Hijiki should be avoided, and that the consumption of other algae should be limited to 7 grams dried material per day.

A 2016 report from Norway also indicated that seaweed contains high levels of inorganic arsenic, total arsenic and cadmium, while the levels of mercury and lead were low. The study concluded that this may limit the use of seaweed in food and feed ingredients. From a microbiological viewpoint in February 2012, the first norovirus outbreak of gastroenteritis associated with green seaweed was reported. There is also the potential risk associated with opportunistic contamination of seaweed with biotoxins from dinoflagellates producing toxins that can be isolated in the seaweed.

In March 2018 the European Commission adopted a Recommendation (Commission Recommendation EU 2018/464), where Member States, in collaboration with food and feed business operators, should perform monitoring during the years 2018, 2019 and 2020 on the presence of arsenic, cadmium, iodine, lead and mercury in different species of seaweed, halophytes and products based on seaweed in order to enable an accurate estimation of exposure.

Questions to be addresses by the Scientific Committee

1. What is the nature of the seaweed food chain in Ireland and possible production and processing trends?
2. What are the current and projected future consumption patterns of seaweed and seaweed derived products in Ireland and what are the limitations, if any, in consumption data for risk assessment purposes?
3. What are the current risks associated with the consumption of seaweed and seaweed derived food products?
4. Outline recommendations for further research required to improve this risk assessment.

Additional Notes

Note (1): The consumption of seaweed is recorded in Irish dietary surveys (i.e. national food consumption surveys). However, there's very little consumption recorded (i.e. 5 people eating M&S sushi (which has Nori in it) and 1 record of Kombu and 1 of Irish moss).

Note (2): Only a small intake of dried brown seaweed is required to cause excessive iodine intake. However, the frequency of intake is important in the evaluation of how this affects thyroid function. It is also important to know the bioavailability of iodine and the loss of iodine during food processing (e.g. boiling can destroy 70-80%). More knowledge about these factors is required to help estimate the iodine intake and its effect on the thyroid function in the Irish population.

Note (3): Data on levels in commercially marketed Irish seaweeds is required. A research project led by the Marine Institute has been conducted in Ireland (May 2015 to May 2018) which looked at total and inorganic arsenic in commercially important seaweeds from Irish waters. However, data cannot be provided yet but initial findings will shed light on inorganic arsenic concentrations and how they vary by plant species and also by location on a single plant. Currently there is no legislative limit at national and international level.

Note (4): The report will be updated as new data becomes available including data collected to fulfil the requirements of the seaweed monitoring EC recommendation.

Note (5): Seaweed samples available at retail were taken by FSAI in 2017 and 2018 (n=19 and 10, respectively) and analysed by the Dublin Public Analyst Laboratory for inorganic arsenic.

References

Gesundheitliche Risiken durch zu hohen Jodgehalt in getrockneten Algen (2007). Aktualisierte Stellungnahme *Nr. 026/2007 des Bundesamts für Risikobewertung,* **22**.

Rose, M., Lewis, J., Langford, N., Baxter, M., Origgi, S., Barber, M., MacBain, H. and Thoma, K. (2007) Arsenic in Seaweed-Forms, Concentration and Dietary Exposure. *Food Chemistry and Toxicology*, **45**, 1263-1267.

Takehiroa, M., Manamia, I., et al. (2012). Seaweed Consumption and the Risk of Thyroid Cancer in Women: The Japan Public Health Center-based Prospective Study. *European Journal of Cancer Prevention,* **21**(3), 254–260.

Duinker, A., Roiha, I.S., et al. (2016). Potential Risks Posed by Macroalgae for Application as Feed and Food - A Norwegian Perspective.

MacArtain, P., Gill, C.I.R., et al. (2007). Nutritional Value of Edible Seaweeds. *Nutrition Reviews* **65**, 535-543.

Morrissey, J. Kraan, S. and Guiry, M.D. (2001). A Guide to Commercially Important Seaweeds on the Irish Coast.

Mæhre, H. K., M. K. Malde, et al. (2014). Characterization of Protein, Lipid and Mineral Contents in Common Norwegian Seaweeds and Evaluation of their Potential as Food and Feed. *Journal of the Science of Food and Agriculture,* **94**(15), 3281-3290.

Rhodesa, L., Smitha, K., et al (2014). Epiphytic Dinoflagellates in Sub-Tropical New Zealand, in Particular the Genus *Coolia* Meunier. *Harmful Algae*, **34**, 36-41.

Katagiri, R., Asakura, K., et al (2015). Estimation of Habitual Iodine Intake in Japanese Adults Using 16 d Diet Records over Four Seasons with a Newly Developed Food Composition Database for Iodine. *Br J Nutr.,* **114**(4), 624-634.

Park, J.H., Jeong, H.S. et al (2015). First Norovirus Outbreaks Associated with Consumption of Green Seaweed (Enteromorpha spp.) in South Korea. *Epidemiol. Infect.* **143**(3), 515-521.

Commission Recommendation (EU) 2018/464 of 19 March 2018 on the monitoring of metals and iodine in seaweed, halophytes and products based on seaweed.

http://www.heritagecouncil.ie/fileadmin/user_upload/Publications/Marine/Seaweed_Poster_2010.pdf

ftp://ftp.fao.org/docrep/fao/006/y4765e/y4765e00.pdf

http://www.marine.ie/Home/site-area/areas-activity/marine-environment/marine-chemistry-research-projects

http://www.food.gov.uk/news/pressreleases/2004/jul/hijikipr

http://tna.europarchive.org/20110116113217/http://www.food.gov.uk/multimedia/pdfs/arsenicseaweed.pdf

Members of the Scientific Committee

Chair

Prof. Albert Flynn, University College Cork

Members

Dr Paula Barry Walsh, Department of Agriculture, Food and the Marine

Prof. Kevin Cashman, University College Cork

Dr PJ Cullen, Technological University Dublin

Dr Geraldine Duffy, Teagasc Food Research Centre

Dr Mark Fenelon, Teagasc Food Research Centre

Dr John Keegan, Dublin Public Analyst's Laboratory (retired)

Prof. Brian McKenna, University College Dublin

Dr Eleanor McNamara, Health Service Executive

Dr Michael O'Keeffe, Residue Specialist

Dr Margaret O'Sullivan, Health Service Executive

Mr Ray Parle, Health Service Executive

Dr Dónal Sammin, Department of Agriculture, Food and the Marine

Ms Ita Saul, Children's Health Ireland (CHI) at Crumlin (retired)

Technical Secretariat to the Scientific Committee

Dr Wayne Anderson, FSAI

FSAI Secretariat to the Scientific Committee

Ms Judith Giles, FSAI

Members of the Ad Hoc Subcommittee on Seaweed

Chair

Prof. Brian McKenna, University College Dublin

Members

Ms Mary Curran, Public Analyst's Laboratory, Cork

Dr Marco García-Vaquero, University College Dublin

Dr Maria Hayes, Teagasc Food Research Centre

Dr Evin McGovern, Marine Institute

Dr Liam Morrison, National University of Ireland, Galway

Mr Willie Ryan, Department of Agriculture, Food and the Marine

Dr Jenny Smith, Marine Institute

Prof. Dagmar Stengel, National University of Ireland, Galway

Dr Christina Tlustos, FSAI

Ms Lucy Watson, Bord Iascaigh Mhara

Technical Secretariat to the Ad Hoc Subcommittee on Seaweed

Dr Pat O'Mahony, FSAI

Dr Cristina Arroyo-Casabona, FSAI

Dr Cormac McElhinney, FSAI

Ms Faye Clarke, FSAI

Mr Mohammed Sohail, Student, University College Dublin

FSAI Secretariat to the Ad Hoc Subcommittee on Seaweed

Ms Judith Giles, FSAI

Food Safety Authority of Ireland
The Exchange, George's Dock, IFSC,
Dublin 1, D01 P2V6

T +353 1 817 1300
E info@fsai.ie

Join us on LinkedIn
Follow us on Twitter @FSAIinfo
Say hi on Facebook
Visit us on Instagram
Subscribe to our YouTube channel

www.fsai.ie