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REPORT OF THE EXPERT MEETING ON FOOD SAFETY FOR SEAWEED

CURRENT STATUS AND FUTURE PERSPECTIVES

ROME, 28–29 OCTOBER 2021

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PREPARATION OF THIS DOCUMENT

The world production of marine macroalgae, or seaweed, has more than tripled since the turn of the millennium, increasing from 10.6 million tonnes in 2000 to 32.4 million tonnes in 2018. Increased cultivation and utilization of seaweed are expected to be important pillars of sustainable food security and a robust aquatic economy in the coming years. It is important, therefore, to consider the food safety implications of (increased) seaweed use for food. Many factors can affect the presence of hazards in seaweed, including: the type of seaweed, its physiology, the season in which it is produced, production waters, harvesting methods and processing. Several hazards such as heavy metals and marine biotoxins have been reported to be (potentially) associated with seaweed. However, legislation and guidance documents on the production and utilization of seaweed are generally still lacking. FAO and WHO have therefore developed this report to identify food safety hazards (microbiological, chemical and physical) linked to the consumption of seaweed and aquatic plants. The present analysis could therefore provide a basis for undertaking further work in this area. Moreover, both FAO and WHO believe that there would be a value in developing relevant Codex guidance on this subject.

This report was developed by Kennedy Bomfeh, who drafted the first version and incorporated inputs from the expert group. Esther Garrido Gamarro provided guidance and coordination for the development of the document, as well as the organization of the expert meeting, with help from other members of the FAO and WHO Secretariat. The secretariat's members are Markus Lipp, Vittorio Fattori, Jeffrey Lejeune, Kim Petersen and Moez Sanaa. The report was consolidated during a Joint FAO-WHO Expert Meeting on Seaweed Safety, which was held virtually on 28 and 29 October 2021.

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ABBREVIATIONS AND ACRONYMS

AFSSA	Agence Française de Sécurité Sanitaire des Aliments (French Food Safety Agency)
ANSES	Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail (French Agency for Food, Environmental and Occupational Health & Safety)
ASC	Aquaculture Stewardship Council
ATSDR	Agency for Toxic Substances and Disease Registry
BCM	Bromochloroform
BfR	German Federal Institute for Risk Assessment
CAC	Codex Alimentarius Commission
CEVA	Centre d'Étude et de Valorisation des Algues (Center for the Study and Valorization of Algae)
DA	domoic acid
EC	European Commission
EFSA	European Food Safety Authority
FAO	Food and Agriculture Organization of the United Nations
FSAI	Food Safety Authority of Ireland
FSANZ	Food Standards Australia New Zealand
HACCP	Hazard Analysis and Critical Control Point
IMTA	integrated multitrophic aquaculture
JECFA	Joint FAO/WHO Expert Committee on Food Additives
ML	maximum limit
MRL	maximum residue limit
MSC	Marine Stewardship Council
NFSA	Norwegian Food Safety Authority
PCBs	polychlorinated biphenyls
POPs	persistent organic pollutants

PTX	Palytoxin
RAC	raw agricultural commodity
RASFF	Rapid Alert System for Food and feed
UN	United Nations
WHO	World Health Organization
USD	United States Dollars

EXECUTIVE SUMMARY

Seaweeds or marine macroalgae are pluricellular, photosynthetic organisms found mainly in the marine environment. They are typically classified by their pigmentation as brown, red or green, and are produced from two sources: wild stocks and aquaculture. Seaweeds have diverse food and non-food applications, some of which have been known for centuries. They are consumed as sea vegetables in soups and salads, used in sushi wrappings, and added to various food formulations for nutritional profile, food additives and flavour enhancement. About 80 percent of harvested seaweed goes into human consumption, direct and indirect. Their non-food applications include the production of feed, pharmaceuticals, hydrocolloids, cosmetics, fertilizers, cosmeceuticals, biostimulants and bioactive compounds. In 2018, global seaweed production exceeded 32 million tonnes, tripling from about 11 million tonnes in 2000. In 2019, farmed seaweed production amounted to approximately 35 million tonnes, which constituted 97 percent of global output in that year. Global trade in seaweed and seaweed products amounted to USD 5.6 billion in 2019 alone.

Given, on the one hand, the challenge of an expected increase in the global population to 9.7 billion by 2050 and, on the other, the impact of climate change on food production and utilization, the need for sustainable primary food production is being emphasized. The exploration of an increased use of seaweed as food has therefore been suggested. However, seaweeds have a recognized capacity for the bioaccumulation of hazardous substances, which may present risks for public health.

Despite the current global trade in seaweed – and its projected increased utilization to support food security – there is presently no Codex standard or guidelines that specifically address food safety in seaweeds. Although the Codex *Regional Standard for Laver Products* (CXS 323R-2017) concerns a seaweed product (genus *Pyropia*), when it comes to contaminants this standard refers to the *General Standard for Contaminants and Toxins in Food and Feed* (CXS 193-1995). Furthermore, harmonized regional and national legislation on food safety hazards in seaweed are generally lacking. Although some private standards have been recently introduced (e.g. by the Aquaculture Stewardship Council/Marine Stewardship Council and the Norwegian Seaweed Farms), they either do not address food safety directly, or they do not do so in sufficient depth. There is, therefore, a significant regulatory gap concerning food safety in seaweed that requires attention. It is therefore vital to thoroughly evaluate the occurrence of these hazards in seaweed, and assess their potential food safety significance.

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This document reviews the available/accessible information on food safety in seaweed and makes recommendations for discussions and action on the findings. It reports that although morbidities and mortalities linked to the consumption of seaweeds are rare, the limited and scattered data available suggest that certain hazards in seaweed present potential moderate to minor food safety concerns. These include: chemical hazards such as heavy metals (principally inorganic arsenic and cadmium), persistent organic pollutants (e.g. dioxins and polychlorinated biphenyls), radionuclides and pesticide residues; microbiological hazards (e.g. *Salmonella* spp., *Bacillus* spp., and norovirus); physical hazards (e.g. metal pieces, glass splinters, crustacean shells, micro- and nanoplastics); and allergens. Consequently, the report recommends, among other things: the collection and evaluation of seaweed consumption data at national and regional levels; the monitoring of seaweed food and feed products for food safety hazards; and a risk assessment/risk profiling of the relevant seaweed hazard groupings to ascertain their public health significance. It is hoped that following those recommendations would support a much-needed drive to develop appropriate Codex guidelines/standards and regional/national legislation. Such standards and/or legislation would in turn safeguard the production, processing and utilization of seaweed for food and feed, with due regard for the interests of all stakeholders along the value chain.


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CHAPTER 1
INTRODUCTION

The term “seaweed” encompasses several taxonomic groups of marine macroscopic photosynthetic algae (West *et al.*, 2016; Silva *et al.*, 2020). Also called macroalgae, based on their pigmentation they are commonly classified as brown (Phaeophyceae), red (Rhodophyceae) and green (Chlorophyceae) algae, as outlined in Figure 1 (FAO, 2018a; Veluchamy and Palaniswamy, 2020). However, there are significant morphological, compositional, and functional differences between and within these groups (Holdt and Kraan, 2011). Although there are over 12 000 species of seaweed, only 221 are considered to be of commercial value, and even fewer species (about ten) are cultivated intensively (FAO, 2018a). It has been suggested that the name “seaweed” may be interpreted by some people, especially in the West, to mean “weeds from the sea”. This can trigger negative responses, conjuring images of smelly, rotting plant masses on beaches. Consequently, the Japanese term “Kaiso” (derived from “kai”, for “ocean”) is considered by some to be a more acceptable representation of photosynthetic organisms from oceans (Nishizawa, 2002). Other terms such as “sea vegetables” have been suggested (Fleurence, 2016). Nevertheless, irrespective of how negative an image the term seaweed may evoke in some, the usefulness of these organisms to life on Earth has been recognized for centuries, and there are indications that more will be expected from them in future.

Seaweeds have long been important contributors to food security and livelihoods around the world, delivering benefits through diverse food and non-food applications. Their food uses are especially relevant in Asia, which has a history of over 2 000 years of consuming the commodity either fresh (e.g. as salads in Malaysia and Indonesia) or processed (e.g. as “nori”, a dried sheet of seaweed used as sushi wrappings) (Tiwari and Troy, 2015; Cai *et al.*, 2021). The Western world was historically known to use seaweed primarily for non-food applications. Greece and Iceland, for example, used seaweed as animal feed as far back as 100 BCE, while other countries such as Ireland and Scotland derived agronomic benefits through their use as soil fertilizers (FAO, 1984; Tiwari and Troy, 2015; West *et al.*, 2016). Europe developed a strong seaweed industry based on kelp burning in the eighteenth century, in which ashes were used as a source of carbonates for glass making, as per Mouritsen *et al.* (2013); this was followed by the iodine industry in the middle of the nineteenth century.

FIGURE 1. **EXAMPLES OF EDIBLE BROWN, RED AND GREEN SEAWEEDS**

Brown seaweed *Saccharina* sp.

Red seaweed *Vertebrata lanosa*

Green seaweed *Ulva* sp.

With an increasing appreciation of the physicochemical constitution of seaweeds, and advancements in extractive technologies, additional applications have been found for the commodity over the years, with attendant socioeconomic benefits. For example, phycocolloids (agar, alginate, carrageenan and furcellaran; E407) are currently extracted from red and brown seaweeds and make up a large, worldwide industry. These phycocolloids are used in food and feed processing, the production of cosmetics and pharmaceuticals, water purification, as well as probiotics in aquaculture and agriculture (West *et al.*, 2016; Pereira and Yarish, 2008). In food processing they are mostly used as texturing agents, emulsifiers and stabilizers in products such as ice cream, yoghurt and sausage (Bixler and Porse, 2011). The Annex details various species of seaweed and their food and non-food uses in a range of countries.

Despite the wide-ranging non-food applications mentioned earlier, about 80 percent of seaweed production is for direct or indirect human consumption (White and Wilson, 2015; West *et al.*, 2016). In recent decades, interest in the use of seaweed as food has been rising, with an annual growth rate of 7–10 percent in the market for seaweed reported in the West[1] (Dawczynski *et al.*, 2007; FSAI, 2020). The common names of some commercial edible seaweeds are listed in Table 1.

TABLE 1. **EXAMPLES OF SOME COMMERCIAL EDIBLE SEAWEEDS**

GROUP	SCIENTIFIC NAME	COMMON NAMES
Brown algae	*Alaria esculenta*	Atlantic wakame, bladderlocks, winged kelp
	Ascophyllum nodosum	Rockweed, knotted wrack, egg wrack
	Ecklonia bicyclis (syn. *Eisenia bicyclis*)	Arame
	Fucus serratus	Serrated wrack, toothed wrack
	Fucus spiralis	Spiral wrack, flat wrack
	Fucus vesiculosus	Bladderwrack
	Halopteris filicina	Sea fern weed
	Halopteris scoparia	Sea flax weed
	Himanthalia elongata	Seaweed spaghetti, Thong weed
	Laminaria digitata	Oarweed, Atlantic kelp
	Laminaria hyperborea	Tangle
	Saccharina japonica (syn. *Laminaria japonica*)	Royal kombu (common name in Japan: Makombu)
	Saccharina latissima (syn. *Laminaria latissima*)	Sugar kelp, sea belt, sweet oar-weed, sweet kelp
	Sargassum fusiforme	Hijiki

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1 The Western world generally consisting of Europe, North America and Australasia.

GROUP	SCIENTIFIC NAME	COMMON NAMES
Brown algae	*Sargassum muticum*	Japanese wireweed
	Padina pavonica	Peacock's tail
	Pelvetia canaliculata	Channelled wrack, múirín na muc
	Undaria pinnatifida	Wakame, Sea mustard
Red algae	*Chondrus crispus*	Irish moss, carrageen
	Erythroglossum laciniatum (syn. *Porphyra laciniata*)	Red or purple laver Thin dragon beard plant, Ceylon moss, ogo, ogonori
	Gracilariopsis longissima	Chinese nori
	Neoporphyra haitanensis (form. Pyropia haitanensis	
	Palmaria palmata	Dulse, red dulse, sea lettuce flakes
	Porphyra dioica	Black laver
	Porphyra purpurea	Purple laver
	Porphyra umbilicalis	Nori, (tough) laver
	Pyropia columbina (syn. *Porphyra columbina*)	Southern laver
	*Neopyropia leucosticta (*syn. *Porphyra leucosticta)*	Pale patch laver
	*Neopyropia tenera (*syn. *Porphyra tenera)*	Gim, nori
	Neopyropia yezoensis (syn. *Porphyra yezoensis*)	Open sea nori
	Vertebrata lanosa	Wrack siphon weed
Green algae	*Caulerpa* spp.	Sea grapes, green caviar
	Chaetomorpha linum	Flax brick weed
	Rhizoclonium riparium	Rooting green thread weed
	Ulva intestinalis (syn. *Enteromorpha intestinalis*)	Gut weed
	Ulva lactuca	Sea lettuce, green laver
	Ulva linza (syn. *Ulva fasciata*)	Slender sea lettuce, doubled ribbon weed
	Ulva rigida	(Stiff) sea lettuce

Source: Banach, J.L., Hoek-van den Hil, E.F. & van der Fels-Klerx, H.L. 2020a. Food safety hazards in the European seaweed chain. *Comprehensive Reviews in Food Science and Food Safety*, 19: 332–364. DOI: 10.1111/1541-4337.12523

1.1 PRIMARY PRODUCTION OF SEAWEED

The global fresh seaweed supply comes from two sources: wild stocks and aquaculture (FAO, 2018a).[2] Of the two, aquaculture supplies the greater share (West *et al.*, 2016; FAO, 2018b; FSAI, 2020). Seaweed from aquaculture, along with some microalgae and cynobacteria (spirulina), made up 97 percent (34.7 million tonnes) of total global production in 2019, which was 35.8 million tonnes (FAO, 2020a). Aquaculture seaweed production has increased steadily over the years, recording a thousandfold increase from 34.7 thousand tonnes in 1950 to 34.7 million tonnes in 2019 (FAO, 2021). In 1969, aquaculture and wild harvests contributed equally to the 2.2 million tonnes of total global production realized in that year. However, over the subsequent five decades, wild production remained at 1.1 million tonnes, while aquaculture output increased to 35.8 million tonnes in 2019 (Cai, 2021; FAO, 2021). Between 2018 and 2019 alone there was a 58 percent increase in output, whereas wild harvests decreased by 14 percent (FAO, 2021). Furthermore, seaweed aquaculture was responsible for a tripling of global production from 10.6 million tonnes in 2000 to 33.3 million tonnes in 2018 (FAO, 2020b). These increased outputs were largely due to industrial demand for seaweed extracts such as carrageenan (West *et al.*, 2016). Wild and aquaculture seaweed production from 2009 to 2019 is detailed in Table 2.

TABLE 2. **GLOBAL WILD AND AQUACULTURE PRODUCTION (IN TONNES) OF SEAWEED AND AQUATIC PLANTS FROM 2009 TO 2019**

YEAR	WILD	AQUACULTURE	TOTAL	% WILD	% AQUACULTURE
2009	1 112 911	18 656 886	19 769 797	6	94
2010	1 070 976	20 174 317	21 245 293	5	95
2011	1 137 413	21 770 016	22 907 429	5	95
2012	1 144 625	24 669 295	25 813 920	4	96
2013	1 305 303	27 994 534	29 299 837	4	96
2014	1 207 802	29 053 789	30 261 591	4	96
2015	1 078 530	31 063 848	32 142 378	3	97
2016	1 110 416	31 650 491	32 760 907	3	97
2017	1 128 690	32 612 902	33 741 592	3	97
2018	954 979	32 386 189	33 341 168	3	97
2019	1 083 370	34 679 134	35 762 504	3	97
Average	**1 125 165**	**27 003 227**	**317 046 416**	**4**	**96**

Sources: FAO. 2020a. FAO yearbook: Fishery and Aquaculture Statistics 2018. In: FAO *Fisheries and Aquaculture.* Rome. Cited 9 August 2021. fao.org/fishery/static/Yearbook/YB2018_USBcard/index.htm; FAO. 2021. FAO Global Fishery and Aquaculture Production Statistics – FishStatJ, March 2021. In: FAO *Fisheries and Aquaculture.* Rome. Cited 30 October 2021. fao.org/fishery/statistics/software/fishstatj/en.

2 In this document, "aquaculture seaweed" and "farmed seaweed" are used interchangeably to refer to cultivated seaweed.

There are significant differences in regional contributions to total (i.e., wild and aquaculture) seaweed production. Globally, production is concentrated in 49 countries, with Asia maintaining the lead as the largest producer (FAO, 2021; Cai, 2021). In 2019, Asia alone contributed 97.3 percent of global production, followed by the Americas (1.39 percent), Europe (0.80 percent), Africa (0.41 percent) and Oceania (0.05 percent) (Table 3) (FAO, 2021).

TABLE 3. **REGIONAL AND NATIONAL CONTRIBUTIONS (IN DESCENDING ORDER) TO GLOBAL SEAWEED PRODUCTION IN 2019**

COUNTRY/AREA	TOTAL PRODUCTION (AQUACULTURE AND WILD) (TONNES)	SHARE OF GLOBAL TOTAL (%)	AQUACULTURE SHARE IN TOTAL PRODUCTION (%)
World	**35 762 504**	**100.00**	**96.97**
Asia	**34 826 750**	**97.38**	**99.10**
China	20 296 592	56.75	99.14
Indonesia	9 962 900	27.86	99.55
Republic of Korea	1 821 475	5.09	99.52
Philippines	1 500 326	4.20	99.98
Democratic People's Republic of Korea	603 000	1.69	100
Japan	412 300	1.15	83.80
Malaysia	188 110	0.53	100.00
Americas	**487 241**	**1.36**	**4.69**
Chile	426 605	1.19	5.08
Peru	36 348	0.10	0.00
Canada	12 655	0.04	0.00
Mexico	7 336	0.02	0.14
United States of America	3 394	0.01	7.75
Europe	**287 033**	**0.80**	**3.88**
Norway	163 197	0.46	0.07
France	51 476	0.14	0.34
Ireland	29 542	0.08	0.14
Russian Federation	19 544	0.05	54.10
Iceland	17 533	0.05	0.00

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COUNTRY/AREA	TOTAL PRODUCTION (AQUACULTURE AND WILD) (TONNES)	SHARE OF GLOBAL TOTAL (%)	AQUACULTURE SHARE IN TOTAL PRODUCTION (%)
Africa	**144 909**	**0.41**	**81.29**
United Republic of Tanzania	106 069	0.30	100.00
Morocco	17 591	0.05	1.55
South Africa	11 155	0.03	19.32
Madagascar	9 665	0.03	91.72
Oceania	**16 572**	**0.05**	**85.32**
Solomon Islands	5 600	0.02	100.00
Papua New Guinea	4 300	0.01	100.00
Kiribati	3 650	0.01	100.00
Australia	1 923	0.01	0.00

Sources: FAO. 2021. FAO Global Fishery and Aquaculture Production Statistics – FishStatJ, March 2021. In: *FAO Fisheries and Aquaculture*. Rome. Cited 30 October 2021. fao.org/fishery/statistics/software/fishstatj/en; Cai, J. 2021. *Global status of seaweed production, utilization and trade*. Belize. www.competecaribbean.org/wp-content/uploads/2021/05/Global-status-of-seaweed-production-trade-and-utilization-Junning-Cai-FAO.pdf.

Differences are also seen in the genera of seaweed that are contributing to total production. In 2019, only five genera accounted for more than 95 percent of cultivated seaweed. These were *Laminaria/Saccharina* (35.4 percent); *Kappaphycus/Eucheuma* (33.5 percent); *Gracilaria* (10.5 percent); *Porphyra/Pyropia* (8.6 percent); and *Undaria* (7.4 percent) (FAO, 2021).

Over the years, Chile has remained the leading producer of wild seaweed, with Chilean kelp (*Lessonia nigrescens*) the most harvested (FAO, 2018a). China and Norway are the second- and third-largest producers, respectively contributing 16 percent (174 551 tonnes) and 15 percent (163 083 tonnes) of global production in 2019 (FAO, 2021). Table 4 shows wild seaweed production from the top ten producing countries. The reported figures include microalgae and spirulina.

TABLE 4. **GLOBAL WILD SEAWEED AND AQUATIC PLANTS PRODUCTION BY THE TOP TEN PRODUCERS FOR THE PERIOD 2009 TO 2018**

COUNTRY	VOLUME PRODUCED (TONNES)											TOTAL PRODUCTION FOR THE PERIOD	CONTRIBUTION TO PERIOD TOTAL (%)
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019		
[1]Chile	368 032	368 580	403 496	436 035	517 929	417 331	345 704	329 707	415 463	247 025	404 933	4 254 235	37
[2]China	276 170	246 620	274 060	257 640	283 010	245 550	261 770	231 707	203 490	183 490	174551	2 638 058	23
[3]Norway	160 361	158 516	152 382	140 998	154 150	154 230	147 391	169 407	164 550	169 409	163083	1 734 477	15
[4]Japan	104 103	97 231	87 779	98 514	84 498	91 601	94 084	80 721	69 969	76 200	66793	951 493	8
[5]France	18 907	22 597	47 307	41 229	69 126	58 512	19 110	55 041	39 072	40 758	51301	462 960	4
[8]Ireland	29 500	29 500	29 500	29 500	29 500	29 500	29 500	29 500	29 500	29 500	29501	324 501	3
[6]Indonesia	3 030	2 697	5 479	7 641	17 136	70 514	48 740	41 194	46 919	44 383	44833	332 566	3
India	28 000	26 500	25 000	23 500	22 000	18 890	18 650	20 576	22 635	22 635	22 635*	251 021	2
Canada	43 300	42 314	18 196	14 316	15 604	15 118	11 579	12 372	12 864	11 497	12655	209 815	2
[9]Iceland	22 563	21 014	15 737	18 079	17 168	18 427	16 830	17 985	21 313	19 000	17533	205 649	2
Total	**1 053 966**	**1 015 569**	**1 058 936**	**1 067 452**	**1 210 121**	**1 119 673**	**993 358**	**988 210**	**1 025 775**	**843 897**	**987 818**	**11 364 775**	**100**

For 2009 to 2018, the top ten producers are presented in the order of the country names.

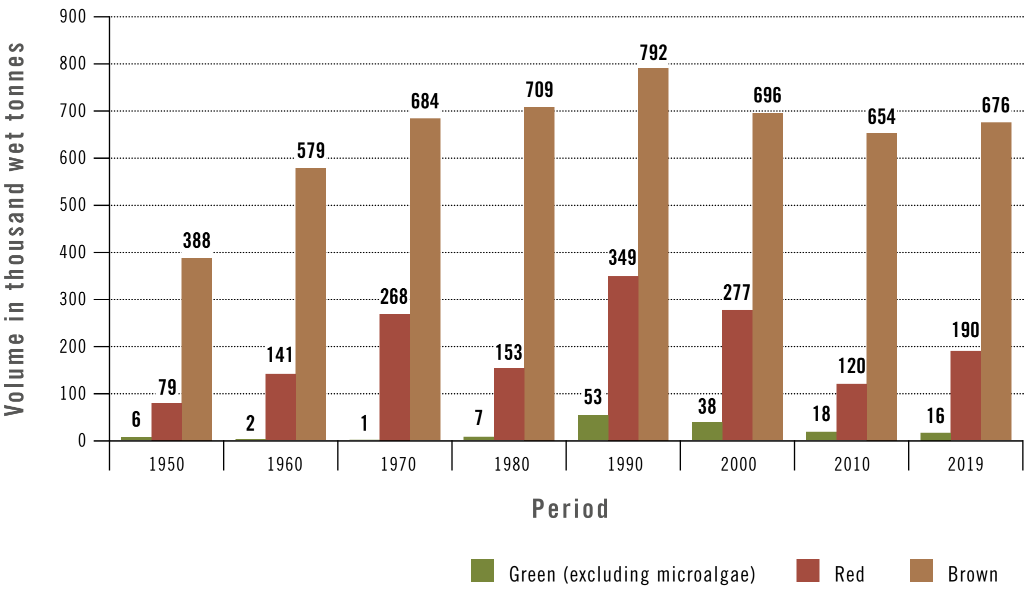
For 2019, the top ten producers are numbered, with 1 being the largest producer. The seventh-largest producer was Peru (36 348 tonnes, not shown in table), and the tenth was Morocco (17 318 tonnes, not shown in table). The latter two countries did not feature in the top ten producers prior to 2019, nor did India and Canada.

*Same figure for 2018 used.

Sources: FAO. 2020b. *The State of World Fisheries and Aquaculture 2020. Sustainability in action*. Rome. doi.org/10.4060/ca9229e; FAO. 2021. FAO Global Fishery and Aquaculture Production Statistics – FishStatJ, March 2021. In: *FAO Fisheries and Aquaculture*. Rome. Cited 30 October 2021. fao.org/fishery/statistics/software/fishstatj/en

There was an 18 percent decline in the volume of wild seaweed production between 1990 (1.33 million tonnes) and 2019 (1.08 million tonnes) (FAO, 2021). The decline was observed among all three seaweed groups (brown seaweeds: from 792 000 tonnes to 676 000 tonnes; red seaweeds: from 349 000 tonnes to 190 000 tonnes; and green seaweeds: from 53 000 tonnes to 16 000 tonnes) (FAO, 2021; Cai, 2021). Figure 2 illustrates this decline.

FIGURE 2. **WILD SEAWEED PRODUCTION FROM 1950 TO 2019**



Sources: Based on information from FAO. 2021. FAO Global Fishery and Aquaculture Production Statistics – FishStatJ, March 2021. In: *FAO Fisheries and Aquaculture*. Rome. Cited 30 October 2021. fao.org/fishery/statistics/software/fishstatj/en; and Cai, J., Lovatelli, A., Aguilar-Manjarrez, J., Cornish, L., Dabbadie, L., Desrochers, A., Diffey, S., Garrido Gamarro, E., Geehan, J., Hurtado, A., Lucente, D., Mair, G., Miao, W., Potin, P., Przybyla, C., Reantaso, M., Roubach, R., Tauati, M. & Yuan, X. 2021. S*eaweeds and microalgae: an overview for unlocking their potential in global aquaculture development*. FAO Fisheries and Aquaculture Circular No. 1229. Rome, FAO. DOI: 10.4060/cb5670e

Aquaculture seaweed production is dominated by countries in East and Southeast Asia (FAO, 2020b), both in terms of product volume and trade value (White and Wilson, 2015; FAO, 2018b). By production volume the top ten countries are: China, Indonesia, the Philippines, the Republic of Korea, the Democratic People's Republic of Korea, Japan, Malaysia, the United Republic of Tanzania, Zanzibar, Chile and Viet Nam (FAO, 2020a; FAO, 2021). Table 5 details the leading countries in aquaculture seaweed production.

TABLE 5. **GLOBAL AQUACULTURE SEAWEED AND AQUATIC PLANTS PRODUCTION BY THE TOP TEN PRODUCERS FOR THE PERIOD 2009 TO 2018**

COUNTRY	VOLUME PRODUCED (TONNES)											TOTAL PRODUCTION FOR THE PERIOD	CONTRIBUTION TO PERIOD TOTAL (%)
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019		
[1]China	11 814 805	12 273 303	12 531 971	13 943 804	14 690 271	15 021 571	15 619 125	16 500 798	17 533 590	18 575 280	20 122 041	168 626 559	55.4
[2]Indonesia	2 963 556	3 915 017	5 170 201	6 514 854	9 298 474	10 076 992	11 269 341	11 050 301	10 547 552	9 320 298	9 918 067	90 044 653	29.6
[4]Philippines	1 739 995	1 801 272	1 840 833	1 751 071	1 558 378	1 549 576	1 566 361	1 404 519	1 415 321	1 478 301	1 500 025	17 605 652	5.8
[3]Republic of Korea	858 659	901 672	992 283	1 022 326	1 131 305	1 087 048	1 197 125	1 351 258	1 761 525	1 710 500	1 812 731	13 826 432	4.5
[5]Democratic People's Republic of Korea	444 300	445 300	445 300	445 300	446 300	491 000	491 000	553 000	553 000	553 000	603 000	5 470 500	1.8
[6]Japan	456 426	432 796	349 737	440 754	418 365	373 908	400 180	391 208	407 834	389 800	345 507	4 406 515	1.5
[7]Malaysia	138 857	207 892	239 450	331 490	269 431	245 332	260 760	205 989	202 966	174 083	188 110	2 464 360	0.8
[8]United Republic of Tanzania, Zanzibar	102 682	125 157	130 400	150 876	110 438	133 020	172 490	111 142	109 810	103 220	106 069	1 355 304	0.4
[9]Chile	88 193	12 179	14 694	4 126	12 512	12 836	11 952	14 863	16 799	21 178	106 069	315 401	0.1
Viet Nam	15 000	18 221	15 428	19 694	14 585	15 219	13 098	11 178	10 818	19 323	19 323	171 887	0.1
Total	**18 622 473**	**20 132 809**	**21 730 297**	**24 624 295**	**27 950 059**	**29 006 502**	**31 001 432**	**31 594 256**	**32 559 215**	**32 344 983**	**304 287 263**	**304 287 263**	**100.0**

The top ten producers in 2019 are numbered, with 1 being the largest producer. The tenth-largest producer was Chile (10 573 tonnes).

*Same figure for 2018 used.

Sources: FAO. 2020b. *The State of World Fisheries and Aquaculture 2020. Sustainability in action*. Rome. doi.org/10.4060/ca9229e; FAO. 2021. FAO Global Fishery and Aquaculture Production Statistics – FishStatJ, March 2021. In: *FAO Fisheries and Aquaculture*. Rome. Cited 30 October 2021. fao.org/fishery/statistics/software/fishstatj/en

1.2 SEAWEED TRADE

As of 2019, global trade in seaweed and seaweed-based hydrocolloids amounted to USD 5.6 billion (UN Comtrade, 2021, quoted in Cai, 2021). Of that amount, exports from 98 countries contributed USD 2.65 billion, of which USD 909 million came from seaweeds, and USD 1.74 billion came from seaweed-based hydrocolloids (UN Comtrade, 2021, quoted in Cai, 2021). Meanwhile, imports by 128 countries contributed USD 2.9 billion, of which USD 1.26 billion was from seaweeds and the remaining USD 1.64 billion from seaweed-based hydrocolloids (UN Comtrade, 2021, quoted in Cai, 2021).

Countries with significant participation in global seaweed trade include China, Indonesia, Japan, the Republic of Korea, the Philippines, the Democratic People's Republic of Korea, Malaysia, Chile and Sri Lanka (FAO, 2018b). Table 6 and Table 7 show the value of seaweed exports and imports in 2019, as well as the key countries involved in the trade.

TABLE 6. **GLOBAL EXPORT OF SEAWEEDS AND SEAWEED-BASED HYDROCOLLOIDS IN 2019**

SEAWEEDS AND SEAWEED-BASED HYDROCOLLOIDS			SEAWEEDS			SEAWEED-BASED HYDROCOLLOIDS		
Exporter	**Million USD**	**Share of world (%)**	**Exporter**	**Million USD**	**Share of world (%)**	**Exporter**	**Million USD**	**Share of world (%)**
1. China	578	22	1. Republic of Korea	278	34	1. China	523	30
2. Indonesia	329	12	2. Indonesia	218	26	2. Philippines	214	12
3. Republic of Korea	320	12	3. Chile	86	10	3. Spain	138	8
4. Philippines	252	10	4. China	55	7	4. Chile	123	7
5. Chile	209	8	5. Philippines	38	5	5. France	114	7
6. Spain	145	5	6. Ireland	33	4	6. Indonesia	110	6
7. France	124	5	7. Peru	22	3	7. United States of America	84	5
8. United States of America	102	4	8. Japan	21	3	8. Germany	76	4
9. Germany	82	3	9. United States of America	18	2	9. United Kingdom of Great Britain and Northern Ireland	65	4
10. United Kingdom of Great Britain and Northern Ireland	78	3	10. Canada	18	2	10. South Korea	43	2
Rest of the world	432	16	Rest of the world	36	4	Rest of the world	252	14
World	**2 651**	**100**	**World**	**823**	**100**	**World**	**1 742**	**100**

Source: Cai, J. 2021. *Global status of seaweed production, utilization and trade*. Belize. www.competecaribbean.org/wp-content/uploads/2021/05/Global-status-of-seaweed-production-trade-and-utilization-Junning-Cai-FAO.pdf (based on data from UN Comtrade).

TABLE 7. **GLOBAL IMPORT OF SEAWEEDS AND SEAWEED-BASED HYDROCOLLOIDS IN 2019**

SEAWEEDS AND SEAWEED-BASED HYDROCOLLOIDS			SEAWEEDS			SEAWEED-BASED HYDROCOLLOIDS		
Importer	**Million USD**	**Share of world (%)**	**Importer**	**Million USD**	**Share of world (%)**	**Importer**	**Million USD**	**Share of world (%)**
1. China	445	15	1. China	342	29	1. United States of America	225	13
2. Japan	341	12	2. Japan	241	21	2. Germany	112	6
3. United States of America	320	11	3. United States of America	95	8	3. China	103	6
4. Germany	124	4	4. Thailand	55	5	4. Spain	101	6
5. Spain	120	4	5. Taiwan Province of China	48	4	5. Japan	100	6
6. Russian Federation	116	4	6. France	35	3	6. Russian Federation	87	5
7. Thailand	112	4	7. Australia	30	3	7. United Kingdom of Great Britain and Northern Ireland	59	3
8. France	86	3	8. Russian Federation	29	2	8. Thailand	57	3
9. United Kingdom of Great Britain and Northern Ireland	80	3	9. Republic of Korea	29	2	9. Denmark	54	3
10. Denmark	67	2	10. United Kingdom of Great Britain and Northern Ireland	21	2	10. France	51	3
Rest of the world	1 088	38	Rest of the world	236	20	Rest of the world	791	45
World	**2 899**	**100**	**World**	**1 161**	**100**	**World**	**1 740**	**100**

Source: Cai, J. 2021. *Global status of seaweed production, utilization and trade.* Belize. www.competecaribbean.org/wp-content/uploads/2021/05/Global-status-of-seaweed-production-trade-and-utilization-Junning-Cai-FAO.pdf (based on data from UN Comtrade).

1.3 SEAWEED PROCESSING AND UTILIZATION

1.3.1 PROCESSING FOR FOOD AND FOOD INGREDIENTS

Several methods are employed for seaweed processing. These include drying, fermentation, blanching, freezing, or some combination of those methods. Of these, drying is the predominant method. While at the artisanal level this may involve direct sun-drying on wharves or on raised racks, commercial processers use either conventional convection dryers or solar dryers. Each method has varying (temperature-dependent) impacts on the final (nutritional) quality and safety of the products (Cascais *et al.*, 2021). Uribe *et al.* (2020) reported a tenfold reduction in the total flavonoid content of *Saccharina latissima* when dried at 70 ˚C. Badmus *et al.* (2019) also reported losses in amino acids, fatty acids and antioxidant potential in dried *Fucus spiralis*, *Laminaria digitata*, *Fucus serratus*, *Halidrys siliquosa* and *Pelvetia canaliculata*.

Direct artisanal sun-drying, though inexpensive, may cause physical and quality losses in products owing to the general lack of control of the drying conditions

(Kadam *et al.*, 2015; FSAI, 2020). On the other hand, conventional convection dryers require significant energy and may lead to the degradation of nutritional components. These devices have been found to yield dried seaweed with lower total amino acids, polyunsaturated fatty acids, and vitamin C (Chan *et al.*, 1997). An increase in drying temperature has also been found to correspond to a reduction in total phenol and flavonoid content in seaweed (Gupta and Abu-Ghannam, 2011; Badmus *et al.*, 2019), thereby compromising their overall antioxidant capacity. Irrespective of the drying method, Sappati *et al.* (2019) found the total phenolic content, antioxidant activity, and vitamin C content were decreased five- to tenfold compared to the fresh brown seaweed (*S. latissima*). Overall, drying at a lower temperature (< 50 °C) and lower humidity was found to be suitable in terms of the processing cost, functional properties and preservation of the bioactive compounds in *S. latissima*.

Solar drying is a sustainable and relatively inexpensive alternative to oven-drying and continues to gain traction (Kadam *et al.*, 2015). It is, however, dependent on weather conditions, thus potentially limiting its application and associated benefits. In Ireland, non-thermal drying using dehumidifiers or fans is the predominant commercial drying method for seaweed intended for human consumption (FSAI, 2020). The method is considered labour and energy intensive. The use of infrared, microwave and superheated steam drying have been found to improve energy efficiency and product quality. Their commercial viability is, however, limited to high-value, low-volume products (FSAI, 2020).

New practices for the large-scale processing of farmed kelp for food or feed uses are now being developed and are adapted to a temperate climate where solar drying is not feasible. For example, fermentation is already used commercially and research is being conducted to reduce the processing cost of heat treatment, increase seaweed product shelf life, and broaden the food market for seaweeds. Bruhn *et al.* (2019) have reported that a fermented *S. latissima* product has a milder taste, improved visual and olfactory appeal, and a lower content of harmful trace metals. The combined heat treatment (95 °C for 15 minutes) and fermentation caused a reduced saltiness and umami flavour of *S. latissima*, a less slimy visual appearance and a reduced smell of the sea, while its texture and protein content both remained stable. With regard to product safety, the fermentation process reduced the chemical hazards in the tested *S. latissima* as follows: sodium (15 percent lower), cadmium (35 percent lower) and mercury (37 percent lower) (Bruhn *et al.*, 2019).

Blanching is employed in commercial processing, usually before or after freezing biomass, especially for large brown seaweeds (e.g. *Fucus, Laminaria* and *Saccharina* spp.). This is a popular method both for inducing desirable colour changes (brown to more pleasant green), and for reducing iodine levels. According to Nielson *et al.* (2020), blanching *S. latissima* (at 60 °C for 300 seconds) resulted in biomass with an improved profile of health beneficial compounds such as a higher ratio of essential amino acids, and a higher proportion of omega-3 fatty acids. Akomea-Frempong *et al.* (2021) also reported that pre-freezing blanching of *S. latissima* resulted in an improved overall sensory quality of the product.

1.3.2 FOOD USES OF SEAWEED

As noted earlier, the bulk of harvested seaweed is consumed as food and food ingredients. Direct human consumption accounted for 48 percent of global seaweed use in 2018, while indirect consumption through processed foods made up 32 percent in the same year (Brummett *et al.*, 2016; FAO, 2014; Loureiro *et al.*, 2015). The remaining 20 percent was used for industrial non-food applications such as those listed in the Annex.

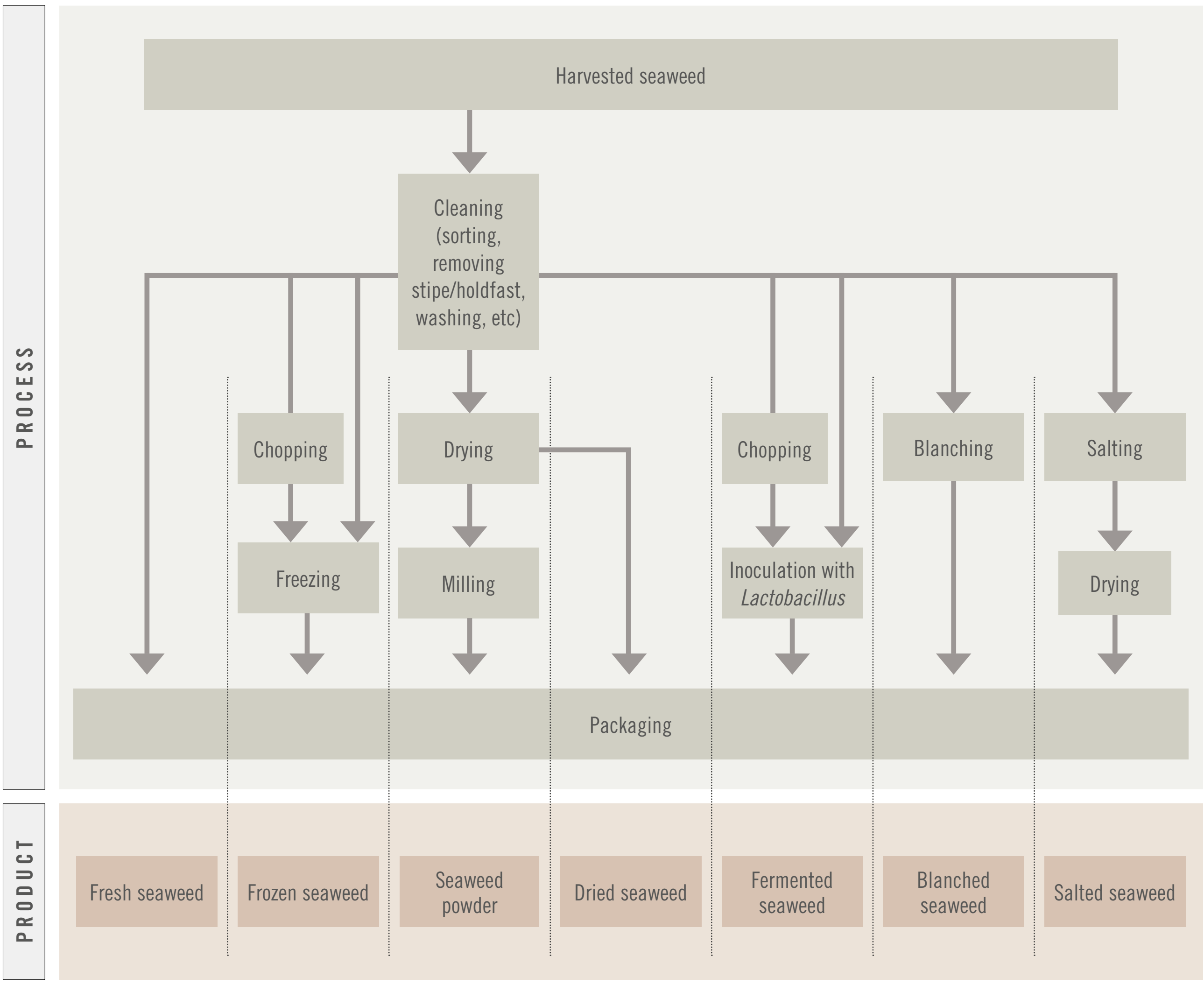
When used as food, seaweed is consumed fresh, dried, defrosted, fermented, cooked, or as products from a combination of the aforementioned methods (Mahadevan, 2015). Of these, consumption in the dried form is the most common. At the consumer level, dried seaweed may be used as a food topping (Figure 3), rehydrated and used in several cuisines, or used for garnishing and seasoning food. Dried seaweed may be domestically ground to varying levels of coarseness or industrially powdered for various uses. In the latter form they may serve as (partial) replacements for wheat and maize flour in cookies, fried chips, grissini and pasta (Forster and Radulovich, 2015). Furthermore, several species of brown seaweed (e.g. *Ascophyllum* spp., *Fucus* spp., *Laminaria* spp. and *Undaria* spp.) are presently used in food supplement formulations (FSAI, 2020). Red seaweeds such as *Palmaria palmata* (dulse) have traditionally been consumed in bread and biscuit products in countries like Ireland (Fitzgerald *et al.*, 2011)

FIGURE 3. **KELP CRISP ON FISH**

Fresh seaweed is added to salads, blended with fruits and vegetable juices, or mixed with beverages (Forster and Radulovich, 2015). It may also be cooked either whole or chopped into various dishes such as rice and beans.

A simplified, general process flow diagram for some seaweed food products is shown in Figure 4. In Table 8, various processing methods are presented for variants of a specific seaweed food product consumed in Japan, wakame (*Undaria pinnatifida*).

FIGURE 4. **SIMPLIFIED, GENERAL PROCESS FLOW FOR SOME SEAWEED FOOD PRODUCTS, DEVELOPED BASED ON EXPERT CONSULTATION**



Source: Developed by author based on expert consultation.

TABLE 8. **PROCESSING METHODS FOR VARIOUS TYPES OF WAKAME (*UNDARIA PINNATIFIDA*) IN JAPAN**

TYPE OF WAKAME	PROCESS FLOW
Suboshi wakame	Raw *Undaria pinnatifida* → Sun-drying → Product
Haiboshi wakame	Raw *U. pinnatifida* → Mixing with ash → Sun-drying → Washing → Sun-drying → Product
Salted wakame	Raw *U. pinnatifida* → Salting → Dehydration → Removal of mid-rib → Sorting → Packaging → Product
Boiled and salted wakame	Raw *U. pinnatifida* → Boiling → Cooling → Salting and dehydration → Removal of mid-rib → Sorting → Packaging → Product
Dried cut wakame	Boiled and salted wakame → Sifting → Washing → Dehydration → Cutting → Washing → Dehydration → Desalination (salt removal) → Mechanical drying → Mechanical sorting → Visual inspection → Metal detection → Packaging → Product

Note: Y. Sato (personal communication, 2021) confirmed thatwthe processing methods in the table were still in use in 2021.

Source: Adapted from Yamanaka, R. & Akiyama, K. 1993. Cultivation and utilization of *Undaria pinnafida* (wakame) as food. *Journal of Applied Phycology*, 5:249–253. DOI:10.1007/BF00004026.

Some studies have evaluated the use of seaweeds as food processing aids, nutritional profile enhancers and as ingredients for improving the shelf stability of bakery and cereal products. For example, glycine betaine – previously identified in the seaweed *Codium fragile* (Dead man's fingers) – could be used as an osmolyte to prevent baked goods drying out during storage (Valverde *et al.*, 2015). Extracts from *Ascophyllum nodosum* and *Fucus vesiculosus* have also been added to yoghurt to enhance their sensory profile and reduce lipid oxidation (O'Sullivan *et al.*, 2016). The findings of some of such studies are summarized in Table 9.

TABLE 9. **SELECTED STUDY FINDINGS ON SOME POTENTIAL FOOD APPLICATIONS OF SEAWEED**

FOOD APPLICATION	SEAWEED	FORM	REMARKS	REFERENCES
Bread	*A. nodosum* (at 1–4%)	Powdered	Appetite management; significant reduction in total energy in the following 24-hour energy intake at subsequent meal test for consumers	Hall *et al.* (2012)
Noodle	*Monostroma nitidu* (at 4%, 6% and 8%)	Powdered	The addition of seaweed increased the crude fibre contents of raw fresh noodles. The increase in fibre led to an increase in water absorption. Breaking energy, springiness, extensibility, and viscoelasticity were decreased.	Chang and Wu (2008)

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FOOD APPLICATION	SEAWEED	FORM	REMARKS	REFERENCES
Pakoda	*Ulva compressa (Enteromorpha compressa (Linnaeus)* (at 5%, 7.5%, 10%, 12.5% and 15%)	Powdered	The addition of *Enteromorpha* to pakoda pastry increased its iron and calcium content. Significant increases in dietary fibre, protein, and vitamin content were also observed. However, the free-radical-scavenging activity and total phenol content decreased with the addition of *Enteromorpha*.	Mamatha *et al.* (2007)
Pasta	*U. pinnatifida* (at 5%, 10%, 20%, 30%)	Powdered	The starch granules and protein matrix were shown to be enhanced in pasta containing seaweeds up to 20%. Fucoxanthin was not affected by the pasta-making process or the cooking method.	Prabhasankar *et al.* (2009b)
Pasta	*Sargassum marginatum* (1%, 2.5%, 5%)	Powdered	The reducing power of the pasta increased with an increased percentage of seaweed. Seaweed levels up to 2.5% decreased cooking loss and enhanced the pasta's gluten network.	Prabhasankar *et al.* (2009a)
Beef patty	*U. pinnatifida* (3%)	Dried and ground	The inclusion of seaweed decreased thawing and cooking losses and created beef patties with a softer texture. The addition of seaweed also increased the mineral and dietary fibre content.	López-López *et al.* (2010)
Breakfast sausages	*Saccharina japonica* (1–4%)	Powdered	The addition of seaweed at all levels produced no difference in moisture, protein, and fat content. The ash content increased with increasing seaweed content. The 1% seaweed sausages revealed the greatest improvement in terms of physiochemical and sensory properties.	Kim *et al.* (2010)
Chicken breast meat	*U. pinnatifida* (200 mg/kg meat (w/w))	Extract carotenoid pigment, fucoxanthin	The addition of seaweed increased colour redness and yellowness in ground chicken breast meat. Lipid peroxidation was inhibited in chilling storage after cooking.	Sasaki *et al.* (2008)
Restructured poultry steak	*Himanthalia elongata* (3%)	Powdered	Purge loss slightly increased with the addition of seaweed, but cooking losses were reduced. Total viable counts and lactic acid bacteria were higher in the products with seaweed, as were the levels of tyramine and spermidine.	Cofrades *et al.* (2011)

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FOOD APPLICATION	SEAWEED	FORM	REMARKS	REFERENCES
Pork meat emulsion	*H. elongata*, *U. pinnatifida*, *P. umbilicalis* (5.6%)	Dried and ground	Significantly increased the polyunsaturated omega-3 fatty acids (PUFA) and decreased the w-6/w-3 PUFA ratio. The seaweed emulsions were significantly lower in sodium than the control. Concentrations of K, Ca, Mg, and Mn increased with the seaweed. Levels of serine, glycine, alanine, valine, tyrosine, phenylalanine, and arginine increased with *P. umbilicalis*. The seaweed increased the antioxidant capacity. *H. elongata* increased the polyphenol supply and antioxidant capacity.	López-López *et al.* (2009a)
Frankfurters (low-fat)	*H. elongata* (5.5%), *algal oil* (1.14%)	Dried and ground	The incorporation of algal oil produced frankfurters with high levels of long-chain w-3 PUFA. There were no significant changes in the lipid or amino acid content, but it provided the potential for Ca-rich, low-sodium frankfurters with better Na/K ratios, all while increasing the fibre content.	López-López *et al.* (2009b)
Cod	*Fucus vesiculosus (Linnaeus)* (300 mg/kg model)	Extract and subfractions	Phlorotannins from the *F. vesiculosus* extract was shown to inhibit lipid oxidation in fish model systems.	Wang *et al.* (2010)
Fish	*Kappaphycus alvarezii* (*Eucheuma*) (5%, 7.5%, 10%, 12.5%, 15%)	Powdered	Seaweed could be incorporated up to 10% without influencing the appearance, texture, and acceptability ratings in the taste panel.	Senthil *et al.* (2005)
Spice adjunct mix	*K. alvarezii* (Eucheuma) (15%, 20%, 25%)	Dried and ground, then steamed before using	The addition of *Eucheuma* powder to the spice adjunct increased the ash, protein, and crude fibre content. It also had a high amount of vitamin E and a small amount of niacin and vitamin B2. The addition of *Eucheuma* up to 20% did not affect its sensory acceptability.	Senthil *et al.* (2011)

Source: Adapted from Mahadevan, K. 2015. Seaweeds: a sustainable food source. In J. Fleurence & I. Levine, eds. *Seaweed in health and disease prevention*, pp. 347–363. Amsterdam, Academic Press.

1.3.3 PROCESSING FOR NON-FOOD USES

1.3.3.1 Extraction of bioactive compounds

Several compounds are extracted from non-thermally dried seaweed for potential use in the prevention of (non-communicable) diseases (Choudhary *et al.*, 2021; Cho and Rhee, 2019). These compounds include fucoidans, lectins, β-carotene, fucoxanthin, astaxanthin and eicosapentaenoic acid (EPA), sulphated polysaccharides, soluble polysaccharides, carotenoids, omega-3 fatty acids, vitamins, tocopherols, and phycocyanins (Kadam and Prabhasankar, 2010). Laver (genera: *Porphyra* and *Pyropia*) are exploited for such components as porphyran, taurine and vitamin B12 (Cho and Rhee, 2019). There are claims that extracted bioactive compounds in seaweed can act as antitumor, antioxidant, anticoagulant and anti-inflammatory agents (Holdt and Kraan, 2011). Porphyran, for example, is the main dietary fibre found in laver; it is claimed to be of use in the prevention of cardiovascular, nervous, bone and diabetic disorders (Cao *et al.*, 2016; Bito *et al.*, 2017).

Other studies suggest that populations noted for high seaweed intake (e.g. in Asia) may be protected from several diet-related chronic diseases affecting countries with low intake of seaweed, notably in the West (Déléris *et al.*, 2016). Iso (2010) and Nanri *et al.* (2017) suggest a plausible link between seaweed intake in Japan's lower incidence of cardiovascular diseases and all-cause mortality.

1.3.3.2 Processing and use for feed

As noted above, there is a long history of seaweed being used as animal feed, especially in coastal areas (Kadam *et al.*, 2015). The North Ronaldsay sheep in Scotland (Orkney archipelago) are known to feed entirely on seaweed (Fleurence, 2016; Abbot *et al.*, 2020). As feed, seaweed is used either as fodder (e.g. for cattle and sheep in Finland and Norway) or as a meal. The latter use is more common. For example, due to their high carotenoid content, some seaweeds (e.g. *Ulva* spp.) are added to the diets of hens to produce eggs with a bright yellow–orange colour (Wang *et al.*, 2013). Increased egg weight, shell thickness, and reduced yolk cholesterol – all desirable qualities – have reportedly been associated with the inclusion of the green seaweed *Enteromorpha prolifera* in poultry meal (Al-Harthi and El-Deek, 2012; Wang *et al.*, 2013). The immune status and gut microbiota of poultry are also reported to be improved by seaweed meals (Makkar *et al.*, 2016). *Ascophyllum nodosum* meals are also reported to increase the growth performance of broilers. Other species such as *Laminaria* sp., *Fucus* sp., and *Alaria* sp., are included in diets for pigs (Fleurence, 2016). In the United States of America, the use of seaweed for animal nutrition extends from livestock to pets (McHugh, 2003). Feeding a low level of dried *S. latissima* to lamb in a total mixed ration during the last five weeks before slaughter improved meat quality (increased tenderness, red colour intensity and storage stability) and increased the iodine and selenium content of the meat (Grabez *et al.*, 2021). Seaweeds are also exploited as sources of bioactive compounds for feed for monogastric livestock (Øverland *et al.,* 2019).

Recently, the use of seaweeds in animal feed as an additive to reduce methane emissions from ruminants has been examined. Several studies have identified the red seaweed *Asparagopsis taxiformis* as beneficial in this regard (Roque *et al*., 2020; Kinley *et al*., 2020). These reductions are attributed to an active component called bromochloroform (BCM), which is known to be toxic (Machado *et al*., 2016). Muizelaar *et al*. (2021) report that BCM does not accumulate in animal tissue but can be transferred to milk in lactating cows. However, Searchinger *et al*. (2021) suggest that the presence of BCM in red seaweed does not cause increased BCM levels in milk. Further studies are therefore needed to establish the extent to which BCM in red seaweed influences the safety of meat and milk from ruminants.

In recent years, the complex carbohydrates in seaweed have been recognized as having a prebiotic effect when used in low levels in animal diets. The occurrence of laminarin, fucoidan and polyphenols in seaweed is expected to facilitate increased commercial use of seaweed products as feed ingredients. Research has shown the effects of dietary supplementation with seaweed or seaweed extracts on the immune status and intestinal health of several monogastric farm animal species including pigs, broiler chicken and fish. Because of their health- and growth-promoting effects, it has been suggested that bioactive components from seaweeds such as *Laminaria*-derived laminarin and fucoidan can serve as alternatives to in-feed antibiotics or as environmentally friendly alternatives to therapeutic dosages of zinc oxide in pig diets.

Hansen *et al.* (2021) also demonstrated the potential of seaweed as a substrate for yeast production, uptake of seaweed minerals into the yeast, and the bioavailability of minerals from this yeast in Atlantic salmon.

It is considered that the use of seaweed meals as feed for aquaculture holds promise for the future.

Emblemsvåg *et al.* (2021) investigated the economic potential in replacing soy protein concentrate as a key ingredient in fish feed with proteins extracted from seaweed. They reported that coupling the protein extraction with high-value components (such as mannitol and laminarin) could be a viable venture. In terms of impact on harvest quality, studies have shown that including *Ulva* spp., *A. nodosum*, or *Porphyra* spp. to the feed of sea bream (*Pagrus major*) or Atlantic salmon (*Salmo salar*) improved the disease resistance of these fish species (Mustafa and Nakagawa, 1995; Gabrielsen and Austreng, 1998). Increased growth rate and improved flesh quality have also been reported for fish fed with seaweed meals (Mustafa *et al.*, 1995; Kamunde *et al.,* 2019). Biancarosa *et al*. (2019) also reported the potential of using seaweed-fed insect larvae for the preparation of insect meals for fish feeding.

The above benefits notwithstanding, Morais *et al.*, 2020 cautioned that seaweed supplementation level in animal feed should not exceed 10 percent. Their study cites the deleterious effects of excessive supplementation and, in some cases, the refusal of animals to eat feeds so treated. Kamunde *et al*. (2019) also recommended the same supplementation level, based on findings of improved food intake, enhanced growth performance and improved plasma antioxidant capacity in farmed Atlantic salmon placed on feeds supplemented with *Laminaria* sp.

1.4 FOOD SAFETY CONSIDERATIONS

Given the combined challenge to food production and utilization of a projected population increase to 9.8 billion by 2050 (UN, 2017) and climate change, the need for sustainable primary food production is being emphasized. The exploration of an increased use of seaweed as food has therefore been suggested by various studies (Ginneken and d'Vries, 2015; Radulovich *et al.*, 2015; Forster and Radulovich, 2015; Brummett *et al.*, 2016; Banach *et al.*, 2020a; Cavallo *et al.*, 2021). Critical to this process is a thorough evaluation of the food safety implications of (increased) seaweed production, processing and consumption. It is also important to evaluate the extent to which hazards in seaweed-containing feed may be passed on to humans in animal food.

Although reports of morbidities and mortalities linked to the consumption of seaweeds are rare (Cheney, 2016), the occurrence of several chemical, biological and physical hazards in the commodities may potentially present risks to public health (FSAI, 2020). There is an acknowledged dearth of data on the occurrence of hazards in seaweed. In reviewing the toxicological effects associated with some seaweeds, Kumar and Sharma (2021) pointed to the general lack of attention on the role of seaweeds in foodborne illnesses and recommended close monitoring of the same. Since food safety legislation and related best-practice instruments are based on information on the occurrence of (potential) hazards, documenting and/or screening relevant hazards in seaweed is vital to realizing the potential food security benefits of an increased production, trade and consumption of seaweed.

In subsequent sections, current accessible evidence on the occurrence of food safety hazards in seaweed is reviewed, along with the availability of legislation covering such hazards. Data and legislative gaps are highlighted, and recommendations made for appropriate actions. Although efforts were made to find and present material representative of all regions, more information was obtained from the West than from the rest of the world.[3] More importantly, although Asia features prominently in global seaweed production, utilization and trade (see Section 1.1 to Section 1.3), food safety information on seaweed was not readily obtainable on/from that continent. These limitations notwithstanding, the material presented should suffice as a starting point for balanced discussions on food safety in seaweed. Moreover, it should enable a fair consideration of the interests of all stakeholders along the entire value chain, with the ultimate aim of safeguarding food security and trade as it relates to this commodity.

[3] Information was gathered from literature and reviewed by consenting experts.

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CHAPTER 2
FOOD SAFETY HAZARDS IN SEAWEED

Several chemical, microbiological and physical hazards have been detected in, or are potentially associated with, seaweed (EFSA, 2019; Cavallo *et al.*, 2021). A simplified overview of potential hazards in seaweed is given in Figure 5. These hazards may raise concerns for public health to varying degrees, depending on factors such as the quality of the harvested or procured seaweed food product, consumer handling practices and the form in which seaweed is consumed (raw or processed). For example, due to their specific structural characteristics, seaweeds present a high concentration potential for minerals and trace elements present in the surrounding waters. As a result, the levels of these elements are, on average, several orders of magnitude higher in seaweed than in water (Jadeja and Batty, 2013; Malea *et al.*, 2015; Bonanno and Orlando-Bonaca, 2018; EFSA, 2019). On the other hand, some food preparation practices (such as soaking and washing) have been shown to reduce the levels of some of these hazards, as will be discussed later. Therefore, whereas some intrinsic properties of seaweed may suggest concerns for food safety, some extrinsic factors may ameliorate these concerns (or, in some cases – such as unsanitary/inappropriate handling – worsen them).

With regard to the form in which seaweed is consumed, raw seaweed used in salads may pose higher risks for microbiological hazard ingestion than cooked seaweed. Hazard levels may also differ depending on the part of seaweed considered. Moreover, when used to produce food supplements, seaweed has the potential to contribute to an excessive intake of certain minerals (such as iodine), particularly among high-risk groups such as pregnant and breastfeeding women and those with thyroid dysfunction (FSANZ, 2011; EFSA, 2014). Understanding the occurrence of food safety hazards in seaweed is important in order to develop appropriate guidelines for primary production, regulating the hazards and issuing consumption advice where appropriate.

FIGURE 5. **SOME FOOD SAFETY HAZARDS POTENTIALLY ASSOCIATED WITH SEAWEED**

POTENTIAL FOOD SAFETY HAZARDS IN SEAWEED

Chemical hazards

- Heavy metals (e.g. lead, arsenic, mercury, cadmium)
- Iodine
- Pesticide residues
- Radionuclides (e.g. ^{210}Polonium, ^{7}Beryllium, ^{234}Thorium, ^{228}Radon, ^{90}Strontium, ^{137}Caesium, ^{238}Plutonium)
- Persistent organic pollutants (e.g. dioxins and polychlorinated biphenyls)
- Allergens
- Biotoxins

Microbiological hazards

- Pathogenic bacteria (e.g. *Salmonella*, *Bacillus*, pathogenic *Escherichia coli*, *Listeria*, *Staphylococcus aureus*, and *Vibrio parahaemolyticus*)
- Viruses (e.g. norovirus, hepatitis E virus)
- Biotoxins
- Dinoflagellate toxins
- Cyanobacteria

Physical hazards

- Metal pieces from harvesting and/or processing
- Glass splinters
- Micro- and nanoplastics
- Small crustaceans/invertebrates

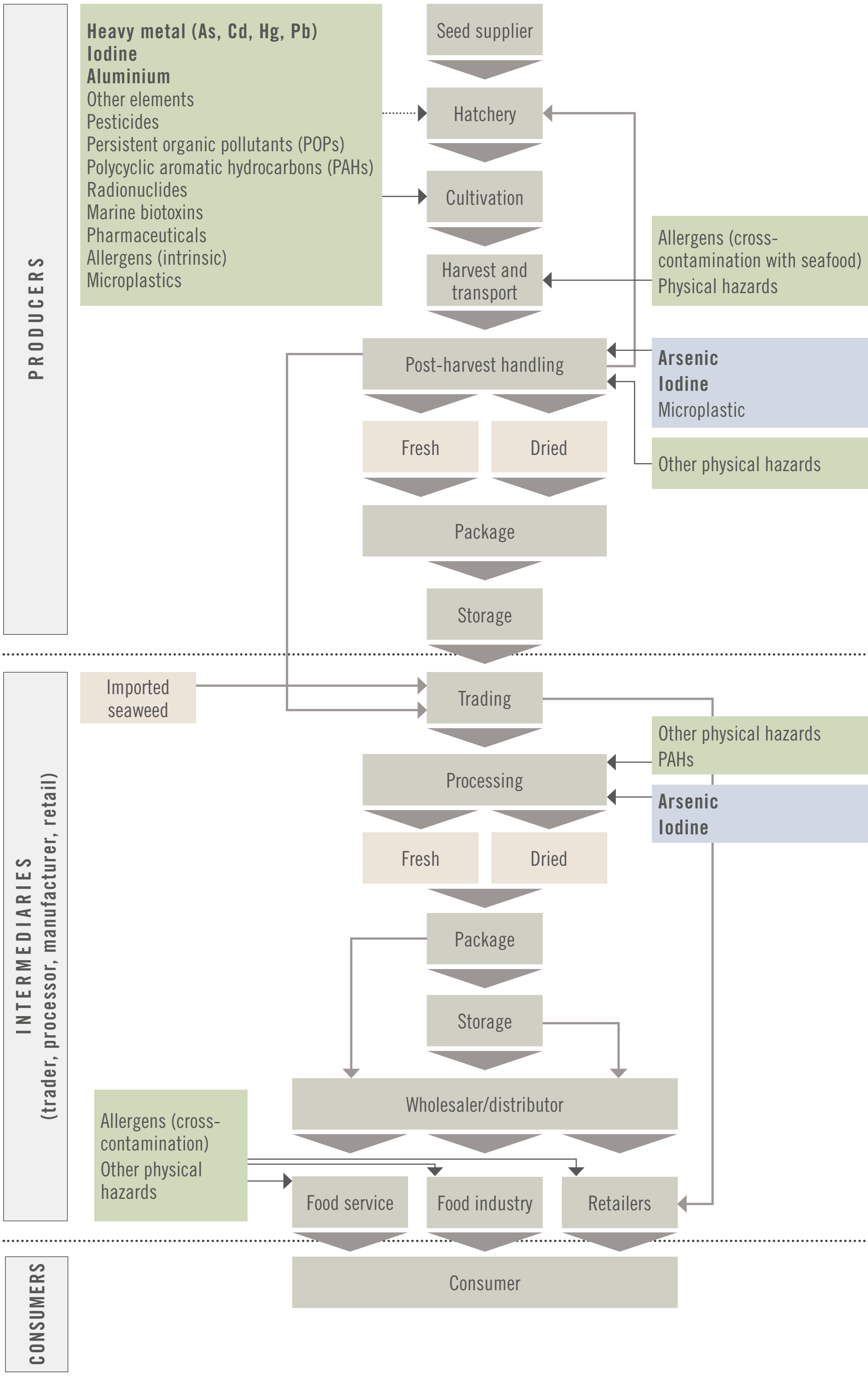
Note: This list is not exhaustive.

Sources: Based on information from Banach, J.L., Hoek-van den Hil, E.F. & van der Fels-Klerx, H.L. 2020a. Food safety hazards in the European seaweed chain. *Comprehensive Reviews in Food Science and Food Safety*, 19: 332–364. DOI: 10.1111/1541-4337.12523; Food Safety Authority of Ireland (FSAI). 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 (FSAI). Dublin. fsai.ie/SafetyConsiderations_SeaweedAndSeaweedDerivedFoods_IrishMarket; and Concepcion, A., DeRosia-Banick, K. & Balcom, N. 2020. Seaweed production and processing in Connecticut: A guide to understanding and controlling potential food safety hazards. Groton, Connecticut, USA. seagrant.uconn.edu/wp-content/uploads/sites/1985/2020/01/Seaweed-Hazards-Guide_Jan2020_accessible.pdf

2.1 CHEMICAL HAZARDS

Figure 6 gives an overview of a typical seaweed aquaculture value chain, and the points at which (chemical) hazards can be introduced or reduced (Banach *et al.*, forthcoming). Hazards listed as associated with the cultivation environment of farmed seaweed may also be found in wild harvested seaweed.

FIGURE 6. **OVERVIEW OF FARMED SEAWEED VALUE CHAIN SHOWING POINTS AT WHICH CHEMICAL HAZARDS ARE INTRODUCED (GREEN) OR REDUCED (BLUE)**



Source: Banach, J. L., Hoffmans, Y., Faassen, E. J. & Hoek–van den Hil, E. F. (forthcoming). Food safety in the seaweed food supply chain: Inventory of production, consumption and chemical and physical hazards.

2.1.1 HEAVY METALS

Certain heavy metals are known food safety hazards. Examples are lead, mercury and cadmium. These are known to present food safety concerns in other seafood products. In seaweeds, the food safety significance of heavy metals lies in the commodity's bioaccumulation potential of these metals. Accordingly, the (heavy) metal content of seaweeds has been used to measure metal pollution in some coastlines (Morrison *et al.*, 2008).

The uptake of trace and heavy metals in seaweed is influenced by factors such as their presence in the environment and the intrinsic uptake capacity of the seaweed species concerned. Studies have reported differences in contamination levels between species and growing waters. Cadmium, for example, has been found to occur at higher levels in red than in brown seaweeds, whereas the reverse was the case for mercury (Chen *et al.*, 2018). Once present in seaweed, the hazards may end up on the plate of the consumer through direct consumption or indirectly through the food chain (e.g. consuming fish that bioaccumulates the metals from feeding on seaweed).

Although European Union (EU) legislation exists for inorganic and total arsenic, cadmium, lead and mercury in seaweed used in/as animal feed, no such standards have been developed yet for seaweed used as food. For food supplements made exclusively from or mainly of seaweed, Commission Regulation (EC) No 1881/2006 (EC, 2006) set out maximum levels for cadmium, lead and mercury. France has provided recommended maximum levels for inorganic arsenic, cadmium, lead, and mercury in seaweeds, in addition to other elements like tin and iodine (AFSSA, 2009; ANSES, 2018; CEVA, 2014).

From 2018 to 2020, the European Food Safety Authority (EFSA) required that Member States collect data on the occurrence of arsenic, cadmium, iodine, lead and mercury in seaweeds and their products in order to provide evidence to assess the contribution of seaweed to the total exposure to these hazards (Commission Recommendation (EU) 2018/464; EC, 2018). The data is expected to be used to ascertain whether maximum levels for arsenic, cadmium and lead are needed in these products, whether the maximum level (ML) for mercury in algae and prokaryotes requires amendment, or if exposure to iodine from these products warrants risk management action (FSAI, 2020). No information has been identified about other countries or regions considering the same kind of data collection.

Since seaweed is mostly sold dried, the levels of metals in such products are about five to ten times higher than in fresh seaweed (Duinker *et al.* 2020). By extension, the metal levels in dried seaweed are higher (weight for weight) than in other food types sold fresh. Consequently, cross-product comparisons (seaweed vs. seaweed, and seaweed vs. other food types) should be done on a dry matter basis. The general lack of intake data (quantities, frequencies, mode of use) for seaweed hampers an exposure assessment for the hazard.

2.1.1.1 Cadmium

Several studies have reported the occurrence of cadmium in seaweed, with levels ranging from below the detection limit of 0.001 µg/mL to 9.8 mg/kg dry weight (dw) (Banach *et al.*, 2020a). In China, Chen *et al*. (2021) reported a cadmium level of 2.62 mg/kg in *Porphyra* and *Laminaria* sampled from a coastal city. They further reported that the level was comparable to those found in previous studies.

In the United States, the regulatory requirement for heavy metals is < 40 mg/kg dry matter for total heavy metal, < 3 mg/kg dry matter for inorganic arsenic and < 10 mg/kg for lead (Holdt and Kraan, 2011). No legislative limit has yet been set for cadmium in edible seaweed in the European Union. France, however, has recommended a maximum level of 0.5 mg/kg dry matter in edible seaweed (ANSES, 2020). In food supplements made exclusively or mainly of seaweed, the EU maximum level for cadmium is 3 mg/kg wet weight (Commission Regulation (EU) No 1881/2006). In animal feed, the applicable maximum level is 1 mg/kg (relative to a feed with a moisture content of 12 percent) (EC, 2002a), designated for feed of vegetable origin. No information about the maximum level for Cadmium was found for other countries or regions.

2.1.1.2 Lead

Reported lead levels in seaweed range from < 0.05 mg/kg to 2.44 mg/kg dry weight (Almela *et al.*, 2006). No information about legislative limits have been found for lead in seaweed for food. France recommends a maximum level of 5 mg/kg dry matter in seaweed (ANSES, 2020). In general, human exposure to lead through seaweed consumption is considered minimal (FSAI, 2020). However, given the potential for bioaccumulation and uncertainties regarding the contamination levels in various species, it may be helpful to assume a precautionary stance for the protection of public health while efforts are made to close data gaps.

2.1.1.3 Mercury

The occurrence of mercury in seaweed results from environmental contamination and anthropogenic activities. Contamination levels vary with species and origin (Banach *et al.*, 2020a). No information about regional or national regulatory limits for mercury in edible seaweed have been found. France, however, recommends a maximum level of 0.1 mg/kg dry matter (ANSES, 2020). For seaweed-derived food supplements, the European Union requires no more than 0.10 mg/kg wet weight (Commission Regulation (EC) 1881/2006).

2.1.1.4 Arsenic

Arsenic occurs in organic and inorganic forms and shows varying levels of toxicity (FSAI, 2020).

Inorganic arsenic is a carcinogen and is thus the form relevant to consider for public health (WHO, 2011). Studies have reported inorganic arsenic levels of up to 117 mg/kg dw in *Hizikia (Sargassum) fusiforme* (Almela *et al.*, 2006; Besada *et al.*, 2009). Similar levels of inorganic arsenic in *Hijiki* can be found in *Laminaria digitata* (Ronan *et al.* 2017; Duinker *et al.*, 2020). In the United Kingdom of Great Britain and Northern Ireland, health advisories were issued in 2004 and 2010 by the Food Standards Agency, cautioning consumers to avoid products containing *H. fusiforme* since it could contain high levels of inorganic arsenic (Cheney, 2016). Irish regulations warn that any edible seaweed should be deemed to contain more than 1 mg/kg of arsenic from natural occurrence (FSAI, 2020). Based on the work of Duinker *et al*., 2020, the Norwegian Food Safety Authority (NFSA) advises consumers to avoid products from *Laminaria digitata* because of high levels of inorganic arsenic (NFSA, 2020).

Some studies report that processing/cooking affects the level of arsenic in food. For example, the total arsenic content was reduced by up to 60 percent through washing and soaking (Hanaoka *et al.*, 2001). Accordingly, the FAO/WHO Joint Expert Committee on Food Additives (JECFA) recommends this practice (WHO, 2011; JECFA, 2011). The Japanese Ministry of Agriculture, Forestry and Fisheries (2015) also cautioned consumers in Japan to apply various home cooking practices such as washing and soaking to reduce the arsenic content of *hijiki*. It could be expected, however, that the nutritional content of the seaweed after such treatment may be lower due to potential losses in water-soluble nutrients.

Like the other metals, no maximum levels are available for total and inorganic arsenic in seaweeds in the European Union, although a value of 40 mg/kg of total arsenic has been set for feeds (based on 12 percent moisture) (Directive 2002/32/EC; EC, 2002a). The EU directive cited further requires seaweed producers to demonstrate that inorganic acid levels in seaweed (especially in *Hizika fusiforme*) fall below 2 ppm, if requested by a competent authority. France recommends 3 mg/kg dry matter (ANSES, 2020).

France was the first European country to carry out a specific evaluation of the use of macroalgae for human consumption as non–traditional food substances (CEVA, 2019). A total of 25 algae species (3 of these are microalgae) are listed as food (vegetables or condiments). Of the macroalgae, 9 brown macroalgae species (including CS3 *Laminaria saccharina* or *S. lattisima)*, 11 red macroalgae species and 2 green macroalgae species (including *Ulva spp* but not *Codium tomentosum)* are listed. In addition, there are French recommendations for maximum levels in inorganic arsenic, cadmium, lead, and mercury in edible macroalgae (CEVA, 2019).

Food Standards Australia New Zealand (FSANZ) conducted a survey investigating levels of inorganic arsenic in dried seaweed and products containing seaweed available in Australia. The maximum level for inorganic arsenic for seaweed was stablished at 1 mg/kg in the Australia New Zealand Food Standards Code (FSANZ, 2004).

2.1.2 IODINE

Iodine is an essential trace mineral required for the synthesis of thyroid hormones, which play critical roles in metabolism, embryogenesis and neurological development. Iodine is ingested as different inorganic and organic species. The inorganic iodine species is reduced to iodide in the gut and subsequently absorbed (Jahreis *et al.*, 2001).

All biological actions of iodide in humans are attributed to the thyroid hormones. Thyroxine (T4) is the major hormone secreted by the thyroid gland. T4 in circulation is taken up by the cells and is de-iodinated to triiodothyronine (T3), the active form of the thyroid hormone. While a physiological amount of iodine is required for ensuring a normal thyroid function, a large excess of iodine can inhibit the process of synthesis and the release of thyroid hormones. This is known as the Wolff-Chaikoff effect (ATSDR, 2004). The Wolff-Chaikoff effect is temporary, and with repeated exposure to high doses of iodide, the thyroid gland returns to normal levels of hormone synthesis, referred to as escape from the Wolff-Chaikoff effect (ATSDR, 2004).

Generally, seaweed is considered an iodine-rich material which, depending on the volumes consumed, could cause an excessive intake of iodine (Aakre *et al*., 2020). Some brown seaweeds, and especially *Laminaria* sp. and *Saccharina*, have been recognized to have significant bioaccumulation capacity for iodide. It has been proposed that the biological role of iodide in seaweed is its activity as an inorganic antioxidant, readily scavenging a variety of reactive oxygen species that may be produced in seaweed due to biofilms or exposure to sunlight (Küpper *et al*., 2008).

Aakre *et al.* (2021) assessed the iodine content of (foods containing) seaweed and reported levels generally exceeding the tolerable upper intake level of the nutrient. Therefore, it may be expected that a high intake of iodine in seaweed within a short period may temporarily induce the Wolff-Chaikoff effect. However, since the effect is reversible and reports of its clinical symptoms are rare, a high intake of iodine over a short time span is unlikely to result in adverse health effects (M. Hansen, personal communication, 2021).

Food preparation practices and cooking methods have been found to influence the iodine content of seaweed (Teas *et al.*, 2004; Zava and Zava, 2011; Nitschke and Stengel, 2016; Nielsen *et al.*, 2019). Whereas soaking in water for 1 hour reduced the iodine content in *Saccharina latissima* by 60 percent (Stévant *et al.*, 2018), boiling in water for 2 minutes caused a 30 percent reduction (Teas *et al.*, 2004). Rehydration has also been found to reduce iodine levels in brown seaweed by up to 60 percent (Nitschke and Stengel, 2016). The iodine content of kelps is reduced drastically (over 90 percent) by boiling in tap water. However, this process is also associated with significant losses of other nutrients (e.g. minerals, vitamin C, phenolic compounds, and free amino acids) (Stevant *et al.* 2018; Nielsen *et al.* 2019).

A maximum level of 2 000 mg/kg dry matter for all species of edible seaweed is recommended in France (ANSES, 2018), with the caution that seaweed and seaweed-derived products should not be consumed by: (i) people with thyroid dysfunction, heart disease or kidney failure; (ii) those taking medication containing iodine or lithium; and (iii) pregnant or breastfeeding women (ANSES, 2018). Germany allows a maximum concentration of 20 mg/kg of iodine in dried seaweed for consumption (BfR, 2004). The EFSA Panel on Additives and Products or Substances used in Animal Feed (FEEDAP) recommends that the maximum iodine contents in complete feed be reduced to 2 mg I/kg for dairy cows and minor dairy ruminants, and 3 mg I/kg for laying hens (EFSA, 2013).

Norway has not established any national MLs for seaweed. However, the Norwegian Food Safety Authority (NFSA) advises consumers to consume seaweed in moderation to avoid excessive iodine intake. Some vulnerable groups of the population are advised to be even more mindful of their intake (NFSA, 2016). Norwegian seaweed producers have published a guideline that includes labelling recommendations for products with a high iodine content, to ensure that consumers can make an informed choice (Norwegian Seaweed Farms, 2020). Food Standards Australia New Zealand (FSANZ) also issued advice for pregnant women, breastfeeding women and children to consume no more than one serving a week of brown seaweed, due to concerns over potential excessive intake of iodine (FSANZ, 2011).

2.1.3 PESTICIDE RESIDUES

Given that the bulk of seaweed production comes from aquaculture production, the use of plant protection products in aquaculture could potentially result in pesticide residues in the seaweed produced. Contamination of wild seaweed could also occur through run-off and leaching from agronomic applications (Sapkota *et al.*, 2008). There is limited information on the monitoring of pesticide residues in edible seaweed, although studies hafve shown a significant uptake capacity for pesticide residues (Banach *et al.*, 2020a). In the European Union, a default maximum residue limit (MRL) of 0.01 mg/kg is considered applicable to seaweeds where specific values have not been assigned. Commission Regulation (EC) No 396/2005 provides MRLs for some seaweeds (EC, 2005a).

2.1.4 RADIONUCLIDES

Seaweed has the capacity to accumulate radionuclides (Banach *et al.*, 2020a; Goddard and Jupp, 2001) and has, for example, been used as a bioindicator for ^{129}Iodine (Gómez-Guzmán *et al.*, 2014) and for radioactive pollution of marine environments (Duinker *et al.*, 2020). Naturally occurring ^{210}Polonum, ^{7}Beryllium, ^{234}Thorium and ^{228}Radon are associated with seaweed (McMahon *et al.*, 2005). Other radionuclides such as ^{3}Hydrogen, ^{14}Carbon, ^{90}Strontium, and ^{137}Caesium result from human activities such as nuclear weapon testing and can persist in the environment

(FSAI, 2020; McMahon *et al.*, 2005). This being said, the food safety implications of radionuclides in seaweed remain largely unexplored (Duinker *et al.*, 2020). The few studies that have considered the issue reported no significant differences between the contamination levels in seaweed and other foods (Tuo *et al.*, 2016), and that the contaminant levels do not pose food safety concerns (Moreda-Piñeiro *et al.*,2011; Skjerdal *et al.*, 2017).

Codex has set guidelines for radionuclides in foods contaminated following a nuclear or radiological emergency (CAC, 1995). Two broad food categories are covered under the guidelines: infant foods and foods other than infant foods. It may be considered that seaweed falls in the second category. Applicable limits range from 10 Bq/kg (e.g. for ^{238}Plutonium, ^{239}Plutonium, ^{240}Plutonium, and ^{241}Americium) to 10 000 Bq/kg (e.g. for ^{3}Hydrogen, ^{14}Carbon and ^{99}Technicium) (CAC, 1995).

In the European Union, Regulation (Euratom) No. 2016/52 (EC, 2016) provides maximum levels for radionuclides in foods following nuclear accidents/disasters. The regulation outlines provisions for seaweed under the category "other food except minor food". For example, the maximum permitted levels are 750 Bq/kg for the sum of isotopes of strontium; 2 000 Bq/kg for the sum of isotopes of Iodine; 80 Bq/kg for the sum of alpha-emitting isotopes of plutonium and transplutonium elements; and 1 250 Bq/kg for the sum of all other nuclides with a half-life greater than 10 days.

2.1.5 PERSISTENT ORGANIC POLLUTANTS

Persistent organic pollutants (POPs) are organic environmental pollutants with high chemical stability. They include dioxins and polychlorinated biphenyls (PCBs), which are known to accumulate principally in the fatty tissues of animals. Although seaweeds generally have a low lipid content, they can be contaminated with POPs, particularly in areas where these pollutants occur at elevated levels. Cheney *et al.* (2014) reported that seaweeds grown in POP-contaminated sites accumulate hazards. In such cases, the hazards can be passed along the feed and food chain and pose risks to public health. Duinker *et al.* (2020) reported low levels of POP in farmed kelp on the coast of Norway. No regulatory limits have been set specifically for seaweed in the European Union. Data on the occurrence of POPs in seaweed are limited (Banach *et al.*, 2020a).

2.1.6 ALLERGENS

A few studies have reported allergic reactions to some red seaweeds (e.g. *Porphyrae*). This is due to porphyran (a major component of *Porphyra tenera* and *Porphyra yezoensis*) which can cause hypersensitivity reactions (Thomas *et al.*, 2019). The green seaweed (*Ulva* spp.) has also been cited for allergenicity (Polikovsky *et al.*, 2019). Bito *et al.* (2017) identified similar immunoreactive components in nori as those in crustaceans frequently implicated in food allergies. In the United States of

America, due to the potential of crustacean contamination of seaweed cultivated on longlines, crustacean shellfish allergens (especially due to the protein tropomyosin) have been described as significant chemical hazards in seaweed (Concepcion *et al.*, 2020). In contrast, other studies ascribe anti-allergic properties to some seaweeds (especially brown seaweed) (Farrohki *et al.*, 2009; Samee *et al.*, 2009; Olsthoorn *et al.*, 2021). Miyake *et al.* (2006) suggested a link between higher seaweed intake and lower prevalence of allergic rhinitis among Japanese young female adults. Overall, literature on the allergenicity of seaweeds is limited. No legislation was found on allergens in seaweed for food and feed.

2.1.7 BIOTOXINS

Seaweed-linked biotoxins are naturally occurring toxic metabolites found on seaweed and typically produced by cyanobacteria and dinoflagellates that grow on seaweed (Gerssen *et al.*, 2010). Those reported to be associated with edible seaweed include palytoxin (PTX), domoic acid (DA) and its analogues, ciguatoxins, and cyclic imines (CIs) (Banach *et al.*, 2020a). *Ostreopsis* sp., a PTX-producing dinoflagellate known for toxic algal blooms, has been reported to be associated with brown and red seaweeds (Rhodes *et al.*, 2000; Monti *et al.*, 2007). A neurotoxin that is a concern in some diatom microalgae, DA, has been reported to occur in red seaweeds such as *Chondria armata,* although poisoning with this antihelminthic compound is rare, or undocumented (FAO, 2004).

The dinoflagellate *Gambierdiscus toxicus* may occur epiphytically on seaweeds and produce ciguatoxins, the toxin known for ciguatera fish poisoning (FAO and WHO, 2020). Although *Gambierdiscus* spp. can be associated with all seaweed groups (red, brown and green), studies have reported varying epiphytic behaviours for different hosts (Rains and Parsons, 2015), with potential implications for the toxin levels that may be found in each species.

CIs are noted for their fast-acting toxicity and include spirolides, gymnodimines, pinnatoxins, pteriatoxins, prorocentrolides, and spiro-prorocentrimine (Otero *et al.*, 2011). As with the other marine biotoxins, the occurrence of CIs is typically linked to the association of dinoflagellates with seaweed (Rambla-Alegre *et al.*, 2017).

Other biotoxins include prostaglandins, polycavernoside, aplysiatoxin, and debromoaplysiatoxin. These have reportedly been implicated in foodborne illnesses and deaths linked to seaweed (Cheney, 2016). The neuroactive toxin kainic acid can be found in some strains of dulse (*P. palmata*), albeit at such low levels that only an exaggerated intake could result in an adverse response (Mouritsen *et al.*, 2013). Kainic acid is a neurotoxin that is similar to domoic acid (an amino acid associated with certain harmful algal blooms and causes amnesic shellfish poisoning) and can be found in *Palmaria palmata* (Holdt and Kraan, 2011). Some studies on dwarf specimen have shown high concentrations of concern, although a study on fresh material from different countries and commercially dried products performed by the Danish National Food Authorities did not find concentrations of concern.

Presently, Codex standards for marine biotoxins cover bivalve molluscs (CAC, 2015). Guidance levels in seaweed have not yet been established.

2.2 MICROBIOLOGICAL HAZARDS

Depending on their growth/cultivation environment and handling practices, seaweed may be contaminated with a diverse group of pathogenic microorganisms. Hazards generally associated with fishery products such as *Salmonella, Bacillus*, pathogenic *Escherichia coli, Listeria*, *Staphylococcus aureus* and *Vibrio,* may also be found in fresh or processed seaweed (Cho and Rhee, 2020; Banach *et al.*, 2020a). Maintaining good sanitary conditions during the cultivation, harvesting, transportation, processing, and consumption of seaweed is essential for reducing microbial contamination. In farmed kelp from Norwegian waters, low counts (1–3 log colony forming units per gram) for total aerobic count, psychrotrophic bacteria, and spore-forming bacteria were found, while enterococci, coliforms, pathogenic vibrios and *Listeria monocytogenes* were not detected. However, *Bacillus* spp. were isolated (Blikra *et al.* 2019). A salmonellosis outbreak in Hawaii in 2016 was linked to seaweed from an aquaculture farm, where the sanitary conditions were less than ideal (Nichols *et al.*, 2017).

Besides pathogenic bacteria, viruses may also be associated with seaweed. Outbreaks of norovirus GII have been linked to seaweed (Park *et al.*, 2015; Sakon *et al.*, 2018). Broadly speaking, the general principles of food hygiene are expected to be applied to the production and processing of seaweed

In the European Union, no specific legislation is provided concerning biological hazards in seaweed in Regulation (EC) No 2073/2005, which sets out regulations concerning microbiological criteria for foodstuffs (EC, 2005b). The only criteria is the more general maximum limit for *Listeria monocytogenes* introduced for all food products in Regulation (EC) 2073/2005 (EC, 2005b). France has regulations for microbiological hazards in dried algae (CEVA, 2019) (Table 11).

TABLE 11. **MICROBIOLOGICAL LIMITS APPLIED TO DRIED ALGAE IN FRANCE**

ITEM/ORGANISM	LIMIT
Mesophilic aerobic microorganisms	< 105 / gram
Faecal coliforms	< 10 / gram
Anaerobic sulphur-reducing bacteria	<102 / gram
Staphylococcus aureus	< 102 / gram
Clostridium perfringens	<1 / gram
Salmonella	Absence in 25 grams

Source: CEVA. 2019. *Edible seaweed and microalgae Regulatory status in France and Europe.*
Retrieved from www.ceva-algues.com/wp-content/uploads/2020/03/CEVA-Edible-algae-FR-and-EU-regulatory-update-2019.pdfhttps://www.ce

2.3 PHYSICAL HAZARDS

The main physical hazards of concern in seaweeds are (pieces of) shells from mussels, small crustaceans, and small stones on which spores settle for growth (Concepcion *et al.*, 2020). These may not be detected in seaweed during processing or consumption in the raw form. Microplastics and nanoplastics are also known to adhere to seaweed effectively (EFSA, 2016). These include different types and shapes of plastic particles (e.g. fragments, pellets, beads, fibres, spheroids and granules) measuring 0.1 to 5 000 µm in size. They are categorized as primary (resulting from manufacture) and secondary microplastics (resulting from the breakdown of larger plastic materials) (EFSA, 2016). Adhering microplastics can serve as vehicles for chemical and microbial contaminants. However, studies have shown that washing significantly decreases the amount of microplastics in seaweed (Sundbæk *et al.*, 2018). Current evidence is insufficient to arrive at a conclusion on the characterization of microplastics and nanoplastics in seaweed, and legal limits have not yet been set (FSAI, 2020).

Other physical hazards include metal pieces and glass. These may occur in packaged seaweed when their process flow involves size reduction or packaging in glass (Concepcion *et al.*, 2020).

2.4 SOME CASES OF FOODBORNE ILLNESSES REPORTED TO BE LINKED TO SEAWEED CONSUMPTION

Reports of foodborne illnesses associated with seaweed consumption are few and far between. Cheney (2016) studied global reports of fresh seaweed-linked illnesses and deaths and found low numbers of cases: 73 illnesses and 14 deaths within a period of 36 years (1967–2003). Details of the specific cases and the implicated hazards are summarized in Table 12.

TABLE 12. **ILLNESSES AND DEATHS REPORTED TO BE ASSOCIATED WITH THE CONSUMPTION OF RAW SEAWEED**

SEAWEED GROUP	SPECIES	LOCATION	YEAR	NO. OF ILLNESSES	NO. OF DEATHS	AGENT
Brown algae	*Nemacystus decipiens, Cladosiphon okamuranus*	Japan	1967	2	0	Diethyl peroxides
Red algae	*Gracilaria chorda*	Japan	1980	4	1	Prostaglandins
	Gracilaria verrucosa	Japan	1982	6	1	Prostaglandins
	Gracilaria edulis	Guam	1991	13	3	Polycavernosides
	Gracilaria lemaneiformis	California	1992	3	0	Aplysiatoxin Debromoaplysiatoxin
	Gracilaria verrucosa	Japan	1993	2	1	Prostaglandins
	Gracilaria coronopifolia	Hawaii	1994	7	0	Aplysiatoxin Debromoaplysiatoxin

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SEAWEED GROUP	SPECIES	LOCATION	YEAR	NO. OF ILLNESSES	NO. OF DEATHS	AGENT
Red algae	*Gracilaria edulis*	Philippines	2002	9	2	Polycavernosides
	Acanthophora spicifera	Philippines	2002 2003	12 15	3 3	Unknown
Green algae	*Caulerpa racemosa*	Philippines	?	?	0	Caulerpin, Caulerpicin

Note: The causative agents were considered to have been potentially associated with contaminating epiphytic cyanobacteria, rather than being endogenous in the seaweed. In some cases they were linked to the preparation of seaweed with acid maceration, which causes the oxidation of some fatty acids into prostaglandins.

Source: Adapted from Cheney (2016).

From the cases in Table 12, only five species of seaweed were implicated, with *Gracilaria* sp. and *Acanthophora* sp. together accounting for 97 percent of illnesses and 100 percent of deaths. The most widely consumed and commercially valuable species (e.g. *Porphyra*, *Laminaria*, and *Undaria*) were not implicated (Cheney, 2016).

Concerning the causative agents of illnesses and deaths, Cheney (2016) suggested that the named hazards, rather than being endogenous in the seaweed, could be associated with epiphytic cyanobacteria that contaminated the seaweed. All the cases concerned consumption of raw seaweed that were mostly collected by the victims from apparently contaminated waters, which were not treated (washed and/or cooked) before consumption. It seems, therefore, that the reported illnesses and deaths occurred due to improper handling of seaweed.

2.5 FACTORS INFLUENCING THE OCCURRENCE OF FOOD SAFETY HAZARDS IN SEAWEED

The occurrence and persistence of food safety hazards in seaweed are influenced by such factors as cultivation environment, species, age before harvesting (especially for wild seaweed) as well as processing and handling practices.

2.5.1 CULTIVATION ENVIRONMENT

Hazards found in the cultivation environment of seaweed will invariably influence the types and levels of hazards in the harvested seaweed. The sites of wild harvesting and site selection for seaweed farming therefore have significant impacts on the final quality and safety of the commodity. Parameters such as fluvial influence, nutrient sources and concentrations, existing seaweed standing crop, upland farming communities and proximity to industrial activity could all influence the quality and safety of the harvested seaweed (I. Levine, personal communication, 2021).

As previously noted, the poor microbiological quality of harvested seaweed has been linked to poor sanitary conditions of the cultivation environments. Pathogens in the cultivation environment are generally considered significant hazards, especially when the seaweed may be consumed raw (Concepcion *et al.*, 2020). Concerning chemical hazards, their presence is essentially due to uptake from the environment and accumulation over time. Squadrone *et al.* (2018) found significant differences in metal bioaccumulation in seaweed harvested from three different sites of the Mediterranean Sea. The highest concentrations were found in seaweed from a site close to an industrial and touristic harbour.

In general, wild harvests are likely to be more prone to contamination with chemical hazards originating from pollutants (e.g. POPs) due to the multiple potential sources of such pollution (e.g. untreated industrial effluent and run-off) and the low control over hazard occurrence in such environments. In aquaculture, the use of plant protection chemicals may result in contamination with pesticide residues (Sapkota *et al.*, 2008). Contamination from sewage and waste emissions due to anthropogenic activities cannot be completely ruled out for such settings. This highlights the importance of site selection for seaweed farming. A reasonable compromise needs to be struck between growth conditions such as nitrogen availability and eventual product quality and safety (Banach *et al.*, 2020b).

It has been suggested that food safety hazards from other cultivated marine species may contaminate seaweed, especially in integrated multitrophic aquaculture (IMTA). In IMTA, fed species such as finfish or shrimps are farmed with extractive species (such as mussels and seaweed) to allow the unused feed, wastes and by-products of the fed species to be used by the extractive species (Chopin, 2013). For example, in recirculating aquaculture systems for abalone and macroalgae, whereas hazards in seaweed may contaminate the abalone, potential (inorganic) waste accumulation through circular loops may result in hazard uptake by seaweed.

2.5.2 SPECIES

As previously noted, studies suggest interspecies variations in the bioaccumulation of heavy metals in seaweed. Squadrone *et al.* (2018) determined the levels of trace elements in the dominant seaweeds in the northwestern Mediterranean Sea and found significant interspecies differences with higher contaminant levels in brown rather than green and red seaweeds. Sánchez-Quiles *et al.* (2017) also determined the distribution of heavy metals in natural populations of seaweeds across the globe by compiling over 20 000 estimates of trace metal levels in seaweeds. Brown seaweeds were found to have the highest accumulation capacity irrespective of the sampling location, while red seaweeds had the least capacity (Sánchez-Quiles *et al.*, 2017). Similar findings have been reported by other studies (Conti and Cecchetti, 2003; Akcali and Kucuksezgin, 2011; Malea and Kevrekidis, 2014). Differences in morphology, growth rates and affinity for metals have been cited to potentially account for the interspecies differences (Squadrone *et al.*, 2018). In another study, green algae were found to have the lowest levels of cadmium, while brown and red algae were equally represented among the species with higher median concentrations (Duinker *et al.*, 2020).

2.5.3 AGE

Since uptake and accumulation account for the occurrence of (chemical) food safety hazards in seaweed, the longer seaweed stays in a contaminated cultivation environment, the higher the exposure can be to the hazards, and thus the greater the potential extent of the contamination. This is expected to be more important in wild-harvested seaweed since the age of the seaweed prior to harvesting may not be known. Moreover, if the growth environment of wild seaweed has appreciable proximity to sources of (anthropogenic) toxic waste and other emissions, the impact of age may be even more significant. An increase in the biomass of seaweed with age is also expected to contribute to increased accumulation of some chemical hazards.

2.5.4 HARVESTING AND PROCESSING HANDLING

Handling practices during the harvesting and processing of seaweed influence the safety of the products. Unhygienic harvesting conditions could result in the contamination of seaweed with pathogenic microorganisms. Insufficient washing and/or use of contaminated water for post-harvest washing could also compromise the microbial safety of the harvested produce. Some treatments such as washing of the biomass with freshwater instead of seawater increase the risk of pathogenic bacteria growth. Temperature abuse at harvest and during storage could cause growth of pathogenic contaminants (Concepcion *et al.*, 2020).

Seaweed processing methods may also influence the types of hazards that could be expected in the products. For example, whereas toxigenic moulds could be associated with shelf-stable dried seaweed, the hazards may be considered insignificant for raw seaweed intended to be consumed as is (Concepcion *et al.*, 2020). For some product forms (e.g. kelp noodles), a mechanical cutting step is required in the process flow. For such products, the cutting step may be a control point in a hazard analysis and critical control point (HACCP) system for the process in order to prevent metal contaminants (physical hazard) (Concepcion *et al.*, 2020).

2.6 RANKING FOOD SAFETY HAZARDS IN SEAWEED

Although multiple food safety hazards may be associated with a given food, not all the hazards may have foodborne disease significance. The intrinsic properties of the hazards concerned, the point in the food value chain at which they occur, and processing/handling practices, are all factors (among others) that impact their potential to eventually cause harm to (susceptible) consumers. Banach *et al.* (2020a) developed a scoring matrix to rank 22 food safety hazards in seaweed for both feed and food use as minor, moderate or major (Table 13), reflecting an increasing order of significance for public health. They identified 4 major hazards (cadmium, arsenic, iodine and *Salmonella*), 5 moderate hazards (lead, mercury, aluminium, *Bacillus* spp. and norovirus) and 13 minor hazards (Table 13). While these categories may highlight the relative importance of the hazards, such interpretation is valid within the limits of the data used and the assumptions underpinning the ranking. As per the authors' categorization, heavy metals and microbiological hazards require attention in seaweed, the occurrence and persistence of the former being chiefly ascribable to bioaccumulation and the latter to improper post-harvest handling practices.

TABLE 13. **RANKING OF FOOD SAFETY HAZARDS IN SEAWEED**

HAZARD	LITERATURE LINKING HAZARD TO FOOD	LITERATURE LINKING HAZARD TO FEED	RASFF REPORTS THAT SHOW > 2% OF TOTAL REPORTS	CONCERN FOR ≥ 25% OF STAKEHOLDERS	SCORE	ASSIGNED HAZARD CATEGORY
Arsenic	Possibly	Yes	Yes	Yes	1.67	Major
Cadmium	Possibly	Possibly	Yes	Yes	1.59	Major
Iodine	Yes	Yes	Yes	Yes	1.50	Major
Salmonella	Yes	Yes	No	Yes	1.50	Major
Lead	Possibly	Possibly	No	Yes	1.34	Moderate
Mercury	Possibly	Possibly	No	Yes	1.34	Moderate
Aluminium	Possibly	Possibly	Yes	No	1.34	Moderate
Bacillus	Yes	Limited data	No	Yes	1.33	Moderate
Norovirus	Yes	Limited data	No	Yes	1.33	Moderate
Dioxins and polychlorinated biphenyls	Limited data	Limited data	No	Yes	1.17	Minor*
Brominated flame retardants	Limited data	Limited data	No	Yes	1.17	Minor*
Polycyclic aromatic hydrocarbons	Limited data	Limited data	No	Yes	1.17	Minor*
Other pathogenic bacteria	Possibly	Limited data	No	Yes	1.17	Minor*
Hepatitis E virus	Limited data	Limited data	No	Yes	1.17	Minor*
Fluorine	Possibly	Possibly	No	No	1.09	Minor
Pesticide residues	Limited data	Limited data	No	No	0.92	Minor*
Pharmaceuticals	Limited data	Limited data	No	No	0.92	Minor*
Marine biotoxins	Limited data	Limited data	No	No	0.92	Minor*
Allergens	Limited data	Limited data	No	Yes	0.92	Minor*
Micro- and nanoplastics	Limited data	Limited data	No	No	0.92	Minor*
Radionuclides	No	No	No	No	0.75	Minor

Note: Not all hazards ranked in the referenced study have been discussed in this text. The authors (i.e. Banach *et al.*, 2020a) developed a scheme to rank the hazards based on four factors: occurrence of the hazard in food, occurrence in feed, RASFF alerts and survey responses from stakeholders in the seaweed value chain. In the survey, respondents indicated which hazards they considered to be of concern (the more respondents who selected a hazard, the greater the concern considered to be associated with that hazard). Scores were assigned to each factor, the final scores aggregated, and the hazards ranked into major (score 1.75 to 1.50), moderate (score 1.49 to 1.25), or minor (score 1.24 to 0.75).

*Authors indicated data gaps on the assessed hazard.

Source: Adapted from Banach *et al.* (2020a).

As discussed, there is a paucity of regulations on food safety hazards in seaweed, despite the fact that 80 percent of global seaweed production is destined for human consumption (White and Wilson, 2015; West *et al.*, 2016). Hence, it is apparent that more monitoring data is needed on the occurrence of these hazards and their potential risk to public health in particular national contexts.

A search on the EU rapid alert system for food and feed (RASFF) with the keywords "seaweed" and "algae" turned up 268 reports, all in food (the search date was 14 January 2021). Of the 268 notifications, 74 were classified per risk decision as serious, 12 as not serious, and the remaining 182 as undecided (Table 13). Over 90 percent of notifications were due to the major hazards (243 notifications, 91 percent of total). Among the major hazards, excessive iodine levels accounted for 168 (63 percent) of notifications. Arsenic, cadmium and *Salmonella* respectively made up 61 (23 percent), 10 (4 percent) and 4 (1 percent) of the alerts (Table 13). It should be noted, however, that the RASFF notifications rely on local MLs, since no international standards exist for seaweed as food. With the German ML of 20 mg/kg for iodine (BfR, 2004), most algal products will cause notifications, while no notifications will be issued by countries without local MLs.

TABLE 14. **RAPID ALERT SYSTEM FOR FOOD AND FEED (RASFF) NOTIFICATIONS FOR "SEAWEED" AND "ALGAE" SEARCH KEYWORDS**

HAZARD CATEGORY	HAZARD TYPES	NUMBER OF REPORTS	
		Number	Percentage
Major hazards	Iodine	168	63
	Arsenic	61	23
	Cadmium	10	4
	Salmonella spp.	4	1
	Total	**243**	**91**
Moderate hazards	Lead	3	1
	Mercury	1	0.4
	Aluminium	6	2
	Bacillus spp.	1	0.4
	Norovirus	4	1
	Total	**15**	**6**
Other hazards		10	4
Total reports		**268**	**100**

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CHAPTER 3

REGULATION OF FOOD SAFETY HAZARDS IN SEAWEED

As noted, there are significant gaps in regulations concerning food safety hazards in seaweed. Although extensive regulations and accompanying guidance documents are available for other fishery resources, seaweed remains conspicuously left out. In recent times, attention has been drawn to this significant gap (Banach *et al*., 2020a; Banach *et al*., 2020b; Concepcion *et al*., 2020). It is worth noting that most of the regulatory limits and references provided in this document refer to European legislation, as examples from other regions were not available.

3.1 CODEX STANDARDS

At the time of preparing this report, no Codex standard nor specific code of practice for seaweed was available. Although the *Regional Standard for Laver Products* (CXS 323R-2017) concerns a seaweed product (genus *Pyropia*), on the matter of contaminants, the standard refers to the *General Standard for Contaminants and Toxins in Food and Feed* (CXS 193-1995). However, CXS 193 (last updated in 2019) does not address seaweed and has the following scope:

> "This Standard contains the main principles which are recommended by the Codex Alimentarius in **dealing with contaminants and toxins in food and feed** and lists the maximum levels and associated sampling plans of contaminants and natural toxicants in food and feed **which are recommended by the Codex Alimentarius Commission (CAC) to be applied to commodities moving in international trade**. This Standard includes only maximum levels of contaminants and natural toxicants in feed in cases where the contaminant in feed can be transferred to food of animal origin and can be relevant for public health (CXS 193-1995)."

In 2019 alone, global trade in seaweed amounted to USD 5.6 billion (FAO, 2021). In that year, the United States of America alone imported USD 95 million worth of seaweed (FAO, 2021). The movement of seaweed in international trade is therefore quite significant. Moreover, the use of seaweed as food is increasing and expected to continue, in support of efforts to promote dependence on sustainable sources of protein for human consumption; the regulatory gap therefore requires attention.

At Codex, the regulatory interests of stakeholders along the seaweed value chain are represented by Marinalg International (World Association of Seaweed Processors). The group also provides similar representation at the EU level and to national regulatory authorities (Banach *et al.*, 2020b). Nevertheless, it appears that food safety has not yet been registered as a concern by the representative.[4]

3.2 NATIONAL REGULATIONS

In the absence of Codex and regional standards, some countries have made efforts towards the regulation of some food safety hazards in seaweed. A few regulatory limits, and some consumer advice on moderated intake and/or the appropriate handling and food preparation practices, have been variously applied to address food safety in seaweed (see Section 2.0). In China, for example, a regulatory limit has been set for cadmium in edible seaweeds, and France has similarly applied maximum limits for inorganic arsenic, cadmium, lead and mercury in edible seaweeds. Various consumption advisory notices have also been issued (e.g. in Japan, Ireland and Norway) on consumer-level reduction of food safety hazards in seaweed (see Section 2).

In the United States of America, the FDA recently designated unprocessed seaweed (both farmed and wild harvested) as a raw agricultural commodity (RAC). As per this designation, unprocessed seaweed in the country must comply with the general requirements of the Federal Food, Drug and Cosmetic Act (FFD&C Act 402(a)(4), namely that: it must not be prepared, packed or held in unsanitary conditions. Processed seaweeds (including blanched, frozen or cut seaweed) fall outside the RAC definition and must therefore comply with appropriate preventive controls for food quality and safety.

In January 2020, a guidance document was developed in Connecticut (United States of America) for the primary production and processing of kelp and *Gracilaria* for state-level application (Concepcion *et al.*, 2020). The document identifies (potential) food safety hazards associated with each step of the value chain in that context – from primary production through various forms of processing – and provides guidance to develop an HACCP plan for the hazards. As the first document of its kind in the United States of America, some have suggested that it may trigger similar developments across the country (Benson, 2020).

4 It has been suggested that Marinalg International does not represent interests in seaweed production for food (V. Doumeizel, personal communication, 2021).

In the Philippines, the Bureau of Agriculture and Fisheries Standards issued a code of good aquaculture practices for seaweed (PNS/BAFS 208:2021) and a standard for dried seaweed (PNS/BAFS 85:2021) in 2021. Whereas the former addresses primary production, the latter deals with quality specifications and food safety requirements for dried seaweed. Although the documents are helpful, there are still gaps concerning the limits for food safety hazards, since on the matter of contaminants the standard requires that "products should comply with MRLs established by the Codex Alimentarius Commission" (PNS/BAFS 85:2021). As earlier pointed out, CAC MRLs are yet to be established.

The European Union has given a mandate for work on the standardization of algae and algae products (CEN/TC 454), and this includes setting up standards for the gaps where methods are missing for analyses on seaweed (e.g. species determination, pigments, sugars, proteins and lipids).

These aforementioned national efforts notwithstanding, overall food safety in seaweed has not received the necessary and comprehensive regulatory attention at the global or national level.

3.3 PRIVATE STANDARDS

The Aquaculture Stewardship Council (ASC) and Marine Stewardship Council (MSC) jointly developed a private standard for sustainable seaweed production that was published in November 2017 and made effective from 1 March 2018 (ASC/MSC, 2018). The standard has the following five core principles:

- **Principle 1: Sustainable wild populations**
  Harvesting and farming of seaweeds are conducted in a manner that maintains the productive capacity of the wild seaweed populations and their sustainable use.
- **Principle 2: Environmental impacts**
  Harvesting and farming activities allow for the maintenance of the structure, productivity, function and diversity of the ecosystem (including habitat and associated dependent and ecologically related species) on which the activity depends.
- **Principle 3: Effective management**
  Harvesting and farming activities are subject to an effective management system that respects local, national and international laws and standards, and incorporates institutional and operational frameworks that require the use of the resource to be environmentally sustainable and socially responsible.
- **Principle 4: Social responsibility**
  Harvesting and farming activities operate in a socially responsible manner.
- **Principle 5: Community relations and interaction**
  Harvesting and farming activities operate in a manner that minimizes negative impacts on neighbours, respects rights and cultures, and benefits communities.

Food safety is neither directly mentioned nor addressed in the standard. Rather, sustainable primary production is emphasized, in line with the ASC/MSC declared certification vision that "global seafood supplies should be sustainable, responsibly managed, and supported by secure supply chains" (ASC/MSC, 2018). At best, food safety is implied in the standard. The scope criteria that may be considered to have some linkage with food safety is the following:

> Harvesting or farming activities which use mutagenic, carcinogenic or teratogenic pesticides, or any other chemicals that persist as toxins in the marine environment or on the farm or farmed seaweeds, are not eligible for certification. (Scope criteria 2.7, ASC/MSC Seaweed Standard)

Thus, the ASC/MSC private standard does not appear to prioritize or address food safety specifically.

In Norway, seaweed producers have published private guidelines on the cultivation, harvesting and handling of sugar kelp (*Saccharina latissima*) and winged kelp (*Alaria esculenta*) (Norwegian Seaweed Farms, 2020). The guidelines make provisions for food safety, highlighting cadmium, inorganic arsenic, and iodine as the relevant chemical hazards in sugar kelp and winged kelp. Other hazards mentioned include allergens (attributed to the potential occurrence of small crustaceans in kelp), spore-forming bacteria (microbiological hazard) and foreign bodies such as plastic and metal pieces (physical hazards). Members of the association are required to conduct various checks to ensure product quality and safety.

3.4 STAKEHOLDER VIEWS ON REGULATORY GAPS FOR HAZARDS IN THE SEAWEED VALUE CHAIN

In 2020, the United Nations Global Compact's Sustainable Ocean Business Action Platform and the Lloyd's Register Foundation issued what it called the "Seaweed Manifesto", detailing opportunities and barriers facing the global seaweed industry (Lloyds Register Foundation and UN Global Compact, 2020). Among the barriers identified were the paucity and scattered nature of the data on the safety of seaweed for food and feed, the lack of aligned/uniform food safety regulations, and a lack of global discussions on food safety in seaweed. This Seaweed Manifesto is endorsed by the Safe Seaweed Coalition, a global partnership focused on supporting the safety and sustainability of the seaweed industry.

Banach *et al.* (2020b) also elicited the views of experts in the seaweed value chain on the status and gaps in public and private regulatory standards for the commodity. Areas of focus and the corresponding views of experts, as reported by the authors, are summarized below:

i. *Current or potential food or feed safety concerns relevant to seaweed and seaweed aquaculture*

   Experts identified the cultivation environment, handling, processing and testing as relevant food safety issues. Concerning testing, challenges were observed in the unclear differentiation between, for example, organic (less toxic) and inorganic (more toxic) arsenic and in variations in contaminant levels attributable to seasons and sampling locations.

ii. *Standards and regulations currently used to deal with these concerns*

   Although not specifically developed for seaweed, experts opined that, in the absence of specific legislation on seaweed food safety, general public regulations (e.g. HACCP and the EU General Food Law (Regulation (EC) No. 178/2002 (EC, 2002b)) and private regulations (e.g. ISO 22000 and Global Food Safety Initiative) could be applied to address seaweed food safety concerns.

iii. *Concerns that are not yet covered in these standards and regulations.*

   Issues such as the lack of a direct reference to seaweed as food in existing regulations were identified as a significant gap.

iv. *The potential role of a new (private) standard for cultivated seaweed*

   Experts suggested standards with a seaweed focus, since non-specific regulations present challenges for control.

Table 14 provides further details on the responses of experts. In summary, their feedback points to the need to fill the regulatory gaps on seaweed production, processing, trade and utilization.

TABLE 15. **VIEWS OF EXPERTS IN THE SEAWEED VALUE CHAIN ON THE FOOD AND FEED SAFETY CONCERNS, CURRENT STANDARDS AND REGULATIONS, AS WELL AS THE ROLE OF A NEW STANDARD FOR SEAWEED**

STAKEHOLDER	CURRENT OR POTENTIAL FOOD SAFETY ISSUES FOR SEAWEED AND SEAWEED AQUACULTURE	CURRENT STANDARDS AND REGULATIONS AVAILABLE TO DEAL WITH THESE MATTERS	WHICH ISSUES ARE NOT COVERED?	WHAT ROLE DOES A NEW STANDARD FOR CULTIVATED SEAWEED HAVE?
Producer	> Location of cultivation > Handling and processing of seaweed > Seaweed testing: heavy metals (cadmium), arsenic and iodine	> Organic certification (ASC/MSC) > Sustainability certification	> Iodine – regulation and standards	> Organic certification > Location of cultivation > Applicability (i.e. feasibility) of the standard
Producer and processor	> Location of cultivation > Seaweed processing	> HACCP > FSSC 22000 or ISO 22000 > SKAL certificate > ASC/MSC (or a similar certificate) > Novel food	> Direct reference to seaweed as food in the existing regulation > Challenges behind seaweed market development > Allergy notice	> Template of industry standards with a seaweed focus > A sustainability aspect of seaweed cultivation > ASC/MSC certificate for wild seaweed harvesters
Trader	> Contamination and traceability > Analysis of product > Heavy metals (mercury)	> HACCP (minimum) > ISO 22000 > BRC > Integrated food safety system	> Limited demand for organic and sustainable certified seaweed	> Certification has a value, but the current market is still small > Costs for certification are high (considered a limitation)
Business innovator	> Iodine > Heavy metals (cadmium) > Arsenic > Novel food	> National organic certification (similar to EU certification) > ISO > BRC	> Not encountered any issues with other heavy metals	> A common approach to farming, and then a standard
Retailer	> Monitoring of water and environmental contamination > Arsenic > Iodine	> Food safety certificate > BRC or International Food Standard > GFSI > Global GAP > ASC/MSC certification	> Other contaminants > How seaweed is cultivated	> Cooperation with primary producers > Sustainability and origin of growth standards > Taste and healthiness

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STAKEHOLDER	CURRENT OR POTENTIAL FOOD SAFETY ISSUES FOR SEAWEED AND SEAWEED AQUACULTURE	CURRENT STANDARDS AND REGULATIONS AVAILABLE TO DEAL WITH THESE MATTERS	WHICH ISSUES ARE NOT COVERED?	WHAT ROLE DOES A NEW STANDARD FOR CULTIVATED SEAWEED HAVE?
Certification body	> Location of cultivation > Heavy metals > Arsenic > Dioxins > Pesticides	> EU General Food Law and labelling > Novel food regulation > Hygiene codes from other sectors > ISO > FSSC 22000 > GMP > Novel food	> Practical tools to implement legislation and Codex > Hygiene codes to make standards practical > Allergy concerns for seaweed consumption (given allergies to fish) > Processing environment impact on potential cross-contamination of certain allergens	> Non-specific regulation allows the opportunity for interpretation, but a challenge for control > Identify which seaweeds should be considered in the standard > Help monitoring and transparency
National governmental authorities	> Heavy metals > Microorganisms on the seaweed > Marine biotoxins > Minerals (iodine) > Phytotoxins > Concerns during storage (e.g. *Salmonella* spp.) > Pesticides assumed not to be used > Potential risks from anthropogenic activities (e.g. oil spill)	> HACCP > National legislation > Codex > BRC	> Food consumption patterns > The urgency for new standards	> The responsibility of the business is to monitor product quality > The national authorities should keep an eye on developments (monitor/supervise)

Abbreviations: BRC, British Retail Consortium; FSSC 22000, Food Safety System Certification 22000; GFSI, Global Food Safety Initiative; GMP, Good Manufacturing Practice; HACCP, Hazard Analysis and Critical Control Point; ISO 22000, International Organization for Standardization 22000; ISO, International Organization for Standardization.

Source: Banach, J.L., van den Burg, S.W.K. and van der Fels-Klerx, H.J. 2020b. Food safety during seaweed cultivation at offshore wind farms: an exploratory study in the North Sea. Marine Policy, 120, 104082. DOI:10.1016/j.marpol.2020.104082

CHAPTER 4

CONCLUSIONS AND SUGGESTED FURTHER WORK

4.1 CONCLUSIONS

In general, there is limited data on the occurrence of food safety hazards in seaweed, with an attendant paucity of legislation on the hazards. The limited data available suggest that heavy metals (principally inorganic arsenic and cadmium), microbial hazards (*Salmonella* spp.) and iodine might raise food safety concerns in seaweed. In addition, persistent organic pollutants (e.g. dioxins and polychlorinated biphenyls), biological hazards (e.g. *Bacillus* spp. and norovirus), radioactive materials, micro- and nanoplastics, lead, mercury and pesticide residues, among other substances, have been identified as moderate-to-minor food safety hazards in seaweed. The occurrence of the hazards is influenced by factors such as: seaweed classes (brown, red, or green) and families (*Laminariaceae, Alariaceae, Fucaceae*); physiology (e.g. the impact of cell wall structure on the accumulation of contaminants from the surrounding water, varying concentrations of contaminants in different parts of the same weed); the age before harvest; the conditions of the cultivation environment; and handling and processing. The increased cultivation and utilization of seaweed is expected to be important to food security, as well as a robust and sustainable aquatic economy in the near future. These notwithstanding, there is currently no Codex standard or guidelines that specifically address food safety vis-à-vis seaweed production, processing and utilization. National regulations on seaweed safety are also generally lacking. Although some private standards have been introduced, they either do not address food safety directly, or do not do so in sufficient depth. There is thus a significant global regulatory gap concerning food safety in seaweed.

4.2 SUGGESTED FURTHER WORK

1. Evaluate the current extent of seaweed utilization for food and as feed, highlighting national and regional differences and their corresponding impact on food security and trade.
    a. Consider generation of national and regional intake data for seaweed in order to evaluate population's exposure to potentially toxic components.
2. Evaluate current seaweed primary production methods at the national and regional levels vis-à-vis their impact on the occurrence of chemical, biological and physical hazards in the products.
3. Monitor seaweed (raw and processed) for food safety hazards, including but not limited to those highlighted in this document. This will provide much-needed data on the occurrence of the hazard per species and per product (screened for importance by production and/or trade volume), within various national and regional contexts.
4. Develop Codex guidelines for seaweed cultivation and harvesting to streamline primary production methods globally, as a necessary precondition for the development of food safety standards.
5. Conduct a risk assessment of the major hazards identified to establish their public health significance, and provide evidence for the development and subsequent enforcement of legislation covering such hazards.

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ANNEX

SEAWEED SPECIES AND THEIR USES ACROSS THE WORLD

GROUP/SPECIES	USE	COUNTRY
Brown algae		
Alaria esculenta	Food	Ireland, France, United States of America
Ascophyllum nodosum	Agriculture, Alginate	Canada, France, Iceland, Ireland, Norway, United States of America
Chnoospora spp.	Food	Bangladesh
Cladosiphon okamuranus	Food	Japan
Cladosiphon sp.	Food	Tonga
Colpomenia sinuosa	Food	Philippines
Costaria costata	Food	Republic of Korea
Dictyota spp.	Food	Bangladesh
Durvillaea antarctica	Food	Chile, New Zealand
Durvillaea potatorum	Alginate, Agriculture	Australia
Ecklonia cava	Food	Japan
Ecklonia maxima	Agriculture	South Africa
Ecklonia stolonifera	Food	Korea
Egregia menziesii	Food	Canada
Eisenia arborea	Alginate	Mexico
Fucus distichus subsp. Evanescens	Food	Canada
Fucus serratus	Alginate	Ireland
Fucus sp.	Agriculture	France
Fucus spp.	Agriculture	Portugal
Fucus vesiculosus	Food	Portugal
Himanthalia elongata	Food	France, Ireland, United Kingdom of Great Britain and Northern Ireland
Hydroclathrus clathratus	Food	Bangladesh, Philippines
Laminaria bongardiana	Alginate	Russian Federation
Laminaria digitata	Alginate, Agriculture, Food	Denmark, France, Iceland

GROUP/SPECIES	USE	COUNTRY
Laminaria gurjanovae	Alginate	Russian Federation
Laminaria hyperborea	Alginate Food,	France, Ireland, Norway, Russian Federation, Spain
Laminaria longipes	Food, Alginate	Russian Federation
Laminaria ochroleuca	Alginate	Spain
Laminaria pallida	Agriculture	South Africa
Laminaria saccharina	Food, Alginate	Canada, France, Russian Federation, Spain, Norway, Denmark
Laminaria setchellii	Food	Canada
Laminaria spp.	Agriculture	Portugal
Lessonia nigrescens	Alginate	Chile, Peru
Lessonia spp.	Agriculture	New Zealand
Lessonia trabeculata	Alginate	Chile
Macrocystis integrifolia	Agriculture, Food, Roe on kelp, Alginate	Canada, Chile, Peru
Macrocystis pyrifera	Alginate, Agriculture, Food, Roe on kelp	Chile, Mexico, New Zealand, Peru, USA
Nemacystis decipiens	Food	Japan
Nereocystis luetkeana	Food, Agriculture	Canada, United States of America
Padina spp.	Food	Bangladesh
Pelvetia siliquosa	Food	Republic of Korea
Rosenvingea spp.	Food	Bangladesh
Saccharina angustata	Food, Agriculture	Japan, Russian Federation
Saccharina cichorioides	Alginate, Food	China, Democratic People's Republic of Korea, Japan, Republic of Korea, Russian Federation
Saccharina diabolica	Food	Japan
Saccharina groenlandica	Food	Canada
Saccharina japonica	Alginate, Food	China, Democratic People's Republic of Korea, Japan, Russian Federation
Saccharina latissima	Food	Denmark, France, Norway, United States of America
Saccharina longicruris	Food	Canada
Saccharina longissima	Food	Japan
Saccharina ochotensis	Food	Japan
Saccharina religiosa	Food	Japan, Republic of Korea
Saccorhiza spp.	Agriculture	Portugal
Sargassum binderi	Alginate	Philippines

GROUP/SPECIES	USE	COUNTRY
Sargassum cinctum	Alginate	Philippines
Sargassum crassifolium	Alginate	Philippines
Sargassum cristaefolium	Alginate	Philippines
Sargassum feldmannii	Alginate	Philippines
Sargassum fusiformis	Food	Japan, Republic of Korea
Sargassum hemiphyllum	Alginate	Philippines
Sargassum horneri	Food	Republic of Korea
Sargassum oligosystum	Alginate	Philippines
Sargassum paniculatum	Alginate	Philippines
Sargassum polycystum	Alginate	China, Philippines
Sargassum siliquosum	Alginate	Philippines
Sargassum spp.	Food, Medicine, Alginate, Carrageen, Agriculture	Bangladesh, Brazil, Indonesia, Malaysia, Myanmar, Philippines, Viet Nam
Scytosiphon lomentaria	Food	Republic of Korea
Spatoglossum spp.	Food	Bangladesh
Turbinaria spp.	Alginate	Indonesia
Undaria peterseniana	Food	Republic of Korea
Undaria pinnatifida	Food	Australia, China, France, Japan, Republic of Korea, Spain
Red algae		
Acanthophora spicifera	Food, Carrageen	Philippines, Viet Nam
Agardhiella subulata	Carrageen	Italy
Agardhiella tenera	Carrageen	Peru
Ahnfeltia plicata	Carrageen	Chile
Ahnfeltia tobuchiensis	Agar, Food	Russian Federation
Ahnfeltiopsis furcellata	Carrageen	Chile
Asparagopsis taxiformis	Medicine, Food	Philippines
Betaphycus gelatinum	Carrageen, Food	China, Viet Nam
Callophyllis variegata	Food	Chile
Catenella spp.	Food	Bangladesh
Chondracanthus canaliculatus	Carrageen	Mexico
Chondracanthus chamissoi	Carrageen, Food	Chile, Peru
Chondria armata	Medicine	Philippines
Chondrus candiculatus	Carrageen	Peru

GROUP/SPECIES	USE	COUNTRY
Chondrus crispus	Carrageen, Food	France, Ireland, Spain, United States of America
Chondrus spp.	Agriculture, Carrageen	Canada, Portugal
Digenea simplex	Medicine	Philippines
Eucheuma arnoldii	Carrageen	Philippines
Eucheuma denticulatum	Carrageen, Medicine	Indonesia, Madagascar, Philippines, United Republic of Tanzania, Zanzibar
Eucheuma gelatinae	Carrageen, Food	China, Japan, Philippines
Eucheuma isiforme	Food, Carrageen	Belize, Caribbean
Eucheuma spinosum	Carrageen	Indonesia
Eucheuma spp.	Carrageen, Food	Timor-Leste, Fiji, Philippines
Eucheuma striatum	Carrageen	Madagascar
Furcellaria lumbricalis	Carrageen (Danish agar)	Denmark, Poland, Estonia
Gelidiella acerosa	Agar, Food	India, Philippines, Viet Nam
Gelidiella spp.	Food	Bangladesh
Gelidium abbotiorum	Agar	South Africa
Gelidium amansii	Agar, Food	China, Japan, Republic of Korea
Gelidium canariense	Agar	Morocco
Gelidium chilense	Agar	Chile
Gelidium corneum	Agar	Morocco France, Spain, Portugal
Gelidium crinale	Agar	Morocco
Gelidium japonicum	Agar	Japan
Gelidium latifolium	Agar	Morocco, Spain
Gelidium lingulatum	Agar	Chile
Gelidium madagascariense	Agar	Madagascar
Gelidium microdon	Agar	Morocco
Gelidium pacificum	Agar	Japan
Gelidium pristoides	Agar	South Africa
Gelidium pteridifolium	Agar	South Africa
Gelidium pulchellum	Agar	Morocco
Gelidium pusillum	Agar	Morocco
Gelidium rex	Agar	Chile
Gelidium robustum	Agar	Mexico
Gelidium serrulatum	Food	Caribbean
Gelidium sp.	Food, Agar	Bangladesh, Indonesia

GROUP/SPECIES	USE	COUNTRY
Gelidium spinosum	Agar	Morocco
Gelidium spp.	Agar, Medicine, Agriculture	Malaysia, Philippines, Portugal, Taiwan Province of China
Gelidium subcostatum	Agar	Japan
Gelidium vagum	Agar	Canada
Ghondria crassicaulis	Food	Republic of Korea
Gigartina acicularis	Carrageen	Morocco
Gigartina intermedia	Carrageen	Viet Nam
Gigartina pistillata	Carrageen	Morocco
Gigartina skottsbergii	Carrageen	Chile
Gigartina teedii	Carrageen	Morocco
Gloiopeltis complanata	Carrageen	Japan
Gloiopeltis furcata	Carrageen, Food	Japan, Republic of Korea
Gloiopeltis spp.	Food	Viet Nam
Gloiopeltis tenax	Carrageen, Food	Japan, Republic of Korea
Gracilaria asiatica	Agar, Food	Viet Nam
Gracilaria bursa-pastoris	Food	Japan
Gracilaria caudata	Agar	Brazil
Gracilaria changii	Agar	Malaysia
Gracilaria chilensis	Agar, Agriculture	Chile, New Zealand
Gracilaria conferta	Agar	Morocco
Gracilaria cornea	Agar	Brazil
Gracilaria coronopifolia	Food	United States of America, Viet Nam
Gracilaria domingensis	Food	Caribbean
Gracilaria dura	Agar	Morocco
Gracilaria edulis	Agar	India
Gracilaria errucosa	Food	Indonesia
Gracilaria eucheumoides	Food	Viet Nam
Gracilaria firma	Agar, Food	Philippines, Viet Nam
Gracilaria gigas	Agar	Indonesia
Gracilaria gracilis	Agar	Morocco, Namibia, South Africa
Gracilaria heteroclada	Agar, Food	Philippines, Viet Nam
Gracilaria lemaneiformis	Food	Japan
Gracilaria longa	Agar, Paper	Italy

GROUP/SPECIES	USE	COUNTRY
Gracilaria pacifica	Agar	Canada
Gracilaria salicornia	Food	Viet Nam
Gracilaria sp.	Food, Agar	Bangladesh, Philippines
Gracilaria spp.	Food, Medicine, Agriculture	Philippines, Portugal, Viet Nam
Gracilaria tenuistipitata	Agar, Food	Philippines, Viet Nam
Gracilaria tenuistipitata var. liui	Agar	China
Gracilaria vermiculata	Agar	Morocco
Gracilaria vermiculophylla	Agar	China
Gracilariopsis andersonii	Agar	Canada
Gracilariopsis howei	Agar	Peru
Gracilariopsis lemaneiformis	Agar	Mexico, Morocco, Peru
Gracilariopsis longuissima	Agar	Morocco
Gracilariopsis tenuifrons	Agar	Brazil
Gracilaria spp.	Food	Caribbean
Grateloupia filicina	Food	Japan, Philippines
Grateloupia turuturu	Food	Republic of Korea
Gymnogongrus furcellatus	Carrageen	Peru
Halymenia durvillei	Food	Philippines
Halymenia spp.	Food	Bangladesh
Hydropuntia cornea	Food	Caribbean
Hydropuntia crassissima	Food	Caribbean
Hypnea musciformis	Carrageen	Brazil, Italy, Senegal
Hypnea muscoides	Food	Viet Nam
Hypnea pannosa	Food	Philippines
Hypnea spp.	Food, Carrageen	Bangladesh, China, Indonesia, Myanmar, Viet Nam
Hypnea valentiae	Food	Viet Nam
Kappaphycus alvarezii	Carrageen, Food, Medicine	Brazil, Caribbean, China, India, Indonesia, Kiribati, Madagascar, Malaysia, Myanmar, Philippines, Solomon Islands, Timor-Leste, Viet Nam, United Republic of Tanzania, Zanzibar
Kappaphycus procrusteanum	Carrageen	Philippines
Kappaphycus striatum	Carrageen	Philippines
Laurencia cartilaginea	Food	Philippines
Laurencia papillosa	Food	Philippines

GROUP/SPECIES	USE	COUNTRY
Laurencia spp.	Medicine	Philippines
Lithothamnion coralloides	Agriculture	Ireland
Mastocarpus papillatus	Carrageen	Chile
Mastocarpus stellatus	Food, Carrageen	Ireland, Portugal, Spain
Mazzaella laminarioides	Carrageen	Chile
Mazzaella membranacea	Carrageen	Chile
Mazzaella splendens	Agar, Food	Canada
Meristotheca papulosa	Food	Japan
Meristotheca procumbens	Food	Fiji
Meristotheca senegalensis	Food	Senegal
Nemalion vermiculare	Food	Republic of Korea
Osmundea pinnatifida	Food	Portugal
Palmaria hecatensis	Food	Canada
Palmaria mollis	Food	Canada, USA
Palmaria palmata	Food	Canada, France, Ireland, USA
Palmaria spp.	Agriculture	Portugal
Phymatolithon calcareum	Agriculture	Ireland, Iceland
Porphyra abbottae	Food	Canada
Porphyra acanthophora	Food	Brazil
Porphyra columbina	Food	Chile, Peru
Porphyra conwayae	Food	Canada
Porphyra crispate	Food	Viet Nam
Porphyra fallax	Food	Canada
Porphyra (Neoporphyra) haitanensis	Food	China
Porphyra kuniedae	Food	Republic of Korea
Porphyra (Pyropia) leucostica	Food	Portugal
Porphyra nereocystis	Food	Canada
Porphyra pseudolanceolata	Food	Canada
Porphyra seriata	Food	Republic of Korea
Porphyra sp.	Food	France, Philippines
Porphyra spiralis	Food	Brazil
Porphyra spp.	Food, Medicine	Israel, New Zealand, Philippines
Porphyra suborbiculata	Food	Republic of Korea, Viet Nam

GROUP/SPECIES	USE	COUNTRY
Porphyra (Pyropia) tenera	Food	Japan, Republic of Korea, Taiwan Province of China
Porphyra torta	Food	Canada
Porphyra umbilicalis	Food	United States of America, United Kingdom of Great Britain and Northern Ireland
Porphyra (Pyropia) yezoensis	Food	China, Japan, Republic of Korea, United States of America
Prionitis decipiens	Carrageen	Peru
Pterocladia capillacea	Food, Agar	Republic of Korea, New Zealand, Portugal
Pterocladia lucia	Agar	New Zealand
Pterocladiella caerulescens	Agar	Morocco
Pterocladiella capillacea	Agar	Brazil, Morocco
Rhodoglossum denticulatum	Carrageen	Peru
Sarcothalia crispata	Carrageen	Chile
Scinaia hormoides	Food	Philippines
Solieria chordalis	Agriculture	France
Solieria filiformis	Carrageen	Italy
Green algae		
Acetabularia major	Medicine	Philippines
Capsosiphon fulvescens	Food	Republic of Korea
Caulerpa bartlettii	Food	Philippines
Caulerpa intricatum	Food	Philippines
Caulerpa lentillifera	Food, Medicine	Philippines
Caulerpa peltata	Food, Medicine	Philippines
Caulerpa racemosa	Food	Bangladesh, Fiji, Philippines, Viet Nam
Caulerpa sertularioides	Food, Medicine	Bangladesh, Philippines
Caulerpa spp.	Food	Malaysia
Caulerpa taxifolia	Food, Medicine	Philippines
Cladophora spp.	Medicine	Philippines
Codium edule	Food	Philippines
Codium fragile	Food	Republic of Korea
Codium spp.	Food, Agriculture	Bangladesh, Portugal
Codium taylori	Food	Israel
Dictyosphaeria cavernosa	Medicine	Philippines
Enteromorpha clathrata	Food	Republic of Korea

GROUP/SPECIES	USE	COUNTRY
Enteromorpha compressa	Food, Medicine	Republic of Korea, Philippines
Enteromorpha intestinalis	Food	Japan, Republic of Korea
Enteromorpha linza	Food	Republic of Korea
Enteromorpha prolifera	Food	Japan, Republic of Korea
Enteromorpha sp.	Food	France
Enteromorpha spp.	Food, Agriculture	Bangladesh, Philippines, Portugal
Lola spp.	Agriculture	Portugal
Monostroma nitidum	Food	Republic of Korea
Monostroma grevillei	Food	Japan, Republic of Korea
Ulva clathrata	Food	China
Ulva lactuca	Food	Viet Nam, United States of America
Ulva laetevirens	Agriculture, Paper	Italy
Ulva pertusa	Medicine, Food	Philippines, Taiwan Province of China
Ulva reticulata	Food	Viet Nam
Ulva sp.	Food, Agriculture	Bangladesh, France

Source: White,W.L. & Wilson, P. 2015. World Seaweed Utilization. *In* B.K. Tiwari & D.J. Troy, eds. *Seaweed sustainability - food and non-food applications.* DOI: 10.1016/B978-0-12-418697-2.00001-5 2015.



REPORT OF THE EXPERT MEETING ON FOOD SAFETY FOR SEAWEED
CURRENT STATUS AND FUTURE PERSPECTIVES

ROME, 28–29 OCTOBER 2021

Global population increase and climate change continue to present challenges to the sustainability of the primary production of food. Among the efforts to address the challenges, the exploration of increasing the use of seaweed as food is gaining traction. World seaweed production has more than tripled since the turn of the millennium, increasing from 10.6 million tonnes in 2000 to 35.8 million tonnes in 2019. However, seaweed can bioaccumulate hazardous substances and carry pathogens from its cultivation environment. Several food safety hazards such as heavy metals and marine biotoxins have been reported to be associated with the commodity. The extent to which this translates into risks for public health remains largely unexplored. Furthermore, food safety standards and legislation on seaweed are generally lacking at both international and national levels.

This FAO/WHO report discusses food safety of seaweed and makes recommendations for addressing identified challenges with a view to protect consumers and promote sustainable food security for all.

FOOD SYSTEMS AND FOOD SAFETY DIVISION

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