Substantiation

belonging to the advice of the Director of the Office for Risk Assessment and Research on the risk assessment of seaweed; food safety and nature.

1 Introduction

1.1 Background

Seaweeds are also called macroalgae and occur in the sea or in brackish water. They grow on hard substrates (e.g. rocks) or on soft substrates (mud or sand) (Tiekstra, 2020) or are farmed (aquaculture). Expectations for seaweed aquaculture are high due to the potential of sustainable production of (plant based) food, (bio-based) products and (bio) fuels (EC, 2022).

In 2022, more than 37.6 million tonnes of seaweed (wet weight) were produced in aquaculture worldwide, tripling the production in 2000 (11 million tonnes). Most of these (around 80%) were intended for human consumption (FAO & WHO, 2022). More than 97% of global production takes place in Asia. Europe's share in 2019 was 0.8%, with Norway, France, Ireland and Iceland as the largest producers (FAO & WHO, 2022). In the European countries where traditional seaweed is on the menu (Ireland, France and the United Kingdom), seaweed is mainly wild harvested (Tiekstra, 2020). Wild harvesting of seaweed is not sustainable (RIVM, 2018) if it is not replanted. Partly because of this aspect, the cultivation of seaweed (aquaculture) is encouraged by the EU. The EU sees seaweed as an important source of alternative proteins for a sustainable food system and food security. European seas such as the Atlantic and the North Sea have cold, nutrient-rich waters and therefore suitable natural conditions for seaweed cultivation (EC, 2022). However, seaweed cultivation could have adverse effects on the natural ecosystem, such as disturbance of the marine ecosystem (Campbell et al., 2019; EC, 2022), the arise of pests and diseases that can spread to wild seaweed populations and the introduction of alien seaweed species or other alien species associated with the seaweed (Campbell et al., 2019; Tonk & Jansen, 2019). The cultivation of seaweed can also contribute to the establishment and spread of alien species for which seaweed aquaculture is a suitable habitat (ACS/MSC, 2018; Tonk & Jansen, 2019).

The Dutch government is also encouraging (research of) the cultivation of seaweed in Dutch waters (IenW, 2022). The Social Innovation Programme 'Seaweed for Food and Feed', launched in 2017 and funded by the former Ministry of Agriculture, Nature and Food Quality (LNV), had the aim to develop multifunctional seaweed farms in the North Sea (Ammerlaan, 2022). The LNV vision on food from sea and great waters also mentions a future for the cultivation of seaweed (LNV, 2024). In the National Protein Strategy, seaweed is explicitly mentioned as an alternative protein source (LNV, 2020). The advantages of seaweed cultivation in the North Sea are that no agricultural land is used, cultivation without the addition of fertilizers and plant protection products is possible and that no freshwater is needed (Van den Burg, 2019; FAO, 2022). Other benefits described are the fact that seaweed provides a habitat for fish and small benthic animals such as shellfish (Tonk & Jansen, 2019; FAO, 2022), absorbs CO_2 and protects coastal zones from erosion. However, there are also doubts whether cultivation on a large scale in the North Sea is realistic, due to, among others, a limited availability of nutrients (Vilmin & Van Duren, 2021) and practical problems with farming, harvesting and transport to land. The processing of residual flows and sales opportunities would also be (too) limited (Van den Burg, 2019; Van de Meer, 2021).

There is a long history of eating seaweed in China, Japan and Korea (Tiekstra, 2020; FAO, 2022). In Europe, seaweed is eaten much less, but this has increased sharply in recent years. Demand for seaweed-based food and beverages increased by a factor of 2.5 between 2011 and 2015, in line with sustainability and health trends to eat less animal and more plant-based foods (EC, 2022). The consumption of seaweed and seaweed products is also increasing in the Netherlands; between 2009 and 2018, more than 250 new products containing seaweed were introduced to the Dutch market (Banach et al., 2020b).

Seaweeds naturally contain protein, vitamins B and C, small amounts of fatty acids (natural omega-3 fatty acids) and various minerals such as iodine, calcium, phosphorus, magnesium, iron, sodium and potassium (FSAI Sci. Com., 2020; FAO, 2022; Voedingscentrum, 2022; EFSA, 2023). It contains a 10 to 100 times higher mineral concentration than traditional vegetables (Lozano Muñoz & Díaz, 2020). The main components of dried seaweed are carbohydrates (25% to 50%), minerals (10% to 50%), proteins (7% to 15%) and fats (1% to 5%). The exact composition varies by type of seaweed, season, harvest location (quality and composition of the water) and age of the plant (Banach et al., 2020b; FSAI Sci. Com., 2020). Seaweed is seen as a good and sustainable meat substitute (Van Dooren, 2015), although most types of vitamin B12 are lacking.

On the other hand, several studies show that seaweed can be contaminated with contaminants, that may pose a risk to food safety (FAO & WHO, 2022). Many of the contaminants mentioned are heavy metals. In addition, seaweed may contain high concentrations of iodine (EFSA, 2012b;2012a;2014; Lozano Muñoz & Díaz, 2020; FAO, 2022; FAO & WHO, 2022; EFSA, 2023; Hogstad et al., 2023). The occurrence of contaminants and iodine is determined by the environment in which the seaweed grows, the seaweed species and the age of the seaweed at harvest. Environmental factors such as the estuary (with potentially upstream discharged contaminants) of a river and agricultural and industrial activities nearby can thus affect the quality and food safety of the harvested seaweed (FAO & WHO, 2022; Hogstad et al., 2023). In broad terms, higher levels of contaminants are found in brown seaweed species than in green and red species (FAO & WHO, 2022; EFSA, 2023).

In 2018, the European Commission published Recommendation (EU) 2018/464[1] calling for the monitoring of a number of (heavy) metals and iodine in seaweed, halophytes (plants growing on high salinity soils) and products based on seaweed. This call was made by the Commission because:

seaweed and halophytes are an increasingly important part of the consumption patterns of European consumers;
European Food Safety Authority (EFSA) indicates that the consumption of algae products rich in iodine may lead to an excessively high dangerous intake of iodine;
EFSA recommends revising the limit values for impurities in the form of toxic elements for seaweed-based food additives;
existing legislation is limited.

Seaweed cultivation in the Netherlands is not yet that extensive (Tiekstra, 2020; WUR, 2022a). Despite the fact that the cultivation of seaweed in Dutch waters is stimulated by the government, not all the risks resulting from this cultivation are yet in the picture.

1.2 Description of seaweed and applications

Seaweed is a collective name for a diverse group of macroalgae that occurs all over the world (Van der Loos et al., 2021), As opposed to microalgae which refers to single celled algae and algae with a few cells (FAO & WHO, 2022).

Seaweeds can be divided into three main groups, based on their pigmentation: from green seaweeds (*Chlorophyceae)* close to the water surface, via red seaweeds (*Rhodophyceae*) to brown seaweeds (*Phaeophyceae*) at a maximum depth of 200 metres (McHugh, 2003; ANSES, 2020; Banach et al., 2020a; FAO & WHO, 2022). While brown and red macroalgae occur only in saltwater (seaweeds), green macroalgae occur mainly in freshwater (FAO, 2022). The largest group of seaweeds are the red seaweeds, followed by the brown and green seaweeds. Although seaweeds are often considered plants, taxonomically most seaweeds are not (Van der Loos et al., 2021; Hogstad et al., 2023; Wikisage, 2025). Only green seaweeds are true plants (kingdom *Viridiplantae*, phylum *Chlorophyta*). Red seaweeds are related to plants (kingdom *Rhodoplantae*, phylum *Rhodophyta)* and brown seaweeds belong to a totally different taxonomic group (kingdom *Heterokantae*, phylum *Phaeophyta*) (Wikipedia, 2025). In the text, all seaweeds are called plants for readability.

Seaweed, which grows in brackish or saltwater, attaches to the seabed rocks or any other hard substrate (Banach et al., 2020b). There are more than 12,000 seaweed species, of which only a fraction (approximately 200) is of commercial value and about ten species are intensively cultivated (FAO & WHO, 2022). Brown seaweeds are usually large, from kelp up to 20 m long to smaller species of 30-60 cm. Kelp is an order of brown seaweeds (*Laminariales*) which includes several dozen species, such as wakame *(Undaria pinnatifida*), royal kombu (*Saccharina japonica*), sugar kelp (*Saccharina latissima*) and giant kelp (*Macrocystis pyrifera*). Red seaweeds are smaller, from a few centimetres to 1 meter and are not always red, but can also be brown red or purple, for example. In the North Sea, the Southwest Delta and Wadden Sea, 195 native seaweed species

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[1] Commission Recommendation (EU) 2018/464 on the monitoring of metals and iodine in seaweed, halophytes and products based on seaweed

occur: 110 red seaweed species and 85 brown seaweed species (Stichting Anemoon, 2021; Van der Loos et al., 2021). In addition, several alien species are found, including species originating from outside Europe (Van der Loos et al., 2021).

The main application of seaweed is consumption (FAO & WHO, 2022). In Asian countries, seaweed has been a common part of the diet for centuries (McHugh, 2003;

Lähteenmäki-Uutela et al., 2021). Another important application is the use as a thickener (agar agar, alginates, carrageenan) in, for example, sauces and syrup (McHugh, 2003; FAO & WHO, 2022). For Dutch consumers, the use of seaweed leaves in sushi is especially well known. Furthermore, seaweed is added to foods as a seasoning or as a vegetable protein source.

In addition to food for humans, seaweed can also have other uses. In agriculture, seaweed is used as feed or fertilizer (FSAI Sci. Com., 2020; Tiekstra, 2020; FAO & WHO, 2022). Certain types of seaweed are added to feed for cows to reduce methane production (McHugh, 2003; Banach et al., 2020b; Lähteenmäki-Uutela et al., 2021).

In addition to the applications in food and feed, seaweed also has non-food applications; e.g. as an extract in cosmetics or as a raw material for bioplastics (McHugh, 2003; FSAI Sci. Com., 2020; Lähteenmäki-Uutela et al., 2021; FAO, 2022; FAO & WHO, 2022). Seaweed is also used in the production of personal care products, medical applications or as biofuel (Banach et al., 2020b).

2 Approach

This risk assessment of the seaweed production chain aims to identify the hazards and assess the risks to public health (food safety) and Dutch nature (impacts on biodiversity and the aquatic ecosystem caused by alien species including invasive alien species) associated with the cultivation and consumption of seaweed in the Netherlands.

The questions BuRO asked on its own initiative are:

1. Are there any risks to the health of consumers from the consumption of seaweed grown in the Netherlands and/or from the consumption of seaweed products on the Dutch market?

2.Are there any risks to nature in the Netherlands due to the introduction, establishment and spread of alien species as a result of the cultivation of seaweed in Dutch waters?

For these risk assessments, a number of studies were carried out on behalf of BuRO and a number on behalf of LVVN. With regard to food safety, Wageningen Food Safety Research (WFSR), Wageningen Food & Biobased Research (WFBR) and the National Institute for Public Health and the Environment (RIVM) carried out a series of studies (2018 to 2025). For the risks to nature, GiMaRIS carried out three studies on alien species in collaboration with Wageningen Marine Research (WMR) (2019, 2020 and 2025). Based on these reports and additional literature, BuRO has performed the risk assessment. For a more detailed description of the approach and studies, see Annex I. A list of abbreviations and terms is included at the end of the text.

1.1 Methodology

In order to assess the risks to public health (food safety) and nature (alien species), BuRO follows four steps in the risk assessment. This methodology is based on that of the Codex Alimentarius and EFSA's methodology. The four steps are as follows:

1. Hazard identification: identification of potential hazards
2. Hazard characterisation: description of possible effects of the hazards

3. Exposure assessment: Estimation of the extent to which the hazard occurs and causes an effect
4. Risk characterisation: conclusion on risk based on hazard characterisation and exposure assessment

1.2 Scope

This risk assessment shall not include: animal health (seaweed as an ingredient in feed), product safety (seaweed as an ingredient in consumer products) and 'plant' health (possible diseases and pests in seaweed farming).

3 The seaweed chain

3.1 Seaweed production

3.1.1 Worldwide

Until the mid-sixties of the twentieth century, wild harvested seaweed was the most important source of seaweed production worldwide. Research into the life cycle of seaweed has led to the development of seaweed cultivation (McHugh, 2003). Worldwide, seaweed production (including algae and seaweeds not intended for consumption) has grown exponentially from more than half a million tonnes in 1950 to more than 37.6 million tonnes (wet weight) in 2022 (Figure 1). Aquaculture (especially the saltwater cultivation of *Saccharina japonica* and *Eucheuma* spp.) has been growing enormously since the 1990s, supplying more than 95% of world seaweed production since 2011, with China (almost 22.6 million tonnes in 2022) and Indonesia (over 9.3 million tonnes in 2022) as the largest producers.

Wild harvest accounted for only 3.3% of total seaweed production in 2022, with Chile, China and Norway as the three main producers. The quantities produced by the cultivation of seaweed in brackish water worldwide (mainly in Indonesia with mainly *Gracilaria* spp.) are negligible compared to saltwater cultivation (Figure 1) (FAO, 2024).

The seaweed species with the highest global production since 2013 are *Saccharina japonica* (brown seaweed; almost 11 million tonnes in 2022, mainly China), *Eucheuma* spp. (red seaweed; approximately 7.8 million in 2022, mainly Indonesia) and *Gracilaria* spp. (red seaweed; around 7.6 million tonnes in 2022, mainly China and Indonesia (FAO, 2024).

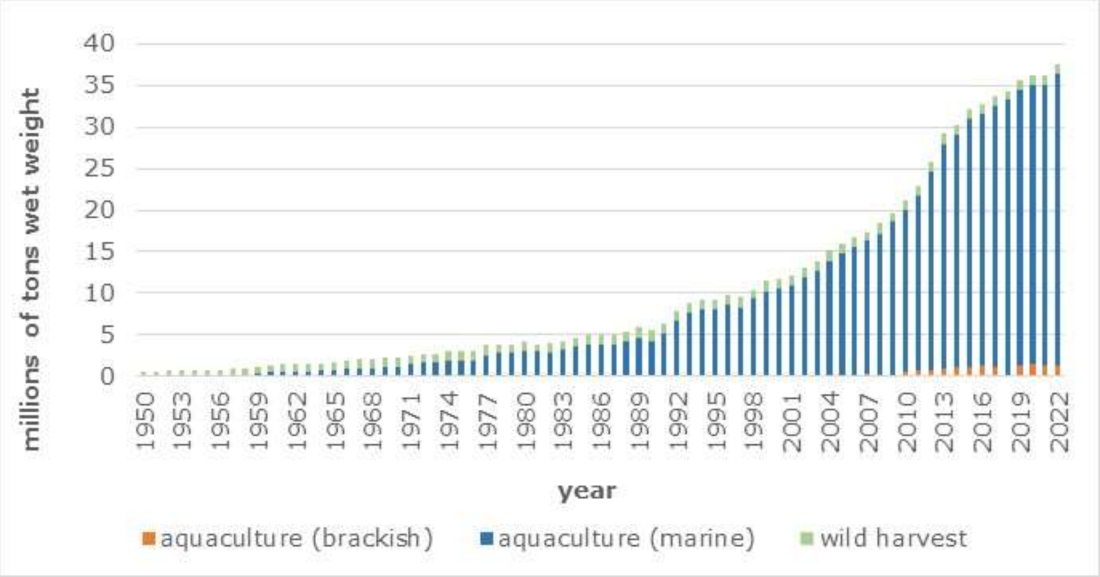

Figure 1 Worldwide production of seaweed, 1950-2019 (millions of tonnes wet weight per year) (based on (FAO, 2024)).

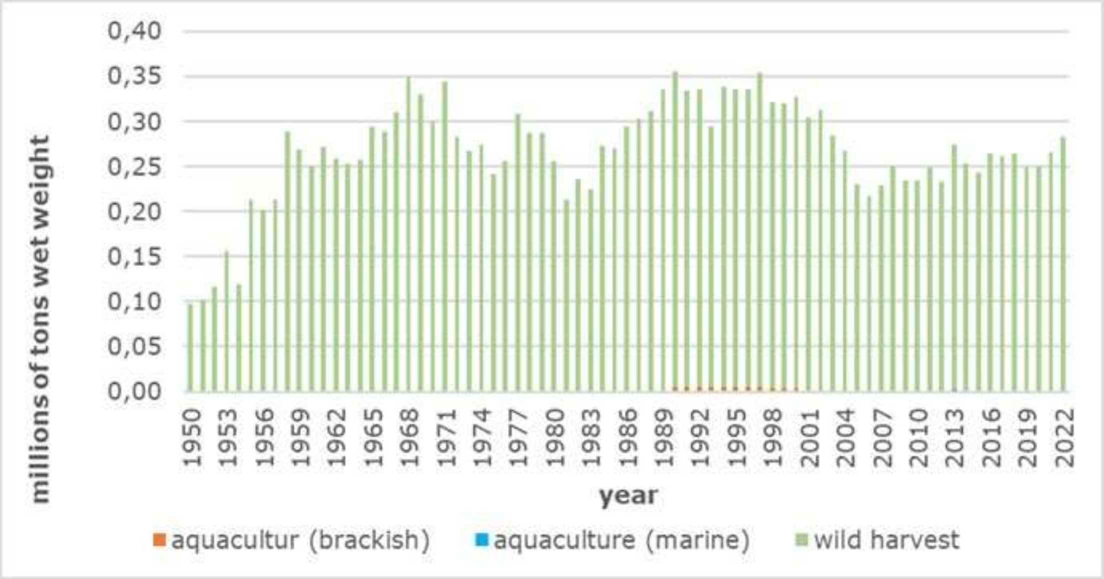

Figure 2 Seaweed production in Norway, France, Ireland and Iceland, 1950-2019 (millions of tonnes wet weight per year) (based on (FAO, 2024)).

3.1.2 Europe

In Europe, seaweed production fluctuated between 200,000 and 350,000 tonnes (wet weight) of seaweed per year between 1960 and 2022 (FAO, 2021;2024). European production since the 1980s has come almost entirely from Norway (60%), France (21%) in the 20th century, with a combined production of 231.428 tonnes in 2022 (FAO, 2024) (Figure 2). Unlike Asian production, in Europe wild harvest is the most important (>98%), especially brown seaweeds. Aquaculture in Europe has been taking place mainly in Ireland, Norway and France since 2014, with the main species being *Saccharina japonica* and species from *Euchema* spp. and *Gracilaria* spp.. This concerns hundreds of thousands of tonnes of seaweed per year (FAO, 2024).

Around 30 different types of seaweed are grown and/or wild harvested in Northwest European countries around the North Sea (Netherlands, France, Ireland, United Kingdom, Denmark). Various alien species are found in Dutch waters, including species originating from outside Europe (Gittenberger et al., 2020b).

3.1.3 The Netherlands

Seaweed cultivation in the Netherlands has not been around that long. Since the '10s of the 21st century, a number of seaweed farmers have been active. Seaweed is grown on lines on tidal flats in the Wadden Sea, in open waters of the North Sea and in the Eastern Scheldt (estuary). In addition, the cultivation of seaweed in saltwater basins on land is studied (Banach et al., 2020b; Gittenberger et al., 2020b). Most seaweed grown in the Netherlands is intended for human consumption (Banach et al., 2020b). In addition, a large part of the cultivation of seaweed is still in the experimental phase (Gittenberger et al., 2020b).

Seaweed species grown in the Netherlands are several species of sea lettuce*(Ulva* spp.*),* sugar kelp *(Saccharina latissima),* oarweed *(Laminaria digitata),* wakame *(Undaria pinnatifida)*, Japanese wireweed (*Sargassum muticum*), Agardh's red weed (*Agardhiella subulata*) and dulse (*Palmaria palmata*) (Table 1, Figure 3) (Gittenberger et al., 2020b)). The most commonly grown species are sugar kelp and the various species of sea lettuce (*Ulva* spp.). The different types of sea lettuce (*Ulva* spp.) however are difficult to distinguish morphologically even with the help of a microscope. Therefore, it is often unclear which species of *Ulva* is grown (Gittenberger et al., 2020b).

Four of the seven seaweed species listed in Table 1 (sea lettuce (specifically *Ulva lactuca*), sugar kelp, oarweed and wakame) were already on the market as food (ingredient) before 15 May 1997 and are included as such in the EU Novel food catalogue.

Figure 3 Main species in Dutch seaweed farming systems (including wild harvest): [A] sea lettuce (Ulva spp.); [B] sugar kelp (Saccharina latissima); [C] oarweed (Laminaria digitata); [D] wakame (Undaria pinnatifida); [E] Japanese wireweed (Sargassum muticum); [F] Agardh's red weed (Agardhiella subulata) and [G] dulse (Palmaria palmata). Reprinted from (Gittenberger et al., 2020b).

Table 1 Seaweed species grown in the Netherlands.

English name	Latin name	Colour	Growth temperature	Growing season in the Netherlands[1]	Use[1]
Sea lettuce	*Ulva* spp.	green	<18 ºC	summer	food feed biostimulant[3]
Sugar kelp	*Saccharina latissima*	brown	15 ºC	winter	food biostimulant
Oarweed	*Laminaria digitata*	brown	<18 ºC	winter	food feed biostimulant
Wakame	*Undaria pinnatifida*	brown	5-15 ºC [2]	winter	food biostimulant
Japanese wireweed	*Sargassum muticum*	brown	10-30 ºC	summer	food
Dulse	*Palmaria palmata*	red	15-20 ºC	n/a, only in quarantaine basins	culture inoculum (destined for Ireland)
Agardh's red	*Agardhiella subulata*	red	-	winter	food

[1] (Gittenberger et al., 2020a)
[2] (McHugh, 2003)
[3] biostimulant stimulates the natural nutritional processes of plants (Ctgb, 2025)

Table 2 Stages of the seaweed production chain.

Stage		Phase
1	starting material	Primary: breeder and propagator of starting material locally collected starting material
2	farming, harvesting, transport and storage of seaweed	Primary (seaweed farm): farmer or wild harvest
3	processing of seaweed into seaweed product and packaging of seaweed (products).	Secondary: producers of seaweed products
4	distribution of seaweed (products) to food processors (catering, large caterers such as restaurants, canteens, schools, hospitals and catering companies) and retail and the preparation of seaweed (products)	Tertiary: trade, distribution and consumption

3.2 Description of the seaweed production chain

For the purpose of this risk assessment, the seaweed chain is described and divided into four s stages (Figure 4, Table 2).

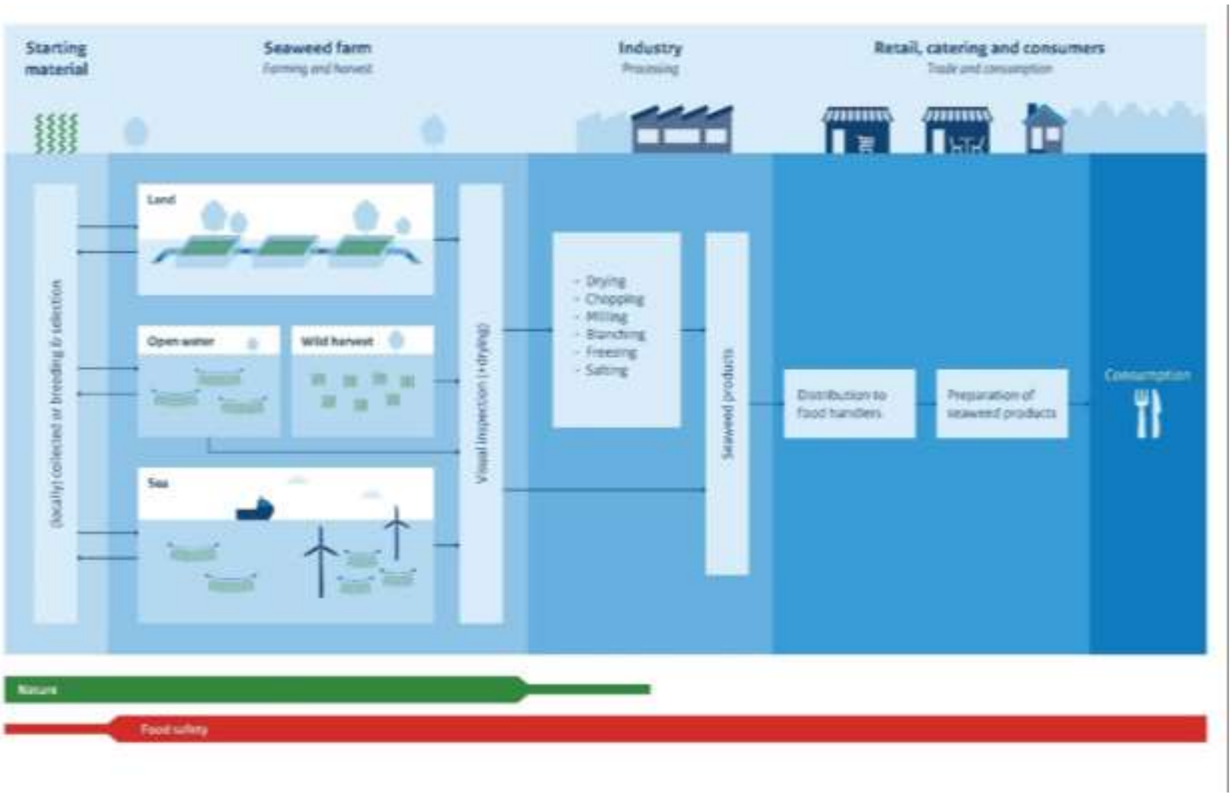

Figure 1 The seaweed production chain in the Netherlands in four stages. The import of seaweed and seaweed products are not included in the figure.

3.2.1 Stage starting material

Seaweed multiplies through microscopic male and female spores. These spores are part of the phytoplankton and 'swim' in the water. Just after the first stage (prothallus or gametophyte), when the spores have grown and are visible to the naked eye, they can attach to a substrate such as shells (Banach et al., 2020b; Gittenberger et al., 2020a). Male prothalli develop sperm cells (male gametes) that fertilize the egg-like structures of female prothalli. After fertilization, a mature and fertile seaweed (sporophyte) develops. Seaweed in seaweed cultivation is usually harvested just before it starts to reproduce (Gittenberger et al., 2020a).

There are also seaweed species that reproduce through so-called vegetative (asexual) reproduction. Small pieces of seaweed can grow into new plants (McHugh, 2003).

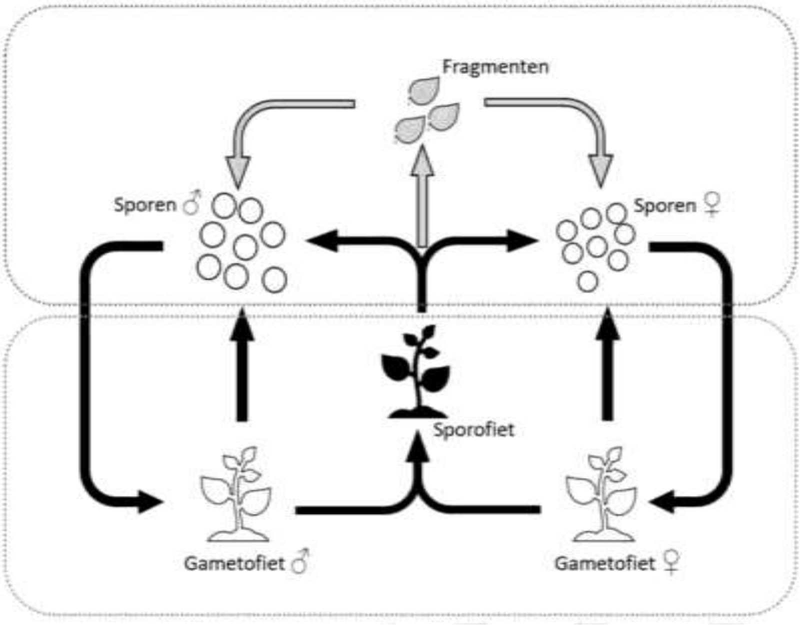

Figure 5 Schematic representation of possible life cycles of seaweeds. The stages in the upper half of the figure are 'free-living'. The stages in the lower half are attached. Not every species goes through all these stages of life. Reprinted from (Gittenberger et al., 2020a).

There is one company in the Netherlands that grows specific inoculum for seaweed farming, including inoculum from alien species. The company gets seaweed from Ireland, Norway and other places in Europe. This is used as the starting material from which inoculum is grown, which is then sold to growers in the country of origin (Gittenberger et al., 2020b).

Dutch seaweed farmers reported in 2019 that they use seaweed collected along the Dutch coast as starting material (Gittenberger et al., 2020b).

3.2.2 Stage cultivation and harvesting

The cultivation of the inoculum can take place in different ways, depending on the seaweed species and the water in which the cultivation takes place: on lines or nets in open water, using artificial substrate or directly at the bottom of open water or in basins.

Brown and red seaweeds grow from autumn to late spring/summer, while green seaweeds grow in summer (Gittenberger et al., 2020a).

3.2.2.1 Open water systems

Inoculum applied in lines gives the so-called seedling lines. The seaweed grows from these lines, with the lines hanging horizontally and/or vertically in the water, depending on the amount of light (geographic location, turbidity of water). The sea close to the coast and the estuaries are relatively turbid in the Netherlands. The lines are therefore kept close to the surface to capture sufficient light. The lines are held in place by buoys (Gittenberger et al., 2020b; Faassen et al., 2022). On a small scale, there is also cultivation of seaweed that spontaneously attaches and grows on lines placed in the water with buoys to float them (Gittenberger et al., 2020b).

In the Netherlands, the possibility to cultivate seaweed in wind farms in the North Sea is being investigated (Gittenberger et al., 2020a; Verhoef, 2020; North Sea Farmers, 2022; WUR, 2022b; Deltares, 2024), together with offshore solar parks (Oceansofenergy, 2020) and in combination with molluscs production.

Seaweed cultivation can consist of one species of seaweed in a field (monoculture), but a combination of several species also occurs (Faassen et al., 2022).

In large-scale production at sea, in addition to sunlight, nitrogen or phosphate are usually the limiting factor for seaweed growth. In addition, copper and zinc can also be limiting growth or at great depth manganese and cobalt. When nutrient levels are too high, seaweed growth may be inhibited by insufficient light due to excessive algal blooms (eutrophication) (Banach et al., 2020b; Faassen et al., 2022).

Harvesting is done by moving along lines with a boat and cutting off the seaweed, or by bringing in the entire line. When seaweed is partially harvested, it grows again and can therefore be harvested several times a year, depending on the species.

3.2.2.2 Cultivation in saltwater basins on land

In the Netherlands, seaweed cultivation also takes place on land in various basins made of plastic or concrete. These can be covered or open basins. The basins are filled with local seawater by a pipeline. Sometimes these are closed systems, sometimes there is a connection to open water via a drain (Banach et al., 2020b; Gittenberger et al., 2020b).

3.2.2.3 Harvesting of wild seaweed

In the Netherlands, a number of companies have permission to harvest wild seaweed in the Wadden Sea and the Eastern Scheldt (Faassen & Van Tuinen, 2019). In the case of wild harvesting, loose seaweed can be collected on the shore, or partially cut off so that the seaweed can continue to grow (Banach et al., 2020b). Manual collection of seaweed occurs at low tide in the Southwest Delta and the Wadden Sea. Several species of seaweed are collected in this way.

In the Eastern Scheldt seaweed is harvested with the help of a cutting-trawl. The seaweed is then cut off above the base of the stem. In this way, the seaweed can recover and soil disturbance is limited. Several species of seaweed are harvested in this way, such as sea lettuce (*Ulva* spp.), wakame (*Undaria pinnatifida*), Agardh's red weed (*Agardhiella subulata*), and Japanese wireweed (*Sargassum muticum*) (Gittenberger et al., 2020b).

3.2.3 Stage processing

After harvesting seaweed in open water, the seaweed is brought ashore with the help of boats for processing. In order to reduce the costs of further transport, a dewatering step can first be carried out. Furthermore, common processing practices are: a visual check for unwanted objects in which various types of seaweed are also separated, washing (rinsing) to remove, among other things, salt and impurities and then centrifuging (Banach et al., 2020b). Before the seaweed is stored, it is usually first dried in the air or dried by centrifugation with or without simultaneous heating (Banach et al., 2020b; FSAI Sci. Com., 2020; Van Tuinen et al., 2023).

If seaweed is not immediately packaged and consumed after harvesting, it must be processed quickly, because it rots quickly. The first step of processing can be drying (airborne or mechanical) (Van den Burg, 2019). When all the water present is removed from seaweed, about 5% to 30% of the weight of seaweed remains (dry weight) (Banach et al., 2020b). After that, the dried seaweed can still be ground (FAO & WHO, 2022). Other techniques used during processing are freezing, fermentation, if desired preceded by finely chopping the seaweed, blanching or salting. After one or more processing steps, seaweed can be added as an ingredient to food (FAO & WHO, 2022) or sold as a 100% seaweed product.

3.2.4 Stage trade and consumption

Dutch imports of seaweed mainly come from China and Japan in addition to imports from Germany, Belgium, France and Spain. Total imports in the period from 2017 to 2022 are more than 3 million kg dry weight seaweed. Total EU-wide imports in the same period amounted to almost 50 million kg dry weight of seaweed (Eurostat, 2023).

In more and more supermarkets and specialty stores in the Netherlands, seaweed products are for sale. These may have been produced from seaweed grown in the Netherlands, but a large part of the seaweed products have been imported. Also restaurants have more and more seaweed on the menu. There are seaweed farmers who deliver directly to restaurants, without the intervention of a trader (The Dutch Weed Burger, 2023).

Preparation steps for the consumption of seaweed are soaking (hydration) and/or washing and/or heating (blanching, cooking, frying) (FAO & WHO, 2022; Nijssen, 2022; EFSA, 2023; Van Tuinen et al., 2023).

3.3 Seaweed products

There is a wide range of seaweed-based foods with a wide range of products. There are products that consist entirely of seaweed, such as seaweed sheets (kelp as a collective name for large-leaf brown seaweeds) that are used, for example, for sushi and products in which seaweed is only processed in small quantities as a seasoning (for example, herbal or spice mixes) (Van den Burg, 2019). For example, in seaweed burgers, seaweed wraps and various seaweed pasta, the percentages of seaweed range from a few percent to over 50% (Van den Burg, 2019). Dried seaweed products are the most common. They are used as a garnish or as a (partial) replacement of flour in pasta, bread and other cereal products. Fresh seaweed is added to salads, mixed in fruit shakes, or cooked with rice and beans (FAO & WHO, 2022). Between 2011 and 2015, the European market for seaweed products grew by 7% (Banach et al., 2020a). In the period 2012-2021, an average of 250 new products containing seaweed as an ingredient appeared on the European market per year (EFSA, 2023).

3.3.1 The Dutch market

There has also been an increase in the number of seaweed products in the Netherlands in recent years. Between 2009 and 2018, 255 new products based on seaweed entered the Dutch market (Database of Innova Market Insights). These are mainly products such as snacks (Japanese mix, chips and sushi; n=90), bakery products (n=29) and ready-to-eat products & side dishes such as salads (n=29) (Banach et al., 2020b).

Information on the composition of products placed on the market in the Netherlands is available via the food database FoodSciffer. This is a database that contains information about foods that come from retailers, manufacturers and wholesalers. The information in this database comes from the label of the products. In April 2022, there were 702 products containing seaweed in this database. The largest groups of seaweed products are 'seaweed as vegetables' and vegetarian products with seaweed (17%), then fish products (15%), followed by 'peanuts, nuts, seeds, salts' (9%), soups and sauces (9%), herbs and spices (8%) and rice products (8%). The residual group (11%) consists of the most diverse products in which seaweed is processed: from beer to biscuits and from chocolate to cereals (Nijssen, 2022).

However, for most products, the label does not state how much seaweed the product contains. Only 15% of the more than 700 products mentioned a percentage of seaweed (Nijssen, 2022). These are dried or roasted seaweed skins and products such as salads, various snacks and herbs and spices. The percentage of seaweed in these products ranges from a few tenths of a percent (a zucchini soup) to 100% seaweed, such as seaweed skins used for sushi or consumed as a snack or processed into seaweed powder. Seaweed salads contain 70-80% seaweed (as opposed to seaweed salads (a few percent)), for snacks that ranges between 40 and 80% and for soups and sauces is listed around 30% seaweed, the pasta products contain a few percent seaweed.

Around 20% of seaweed products the type of seaweed is mentioned at the label (Nijssen, 2022). Of these products, approximately 10% is a mixture of two or more seaweeds. The types of seaweed that are most commonly mentioned are: kelp (approximately 28%), nori (*Porphyra*, 24%), kombu (23%) and wakame (*Undaria*, 22%). Dulse (*Palmaria palmata*) is mentioned in about 10% of the products, but almost always in a mixture with other seaweeds.

The vast majority of seaweed products on the Dutch market consist of imported products from Asia. A number of seaweed products are available based on seaweed grown in the Netherlands, such as the Dutch Weed Burger and Sea Nuggets with seaweed from the Eastern Scheldt (The Dutch Weed Burger, 2023).

3.4 Seaweed consumption

In Asia, seaweed is part of the regular diet, with soups and sushi as the main applications. But also in Europe, the consumption of seaweed is not new, and is regularly on the menu of inhabitants of coastal areas (e.g. France, United Kingdom, Germany, Spain and Ireland) (FSAI Sci. Com., 2020). The introduction of Asian cuisine and especially sushi from Japan has led to an increase in seaweed consumption in Europe. An increase in consumption is further reinforced by the fact that seaweed is increasingly seen as a natural, healthy and locally produced food (Banach et al., 2020b). It turns out that consumers who eat fish are more likely to eat seaweed than consumers who often eat meat (Banach et al., 2020b).

3.4.1 Consumption data outside the Netherlands

Data on seaweed consumption are very limited (FAO & WHO, 2022). In the absence of consumption data from European consumers, Danish researchers have assumed that 5 grams of dry seaweed are consumed once a week (Sá Monteiro et al., 2019). This corresponds to a consumption of 0.7 (=5/7) grams of dry seaweed per day.

A French food consumption survey (2014 − 2015) shows that seaweed and seaweed products are consumed by only a small proportion of French people. The average consumption of seaweed by seaweed consumers on the days they actually ate seaweed was 6.1 g per day by adults (n=10) and 5.4 g per day by children (n=4). Whether the weight is dry or wet is not mentioned in the publication (Carne et al., 2022).

Between November 2020 and February 2021, Ficheux and colleagues examined the seaweed product consumption of French adults (n=780) through an online questionnaire. Seaweed products included vegetables with a meal, sushi, miso soup, salad, bread, pasta, chips, tartar, fish rillettes, mustard, salt, cheese and beverages. Eighty-nine percent of respondents (n=692) had consumed at least one seaweed product (e.g. sushi) in the past 12 months. The authors concluded that seaweed consumption by seaweed products in the general population was 293±905 mg per day (P95=1101 mg/day). Whether the weight is dry or wet is not mentioned in the publication (Ficheux et al., 2022).

Consumption data from Asian countries show an estimated daily consumption of dry seaweed of 5.2 grams in China, 4-7 grams in Japan and 8.5 grams in South Korea (Hwang et al., 2010; Zava & Zava, 2011; Chen et al., 2018). In another study, the estimated average daily consumption of dry seaweed in Japan was lower (1.7 grams/day) (Vellinga et al., 2022).

3.4.2 Dutch consumption data

In the Netherlands, RIVM is responsible for collecting food consumption data (food, drinks). This is done through the Food Consumption Survey (VCP). The VCP from the period 2012-2016, consisting of 2078 participants, contains four participants who have consumed seaweed (on average 15.2 g/day) (Van Rossum et al., 2020; Vellinga et al., 2022). Whether it concerns dry weight or wet weight is not mentioned in the publications. The number of respondents in the VCP who indicate that they consume seaweed is too small to gain sufficient insight into the consumption of seaweed and seaweed products by the Dutch population.

In order to gain a better understanding of seaweed consumption, RIVM, commissioned by BuRO, carried out additional research by means of a questionnaire survey among a representative sample of the Dutch population (Dinnissen et al., 2020). A total of 2710 questionnaires were completed for 1 to 80-year-olds. For children up to and including 15 years of age, the questionnaire has been completed by the parents/carers. Of 2710 participants, 1238 had consumed seaweed products and 632 had consumed seaweed products (i.e. seaweed users) in the past four weeks.

RIVM concluded that a quarter of the participants regularly ate seaweed (products) and that seaweed (products) is eaten in all walks of life. Compared to others, highly educated people, people who earn more than an average income, residents of cities and young adults are more likely to eat seaweed (products). Most seaweed is eaten in the form of chips/prawn crackers ("kroepoek" in Dutch) with seaweed, noodles based on seaweed, "sea spaghetti", wraps with seaweed and seaweed salad (Dinnissen et al., 2020). Table 3 gives an overview of the consumption of both wet and dry seaweed by seaweed consumers (n=632) divided into different age categories. The consumption quantities were calculated on the basis of the (estimated) percentage of seaweed in the seaweed products consumed. RIVM also based its calculation on the fact that 100 g of wet seaweed corresponds to 15 g of dry seaweed (100 g of wet seaweed consists of 85% water) (Dinnissen et al., 2020).

Table 3 Consumption of wet and dry seaweed in grams/day by 1 to 80-year-old seaweed consumers (n=632) broken down by age groups. The 95% confidence interval is shown in parentheses (Dinnissen et al., 2020).

Consumption wet seaweed (g/day*)					
Consumer	N	Mean	P50	P90	P95[#]
1 to 17-year-olds[§]	56	31,8 (12,5-51,1)	6,5 (1-11,9)	54,6 (0-221)	249,6 (64,5-434,7)
18 to 80-year-olds	576	16,5 (12,9-20,2)	3,3 (2,6-3,9)	33,4 (14,1-52,8)	93,9 (25,1-161,4)
18 to 50 year olds	296	20,2 (14,2-26,1)	3,3 (2,6-4,1)	43,3 (0-90,1)	128,8 (24,9 – 232,7)
51 to 80-year-olds	280	9,8 (7-12,5)	2,8 (1,6-3,9)	20 (7,8-32,3)	36,3 (0-78,8)
Consumption dry seaweed (g/day)					
Consumer	N	Mean	P50	P90	P95[#]
1 to 17-year-olds[§]	56	4,5 (1,8-7,3)	0,9 (0,1-1,7)	7,8 (0-31,6)	35,7 (9,2-62,1)
18 to 80-year-olds	576	2,4 (1,8-2,9)	0,5 (0,4-0,6)	4,8 (2,0-7,5)	13,3 (3,6-23,1)
18 to 50 year olds	296	2,9 (2,0-3,7)	0,5 (0,4-0,6)	6,2 (0-12,9)	18,4 (3,6-33,2)
51 to 80-year-olds	280	1,4 (1,0-1,8)	0,4 (0,2-0,6)	2,9 (1,1-4,6)	5,2 (0,0-11,3)

* The indicated frequency of consumption and the indicated quantity in grams is used to calculate the mean daily consumption of that product in grams per day.
[§] The results of 1 to 17-year-old seaweed users are based on less than 100 observations.
[#] These results are influenced by the measurements of individuals with extreme reporting of consumption.

4 Public health risks – food safety

4.1 Introduction

Foods should not be placed on the market if they are unsafe. Foodstuffs are unsafe if they are harmful to health or unfit for human consumption (General Food Regulation (GFL, Regulation (EC) No 178/2002)[2].

Unsafe has to do with danger, which is defined as 'a biological, chemical or physical agent in a food, or the condition of a food, with potential adverse effects on health' (Regulation (EC) No 178/2002). The associated risk of a hazard is defined as the 'function of the likelihood of an adverse health effect and the severity of that effect'. Despite all the measures taken to ensure that our food is safe, there are agents (chemical, microbiological, physical) in our food that can be harmful to health. This can lead to adverse health effects and thus to a burden of disease.

Chemical hazards are compounds that enter food from the environment (e.g. environmental contaminants), are added to it (e.g. food additives), or are formed during processing of food (process contaminants).

Biological hazards of a food are disease-causing microorganisms (pathogens) and antibiotic resistance of microorganisms that can be transmitted to humans via food.

Exposure to chemicals in food does not usually lead to a directly demonstrable burden of disease (Van Kreijl et al., 2004). That's because chemicals usually cause health effects only after prolonged exposure, unlike microorganisms, which cause disease within hours or days or a few weeks at most. For some chemicals there are sometimes acute effects due to high exposure.

Physical hazards in food are 'foreign objects' that may inadvertently be present in a food and subsequently pose a risk to the health of the consumer when the product is used or consumed.

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[2] Regulation (EC) No 178/2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety

These are foreign objects or fragments thereof, such as stones, glass, animal material, plant material (including wood), metal and plastics (including nano- and microplastics). All three angles (chemical, microbiological and physical) of food safety are highlighted in this production chain assessment on seaweed.

4.2 Scope

This risk assessment is about seaweed as food. Food supplements with seaweed as an ingredient are not included, nor are food materials prepared from seaweed (manitol, alginates, etc.) and seaweed harvested by consumers themselves. Also, the presence of possible allergens in the cultivated seaweed was not considered. Finally, no cost/benefit analysis has been made for the consumption of seaweed.

4.3 Approach

4.3.1 Literature research

Literature research on chemical and physical hazards to food safety related to the consumption of seaweed or seaweed products has been carried out by Wageningen Food Safety Research (WFSR) (Banach et al., 2020b) and that on microbiological hazards by Wageningen Food & Biobased Research (WFBR) (Rodríguez Illera & Van Bokhorst-Van de Veen, 2019).

With regard to the chemistry component, BuRO conducted an additional literature review covering the years 2019 to 2022 (20 July 2022). Search strings are included in Annex II. Where relevant, the latest developments (until January 2024) have been taken into account; such as the modified health limits of arsenic.

BuRO supplemented the WFBR literature study on microbiological risks with literature up to 03/10/2023. In addition, an additional search was carried out in relation to seaweed processing methods (2022-2024). Information on the approach to this literature review is included in Annex II.

For the assessment of physical hazards, information was sought and collected until April 2024. The search method is set out in Annex II.

4.3.2 RASFF

The data in the Rapid Alert System for Food and Feed (RASFF) provide an indication of which microbiological, chemical and physical hazards may be present in the different foods in the EU and beyond. This RASFF system has been established in the EU for cross-border food safety incidents. The authorities of the member countries (EU countries, Norway, Liechtenstein, Iceland and Switzerland), the European Commission and EFSA notify and inform each other about observed exceedances of legal maximum levels or other problems in the field of food safety and feed. The RASFF notifications do not only concern exceedances of contaminants or presence of microorganisms, but may also concern incorrect labelling, fraud or organoleptic aspects (e.g. shape, texture, colour or smell). RASFF notifications concern fresh, processed and processed foods. However, the notifications do not give a representative picture of the occurrence of hazards in food, because only the observed exceedances that have been reported cross-border are notified and because the notifications mainly concern food-chemical combination for which standards are set in the EU.

The RASFF system looked for 'food' and 'seaweed' for the years 1980 to 2024. The RASFF system does not contain any notifications on seaweed until 2003 (filter by seaweed and food; In addition, there is 1 notification with 'seeweed'). From 2003 to 2024, 275 notifications in 'food' are related to seaweed (Table 4), with the number of notifications varying between 2 and 28 per year. The vast majority of notifications concern chemicals in seaweed, 233 out of 275 notifications. The different types of notifications are broken down and explained below (section 4.5.2.1 chemical notifications, section 4.6.2.3 microbiological notifications, section 4.7.2.1 physical notifications).

Table 4 RASFF notifications relating to seaweed products from 2003 to 2024.

Type of notification	Number of notifications
Chemical	233
Microbiological	10
Physical	2
Additions/forgery/incorrect labelling	15
Other	15
Final total	275

4.3.3 Dutch data

4.3.3.1 Seaweed farmed in the Netherlands

In 2018, 2019 and 2020, WFSR was commissioned by BuRO and LVVN to sample and analyse seaweed at seaweed farms in the Netherlands for chemical contaminants and iodine. In the same period, similar research was carried out by WFSR on behalf of the then Ministry of Agriculture, Nature and Food Quality, with a focus on representative sampling. All seaweed sampling at the different seaweed farms for these surveys was carried out by WFSR according to a developed sampling protocol (Annex III) (North Sea Farm, 2020). The studies for BuRO and LNV are complementary and the results have been compiled by WFSR in one report (Faassen et al., 2022). The aggregated, anonymised results can be found in the WFSR report (Banach et al., 2020b). In addition, WFSR has been commissioned by LVVN to investigate the influence of seaweed processing and preparation on the levels of a number of contaminants (Van Tuinen et al., 2023; Gsell et al., 2025).

4.3.3.2 Seaweed products

In Dutch supermarkets, a large part of the products in which seaweed is processed originate from abroad. In 2018, 2019 and 2020, the Netherlands Food and Consumer Product Safety Authority (NVWA) sampled seaweed products that consist almost entirely of seaweed and seaweed products with seaweed as an ingredient (such as sushi) for chemical research in stores and wholesalers. These samples were analysed by WFSR for chemical contaminants (Faassen, 2020). However, the results of these measurements lacked the correct information on the products (dried or fresh product, percentage of seaweed processed) for the chemical risk assessment (see also 4.5.2.3).

In 2019, 2020 and 2021, the NVWA sampled seaweed and sea vegetables for microbiological research in retail, wholesalers and food producers. These samples were (partly) examined by WFSR for *the presence of B. cereus* (quantitative) and for *L. monocytogenes*, *Salmonella*, STEC and *Vibrio* spp. (qualitative). The results of sea vegetables have been taken into account in the microbiological risk assessment for comparison with seaweed, because these products also come into contact with seawater during growth/cultivation.

4.3.3.3 Seaweed consumption

On behalf of BuRO, RIVM conducted a study on the consumption of seaweed in the Netherlands (Dinnissen et al., 2020) (see also Section 3.4.2).

4.3.4 Risk assessment methodology

In order to assess the risks to public health (food safety) from seaweed consumption, the four steps of the risk assessment were followed (BuRO, 2024b). This methodology is based on that of the Codex Alimentarius (FAO & WHO, 2019) and EFSA's methodology, and is in line with the systematic risk assessment referred to in the General Food Regulation (GFL, Regulation (EC) No 178/2002)[3]. The four steps are as follows:

1. Hazard identification: identification of potential hazards
2. Hazard characterisation: description of the potential effects of the hazards

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[3] Regulation (EC) No 178/2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety

3. Exposure assessment: Estimation of the extent to which the hazard occurs and causes an effect
4. Risk characterisation: Conclusion of risk based on hazard characterisation and exposure assessment.

Table 5 provides an overview of the data and information on which the chemical, microbiological and physical risk assessment is based.

Table 5 Data used for the food safety risk assessment.

Hazards	Seaweed farmed in the Netherlands	Seaweed products on the Dutch market	Dutch consumption data	International literature
Chemical	x		x	x
Microbiological		x		x
Physical				x

4.4 Laws and regulations

4.4.1 Novel Food

Foods and food ingredients that were not consumed to a significant extent in the European Union before 15 May 1997 are defined as novel food (Novel Food Regulation ((EU) 2015/2283[4])) and should, following an assessment by EFSA, be authorised before being placed on the market. It is also possible to have food authorised that has a 'history of safe use' of at least 25 years outside the EU. Whether a particular type of seaweed is considered a novel food should be considered by species or by product. This is determined by the history of consumption. In 2021, the European Union's Joint Research Centre (JRC) published a technical report providing a comprehensive overview of the novel food status of seaweeds based on their inclusion in national and European lists of authorised foods and food supplements (Araújo & Peteiro, 2021). In addition, based on the overview, the authors make a proposal for updating the Novel Food Status Catalogue. Whether a seaweed species is actually included in the catalogue can be checked via the Novel Food status Catalogue (EC, 2023).

4.4.2 Food safety

Foods should not be placed on the market if they are unsafe. Foodstuffs are unsafe if they are harmful to health or if they are unfit for human consumption. (EC) No 178/2002)[5]. The responsibility for food safety lies with food producers (food business operators). They should apply procedures based on *HACCP (Hazard Analysis and Critical Control Points)*principles in addition to hygienic practices to ensure food safety throughout the food chain. For some hazards, food safety criteria (general or product specific) are laid down in EU legislation or additional national legislation.

Food hygiene legislation lays down requirements for the primary production of food (Regulation (EEC) No. (EC) 852/2004)[6]. This includes the production of seaweed. However, in addition to requirements related to primary production in general, there are also specific requirements for products of plant origin. As most seaweeds are not strictly plants, it is unclear whether seaweed products are covered by the specifically named plant product requirements in this legislation.

4.4.2.1 Maximum levels for chemicals

Legal maximum levels set limits to the maximum permitted concentrations of substances in food. For this purpose, product standards are used that are set at European level, the MRL (Maximum Residue Limit) or ML (Maximum Limit). MRLs belong to substances that can be found as residues in a food, such as from plant protection products. MLs are used for substances that may be unintentionally present in food, such as environmental contaminants.

Maximum Contaminant Limits (MLs) are set at European level if a risk assessment performed by EFSA shows that the consumer exposure to a contaminant exceeds the safe health based guidance

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[4] Regulation (EU) 2015/2283 on novel foods, amending Regulation (EU) No 1169/2011 of the European Parliament and of the Council and repealing Regulation (EC) No 258/97 of the European Parliament and of the Council and Commission Regulation (EC) No 1852/2001

[5] Regulation (EC) No 178/2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety

[6] Regulation (EC) No 852/2004 on the hygiene of foodstuffs

value. Contaminant MLs are based on the ALARA (As Low As Reasonably Achievable) principle, as low as reasonably achievable. In this way, food companies are forced to keep the presence of contaminants in their products as low as possible. Exceeding the ML does not always mean that there is a health risk.

There are no (yet) Codex standard maximum levels for chemicals for the cultivation, processing of seaweed (FAO & WHO, 2022).

Regulation (EU) 2023/915 does not[7] set maximum levels for certain contaminants in seaweed. The exception is food supplements consisting of at least 80% dried seaweed or products derived from seaweed. These supplements shall not contain more than 3.0 mg/kg of cadmium.

Recommendation (EU) 2018/464[8] sets out a call from the European Commission for Member States to monitor the presence of arsenic, cadmium, iodine, lead and mercury in seaweed, halophytes and seaweed-based products during the years 2018, 2019 and 2020 and to provide this data to EFSA. Following the results of this monitoring, the European Commission is working on establishing maximum levels for iodine and metals in seaweed.

Regulation (EC) No 396/2005[9] sets the maximum residue level of mercury compounds (sum of mercury compounds expressed as mercury) in algae and prokaryotic organisms at 0,01 mg/kg.

Regulation (EC) No 1333/2008[10,11] lays down specifications for food additives based on seaweed. E406 (agar agar), E407 (carrageenan) and E407a (processed *Eucheuma algae)*may contain up to 3 mg/kg arsenic, 5 mg/kg lead and 1 mg/kg mercury. Cadmium is subject to a maximum of 1 mg/kg (E406) or 2 mg/kg (E407 and E407a).

In the absence of European legislation on seaweed, a number of countries have set national maximum levels for contaminants in seaweed. In 1988 and 1990, the French High Council for Public Health (CSHPF) reported the following maximum levels in seaweed used as a vegetable or as a herb: inorganic arsenic 3 mg/kg, cadmium 0.5 mg/kg, mercury 0.1 mg/kg, lead 5 mg/kg and iodine 2000 mg/kg. All levels are based on dry weight (ANSES, 2020). In 2007, the Bundesinstitut für Risikobewertung (BfR) came to a much lower value, concluding that products made from dried marine algae (i.e. seaweed) should not contain more than 20 mg iodine/kg dry weight because these products may be harmful to health (BfR, 2007). In 2012, Agencia Española de Seguridad Alimentaria y Nutrición (AESAN), in accordance with CSHPF, recommended a maximum limit of 2000 mg iodine/kg dry weight for seaweed (AESAN, 2012). There is currently no specific national legislation in the Netherlands for chemical contaminants in seaweed.

4.4.2.2 Microbiological criteria

In the EU, no specific microbiological criteria for seaweed are included in the legislation. However, a food safety criterion for *L. monocytogenes (Vo.* (EC) No 2073/2005)[11].

In the Netherlands, national legislation lays down food safety criteria for food and beverages that are no longer heated for consumption by the end user (ready-to-eat foods; Wbbl[12]). For these products, *Salmonella*, *Campylobacter* and (as of 1-12025) STEC shall not be detectable in 25 g. The number of culturable *B. cereus*, *C. perfringens* and *S. aureus* shall not exceed 100,000 per gram.

Cressey et al. (2023) and Løvdal et al. (2021) provide an overview of international legislation on microbiological criteria for seaweed (Table 6). There are no specific standards for seaweed in Australia/New Zealand, but there is a standard for ready-to-eat foods (such as seaweed) related to *L. monocytogenes* (Cressey et al., 2023).

The BC Centre for Disease Control (2013) made recommendations for guidelines for harvesting and processing seaweed in Canada (British Colombia). As regards microbiological food safety, the

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[7] Commission Regulation (EU) 2023/915 on maximum levels for certain contaminants in food and repealing Regulation (EC) No 1881/2006

[8] Commission Recommendation (EU) 2018/464 on the monitoring of metals and iodine in seaweed, halophytes and seaweed-based products

[9] Regulation (EC) No 396/2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin and amending Council Directive 91/414/EC

[10] Regulation (EC) No 1333/2008 on food additives

[11] Regulation (EC) No 2073/2005 on microbiological criteria for foodstuffs

[12] Commodities Act Decree on the Preparation and Treatment of Foodstuffs

recommendation was that seaweed should not be harvested in the vicinity of a sewage discharge point or overflow (>300 m distance) or in areas closed to shellfish production (sanitary requirements) and that seaweed should be washed with drinking water before further processing. And specifically for seaweed sold fresh, it should not be harvested from areas closed to shellfish production due to the presence of *V. parahaemolyticus*. In Norway, the seaweed sector has drawn up its own guidelines. As far as microbiological hazards are concerned, only trace formers are mentioned here (FAO & WHO, 2022).

Table 6 Overview of microbiological criteria for seaweed and seaweed products in the Abroad, expressed in CFU/g unless otherwise specified (Source: Cressey et al. (2023), Løvdal et al. (2021)).

Foodstuff	Dried algae	Danish seaweed	Dried seaweed (laver/nori)	Packaged seaweed (algae) products	K&K product
Country	France (kve/g)*	Denmark (kve/g)*	China (kve/g)*	China (kve/g)*	South Korea (kve/g)*
Micro-organism / hygiene-indicator					
Aeroob mesophilic plate count	$\leq 10^5$	-	-	-	-
Aerobic plate count	-	-	$<3\times10^4$	-	-
Coliforms (fecal)	$\leq 10^1$	-	$<3x10^1$ CFU/100g	-	-
E. coli	-	$<10^2$ g	-	-	-
Mold	-	-	$<3x10^2$	-	-
Anaerobic sulfite reducers	$\leq 10^2$	-	-	-	-
B. Cereus	-	-	-	-	$<10^3$
C. perfringens	$\leq 10^0$	-	-	-	$<10^2$
Salmonella spp.	NA/25 g	NA/25 g	NA/25 g	NA/25 g	NA per 25 g
Shigella spp.	-	-	NA/25 g	-	-
S. aureus	$\leq 10^2$	-	NA/25 g	-	$<10^2$
V. parahaemolytic	-	-	NA/25 g	-	$<10^2$

* Unless otherwise indicated
-: no legislation
NA: not demonstrable
K&K: ready-to-eat

4.5 Food safety chemical risks

4.5.1 Approach and scope of chemical risk assessment

The four steps of the risk assessment (section 4.3.4) are completed as follows for the chemical risk assessment.

1. Hazard identification: inventory of chemicals that could end up in seaweed during cultivation, harvesting, storage, transport and processing of seaweed. This is based on literature review and notifications in RASFF.
2. Hazard characterisation: description of the toxic effects of the substances and the health based guidance values. The effects are often derived from animal studies (mainly rats and mice) or from human epidemiological studies. These descriptions are based on data from the scientific literature.
3. Exposure assessment: estimation of the intake of a substance. This is based on the data on the occurrence of a substance in seaweed linked to the consumption of seaweed. In this risk assessment, the exposure assessment was made on the basis of Dutch data (seaweed grown in the Netherlands and Dutch consumption data).
4. Risk characterisation: determine whether the presence of a substance in seaweed poses a risk to public health in the Netherlands by comparing the intake of that substance from seaweed with health based guidance values. In addition, it is important to know what the total intake of that substance via food is and whether it exceeds the health based guidance value.

This risk assessment is based on measurements of contaminants in seaweed grown in the Netherlands. The results of measurements on seaweed products sampled in shops and wholesalers could not be taken into account in this risk assessment due to the lack of the correct information for the chemical risk assessment on the products (dried or fresh product, percentage of seaweed processed; see 4.5.2.3). The chemical risk assessment therefore focuses on seaweed grown in the Netherlands.

In the risk assessment, the assessment shall be performed for individual substance(s) or group(s). The risk assessment of cumulative effects due to exposure to multiple substances at the same time is a field under development. EFSA and RIVM are working together on a research program on developing the methodology to assess cumulative effects of substances (EFSA, 2020).

4.5.1.1 Health based guidance values

The health based guidance value is the amount of a substance that a person can take daily throughout his life without any significant health risk (chronic exposure). The health based guidance value is calculated by extrapolating toxicity data (usually from animal studies) using safety factors. For environmental contaminants that may end up in food, the Tolerable Daily Intake (TDI) or Tolerable Weekly Intake (TWI) is used. Exceeding the TDI increases the probability of an effect, but this does not mean that this effect will always occur, because the TDI is derived from lifetime exposure. Severe or long-term exceedance increases the risk of a health effect. If there is no TDI for a substance, or if there is no useful data to derive a TDI, EFSA recommends using the Margin of Exposure (MoE) in the risk assessment. Margin of Exposure shows the difference between the reference point from the animal study (e.g. BMDL (Benchmark Dose Lower Confidence Limit)) and human exposure. To account for uncertainties (intra- and interspecies variation), a MoE of 100 is usually applied for a non-carcinogenic substance. For carcinogens and genotoxic substances, a MoE of 10,000 or higher gives little cause for concern (EFSA, 2005).

For the assessment of acute health effects, after short-term exposure, the ARfD (Acute Reference Dose) is used. This is the maximum amount of a substance in food or drinking water that a person can take within 24 hours without any health effects occurring.

4.5.2 Risk assessment of chemical hazards

4.5.2.1 Hazard identification

The identification of hazards that may occur in seaweed looked at chemicals that are described in (scientific) publications as dangerous for the food safety of seaweed or are found in seaweed (Banach et al., 2020b; Banach et al., 2022; FAO & WHO, 2022). Also notifications from RASFF are included (Table 7). In addition, it was investigated which processes and actions take place in the various stages and which chemicals could be introduced. On this basis, a list of chemical hazards has been drawn up (Table 8).

RASFF

Of the 275 notifications on seaweed in RASFF, the vast majority concerned chemical notifications (n=233) (Table 4). Most of these chemical notifications concerned notifications of high iodine levels (n=180; 77%) and high levels of arsenic (12%) (Table 7). The RASFF system has been searching for 'food' and 'seaweed' for the years 1980 to 2024, from 2003 there have been notifications related to seaweed.

Table 7 RASFF notifications in seaweed related to chemical notifications (2003 to 2024).

Hazard category	Number of notifications	Percentage of total notifications
	Composition	
High aluminium content	2	0,9
High iodine content	180	77,3
Undeclared iodine	6	2,6
	Metals/Metalloids	
Arsenic	29	12,4
Cadmium	7	3,0
Lead	1	0,4
	Mycotoxins	
Aflatoxins	1	0,4
	Environmental contaminants	
Polycyclic aromatic hydrocarbons (Pack)	1	0,4
	Pesticide residues	
Substance not authorised: ethylene oxide	4	1,7
Substance not authorised: prometryn	2	0,9
TOTAL	233	100

Seaweed cultivation

Seaweed grown in open water can absorb contaminants present in the water (Banach et al., 2020a). The same applies to seaweed that is grown in basins and fed with (sea) water. In addition, substances that occur naturally in (sea) water, such as iodine, chromium, iron, zinc, nickel and aluminium can be absorbed by seaweed.

In marine waters and brackish water areas (micro-)algae and blue-green algae can occur that can produce a wide range of toxins. Algae can also grow on the seaweed (Faassen et al., 2022).

In addition, there are environmental contaminants in the aquatic environment. For example, persistent organic compounds (POPs) such as polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and polycyclic aromatic hydrocarbons (PAHs) produced by combustion processes, and polychlorinated biphenyls (PCBs), highly stable and non-combustible substances, which have been widely added in the past to hydraulic oils and fluids for electrical insulators and capacitors. Furthermore, brominated flame retardants and poly- and perfluoroalkyl substances (PFAS), which are emitted from products such as textiles, electronics, teflon, fire extinguishers and plastics, can end up in the (aquatic) environment.

Less persistent contaminants are also present in surface water, for example as a result of industrial and sewage discharges (effluents from wastewater treatment plants (AWZI and WWTP respectively)). Eventually, these contaminants end up in the sea. Examples of this group of environmental contaminants are pharmaceuticals, personal care products and plasticizers made of plastics.

Plant protection products are found in surface water as a result of their application in agriculture and by private individuals. Plant protection products are also sometimes used in open water aquaculture (FAO & WHO, 2022).

Mineral oils end up in seawater after oil leaks from vessels, after illegal discharges or after a vessel accident. In addition, antifouling residues may be present.

Another group of environmental contaminants is that of the (heavy) metals, which occur naturally in the soil and/or can end up as contamination in the soil after the use of animal manure or as a result of (regional) atmospheric deposition from industrial activities. From the bottom, these substances can then leach to the surface water to eventually end up in the sea. The polysaccharides in seaweeds have the property that they can bind metals strongly (Hogstad et al., 2023), so that heavy metals such as arsenic, cadmium, mercury and lead can be effectively absorbed from the water (Banach et al., 2020b).

Finally, as a result of a radiological accident, radioactive substances may end up in the aquatic environment. Due to the high uptake of iodine (I) by seaweed, 129I is a good indicator of radioactive contamination (Banach et al., 2020b).

In the construction of wind farms in the North Sea, the possibility to cultivate seaweed is being investigated (Verhoef, 2020; North Sea Farmers, 2022; WUR, 2022b; Deltares, 2024). As a result of the emission from the coatings of the wind turbines, substances may be present in the seawater such as a number of metals (zinc, indium, lead and cadmium) and bisphenol A and 4-tert-butylphenol from epoxy-based coatings (RIVM, 2021a; Hof et al., 2022). Due to leaks of lubricating oil from the wind turbines and/or equipment during the maintenance of the wind turbines in wind farms, mineral oil can also leak to the seawater.

Harvest, transport and storage

Chemical hazards may be introduced in this stage by contaminants from equipment (e.g. mineral oils or refrigerants) used during harvesting, transport, drying (fans and/or dehumidifiers) or refrigerated storage of fresh seaweed (FAO & WHO, 2022). Mycotoxins, derived from fungi, can be found on dried seaweed (FAO & WHO, 2022). There is evidence of the use of plant protection products during the storage of seaweed (China) to prevent contamination with mould (Banach et al., 2020b).

Cases for transport, equipment and materials used in the harvesting and processing of seaweed are cleaned and disinfected with cleaning and disinfecting agents. Disinfection is carried out to prevent the spread of pathogenic microorganisms. Residues of these disinfectants could remain on seaweed products if not adequately rinsed.

Finally, from packaging materials used during transport and/or storage, such as crates or plastic bags, substances may migrate and end up in the seaweed.

Processing and packaging

During the processing of seaweed, various substances can end up in or on the seaweed. These can be process aids that are used, for example, in the washing of seaweed, or substances that are added to seaweed (food additives), for example to preserve them. Prior to the processing steps, cleaning and disinfecting agents will also be used to clean and disinfect (disinfect) machines and equipment, from which residues may remain.

New substances can be introduced as a result of the preparation and heating of foods. PAHs can be formed during drying (heating) of seaweed (Banach et al., 2020b) and/or during cooking such as barbecuing (e.g. seaweed burgers). Finally, substances that end up in the food can migrate from packaging materials.

Because chemical analyses in seaweed are not yet routinely carried out, it is not yet possible to analyse the levels of all substances in Table 8 (validated). The substances/groups of substances with validated analytical methods (in Table 8 fat) are listed in Table 9.

Table 8 Overview of possible chemical hazards with examples of substance(s) and introduction routes in the seaweed chain. Fat: chemical analyses have been carried out for these substances or groups of substances in Dutch seaweed and/or seaweed products from Dutch supermarkets.

Hazard category	Compounds	Source or introduction route
Stage – Cultivation, harvest	, transport and storage of seaweed	
Cultivation		
Algae toxins	cyanotoxins cylindrospermopsin (CYN)	freshwater or saltwater algae that produce toxins
Iodine		naturally present in seawater, emissions to (aquatic) environment
Persistent organic compounds	polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF), polycyclic aromatic Hydrocarbons (PAHs)	Persistent substances arising from combustion processes; emissions to the (aquatic) environment.
	Polychlorinated biphenyls (PCB), brominated Fire retardants, poly- and perfluoroalkyl substances	emission of these substances (from plastics, textiles, electronics, printed circuit boards, hydraulic fluids, teflon, fire extinguishers) to (aquatic) environment.
Other environmental contaminants	(veterinary) medicinal products , personal Personal Care Products (PCP)	Emissions from effluents from sewage treatment plant (WWTP) and leaching from manure to aquatic environment.
	Plant protection products	application of plant protection products by agriculture and private individuals.
	mineral oils	leakages and discharges from vessels into seawater.
	bisphenol a, 4-tert-butylphenol	Emissions from the epoxy-based coatings of the windmills
	anti-fouling products	emissions from paint on vessels, aquaculture installations or other structures used in water.
(Heavy) metals and metalloids*	arsenic, cadmium, mercury, lead, nickel, aluminium, zinc	naturally present in soil and from there leaching to aquatic environment. atmospheric deposition to (aquatic) environment. Emissions from the epoxy-based coatings of the windmills
Radioactive substances		pollution in (aquatic) environment (after incident with radioactive substances).
Stage – Cultivation, harvest	Stage – Stage - Cultivation, harvest.	
Harvest, transport and storage		
Plant protectionproducts		application during storage to prevent mold.
Mycotoxins		toxins produced by fungi
Chemicals from machinery	mineral oils refrigerants	leakage from equipment used for harvesting, transporting and cooling seaweed.
Cleaning and disinfecting agents		disinfection of machines, tools (use in harvesting, transporting, sorting) and surfaces (floors, tables, storage areas).
Sateg – Processing and packaging of seaweed		

Cleaning and disinfecting agents		disinfection of machinery and equipment prior to processing. rinsing seaweed with chlorinated (drinking) water.
Process auxiliaries		are used during the processing of food, but are not themselves part of the food.
Foodadditives		additions during production of seaweed products (e.g. preservatives).
Process contaminants	polycyclic aromatic hydrocarbons (PAHs)	occur during smoking and/or drying of foods.
Substances from packagingmaterials and other food contact materials	starting substances and additives, e.g. plasticisers.	migration from packaging materials and other food contact materials.

*The group of (heavy) metals and metalloids is further referred to as (heavy) metals.

The substance groups, such as algae toxins, plant protection products and poly- and perfluoroalkyl substances, each comprise a (large) number of individual substances (Faassen, 2020; Krätschmer, 2024).

The non-bold substances from Table 8, for which analyses could not be carried out, were further excluded from the risk assessment because the exposure estimate could not be made. No information on the presence of these substances has also been found in the literature (see for example (FAO & WHO, 2022).

Table 9 Substances and groups of substances analysed in seaweed from seaweed producers and in seaweed products from wholesalers and supermarkets.

Substances and groups analysed	Chemical analysis in	
	Seaweed from seaweed farmers	Seaweed products from wholesalers and supermarkets
Algae toxins	x	x
Iodine	x	x
Persistent organic compounds (dioxins, dibenzofurans, PCBs, PAHs)	x	x
Poly- and perfluoroalkyl substances (PFAS)	x	
(Veterinaryl) medicinal products (active substances)		x
Plant toxins		x
Plant protection products (active substances)	x	x
Mineral oils	x	x
(Heavy) metals and metalloids (arsenic, cadmium, lead, mercury, nickel)	x	x
Radioactive substances	x	x

4.5.2.2 Hazard characterisation

Only substances analysed in seaweed and/or seaweed products (Table 9) are assigned a hazard characterisation.

Algae toxins

Algae toxins can be produced by algae, both in freshwater and in saltwater. There are many different algal toxins.

Cyanotoxins (blue algae toxins) are a group of toxins produced by blue algae (cyanobacteria). There are many different types of blue algae that can be responsible for different cyanotoxins. The following cyanotoxins are distinguished: neurotoxins, cytotoxins, hepatotoxins and skin irritants (dermatotoxins).

Cylindrospermopsin (CYN) has been found sporadically on seaweed from Dutch farmers. CYN is cytotoxic. Acute effects after oral intake of CYN that are observed are effects on the liver (cytolysis, infiltration of inflammatory cells and proteins), kidneys (tubular necrosis, alteration of the proximal tubule or glomeruli) and sometimes intestines (bleeding). CYN has effects on the liver and kidneys during chronic exposure. The French Agency for Food Safety and the Environment (ANSES) takes as a critical effect the increase in liver and kidney weight and increased serum concentrations of liver enzymes (ANSES, 2019). Furthermore, CYN should be considered a genotoxic substance, where mutagenicity cannot be excluded (BuRO, 2023).

Humpage & Falconer (2003) derived a preliminary TDI of 0.03 µg/kg bw per day. In 2019, based on a NOAEL, ANSES derived a toxicological reference value for CYN of 0.14 µg/kg bw per day (ANSES, 2019). RIVM derived a BMDL for CYN of 9.4 µg/kg body weight per day, based on clinical and histopathological effects on the liver and kidney (mice) with a LOAEL (lowest observed adverse effect level) of 75 µg/kg body weight/day (RIVM, 2020).

Iodine

Iodine occurs naturally in seawater. It enters the environment from iodine-containing rocks or through volcanic activity (EFSA NDA Panel, 2014). But human activity also causes emissions of iodine to the environment; via effluents from treatment plants (use as disinfectant and use in medical treatments) and through applications in the chemical industry (e.g. paints, batteries).

Iodine in seaweed has a function in defence mechanisms against bacteria and in protection against high light intensity during low water or dry fall. Iodine can be actively excreted by seaweed, but also accumulate to high concentrations. Especially in brown seaweeds, high concentrations can occur compared to red and green seaweeds (Faassen et al., 2022; FAO & WHO, 2022).

Iodine is absorbed from food into various organic (monoiodotyrosine and diiodotyrosine) and inorganic (iodate) forms. Inorganic iodine is reduced in the gut to iodide (I-1)and then absorbed (FAO & WHO, 2022). The availability of iodine in seaweed for uptake can vary widely between seaweed species. Percentages are reported from only 2% in fresh *Ulva*, up to 28% in fresh *Laminaria* (Van Tuinen et al., 2023) to 31-90% in brown seaweed (Hogstad et al., 2023).

Iodine deficiency can lead to stunted growth in children due to thyroid dysfunction (EFSA NDA Panel, 2014). In a 2023 report, RIVM concludes that the iodine intake of Dutch adults is just adequate. The Dutch iodine intake comes mainly from iodized salt, including processed in bread. However, Dutch health policy also focuses on a lower salt intake. A decrease in salt intake could lead to an iodine deficiency. To prevent iodine deficiencies, RIVM points to seaweed as a possible substitute iodine-rich food (De Jong et al., 2023).

Excessive intake of iodine can also lead to dysfunction of the thyroid gland (too high or too low production of thyroid hormones). The Health Council recommends a daily adequate intake of 150 µg/day for adults (Gezondheidsraad, 2018). In individuals without underlying thyroid disease, acute excessive iodine intake may result in a decrease in thyroid hormone production. Symptoms of acute iodine poisoning include fever, nausea, vomiting, diarrhoea and coma (BuRO, 2011). A 'minimal risk level' for acute oral exposure (1-14 days) of 10 µg/kg body weight per day has been derived by the Agency for Toxic Substances and Disease Registry (ATSDR) in the United States. This corresponds to EFSA derived tolerable upper limit (UL) for adults (60 kg) of 600 µg per day for chronic exposure. For 1 to 3 year olds, EFSA derived an acceptable upper limit of 200 µg per day. There is no limit for acute intake (Scientific Committee on Food & EFSA NDA Panel, 2006). These limits do not apply to people who are sensitive to high iodine intakes, such as those with conditions due to iodine deficiency, thyroid disease, low iodine intake or iodine treatment under medical supervision. For children up to 10 years of age, the intake of iodine-rich foods or supplements should be discouraged (BuRO, 2011). ANSES concluded that seaweed should not be consumed by people with thyroid disease, with heart problems or malfunctioning kidneys, by people with iodine or lithium treatment under medical supervision and not by pregnant or lactating women (ANSES, 2018). Kelp tables and other seaweed extracts are not recommended for use because of their variable and sometimes very high iodine content (Gezondheidsraad, 2008; Bath et al., 2022).

Dioxins, dibenzofurans and polychlorinated biphenyls

Polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) are substances that arise during combustion processes when the burned materials contain chlorine-containing components (e.g. PVC). But dioxins and dibenzofurans also occur in the production of chlorine-containing pesticides and in paper-bleaching processes. They are often referred to as '(total) dioxins' as a group.

Polychlorinated biphenyls (PCBs) are very stable and non-combustible substances, which were therefore added to hydraulic oils and liquids for electrical insulators and capacitors. Since 1985, the production and use of PCBs is no longer allowed in the EU (EEC Directive 85/467/EECG[13]). Since 2004, there has been a worldwide ban through the Stockholm Convention[14].

A group of 12 PCBs have similar structural and toxicological properties to dioxins. (EFSA CONTAM Panel, 2018). Dioxins and PCBs mainly adsorb to soil particles and organic matter in the environment and can thus be dispersed. They are found everywhere in the environment, including in the aquatic environment.

Dioxins and DL-PCBs are a group of different forms (congeners) that occur in different combinations but have the same toxic profile. They have both acute and chronic toxicity. Effects on the liver (functions), reproduction and development are the main effects. Dioxins, DL-PCBs are carcinogens.

Because the potential of the different dioxins and DL-PCBs for specific toxic effects differs, Toxic Equivalency Factors (TEFs) have been developed for the congeners accumulating in humans. The TEFs allow the addition of the weighted dioxin and DL-PCB levels and the determination of the Toxic Equivalent (TEQ) of the substances together. EFSA adopted a TWI (Tolerable Weekly Intake) of 2 pg WHO-TEQ/kg bw per week (0.28 pg WHO-TEQ/kg bw per day) at the end of 2018 (EFSA CONTAM Panel, 2018).

Polycyclic aromatic hydrocarbons (PAHs)

PAHs form a group with a large number of different compounds consisting of two or more fused aromatic rings. PAHs are produced by (incomplete) combustion or pyrolysis of organic matter and by industrial processes. PAHs can be introduced into the seaweed chain via the environment and can occur during food preparation (EFSA CONTAM Panel, 2008).

The most common and studied PAH is benzo(a)pyrene. EFSA concluded in 2008 that benzo(a)pyrene is not a suitable marker for the occurrence of carcinogenic PAHs in food (EFSA CONTAM Panel, 2008). The use of four or eight PAHs, respectively PAH4 and PAH8, provides a better indicator for PAHs in foods. EFSA concluded that a system with eight substances (PAH8) would not have much added value compared to a system with four substances (PAH4) (EFSA CONTAM Panel, 2008). PAH4 stands for chrysene, benzo(a)pyrene, benzo(a)anthracene and benzo(b)fluoranthene. PAH8 is PAH4 plus benzo(k)fluoranthene, benzo(g,h,i)perylene, dibenzo(a,h)anthracene and indeno(1,2,3,c,d)pyrene.

Most PAHs are carcinogenic (carcinogenic). Benzo(a)pyrene is a genotoxic carcinogen. EFSA derived a BMDL10 (the 95% lower confidence limit of the benchmark dose leading to a 10% increase in the number of laboratory animals with a tumour compared to control animals) of 0.070 mg/kg body weight per day for benzo(a)pyrene and 0.34 mg/kg body weight per day for PAH4 and for PAH8 a BMDL10 of 0.49 mg/kg body weight per day (EFSA CONTAM Panel, 2008). A MoE of 10,000 or more is used by EFSA to conclude that there is little or no concern for consumer health.

Poly- and perfluoroalkyl substances (PFAS)

PFAS is a group name for poly- and perfluoroalkyl substances. PFAS are man-made substances that do not occur naturally in the environment. More than 4000 PFAS are known (OECD, 2018). Due to their chemically and thermally stable properties and their water and dirt-repellent effect, they are used as a coating in many industrial and consumer products. Examples include upholstery fabric, outdoor and rainwear, and food packaging materials (food contact materials). Because PFAS are used in many products and as a result of industrial emissions and incidents, these substances end up in the environment in, among other things, the soil, dredging and surface water. Because of

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[13] Directive 85/467/EEC amending for the sixth time (PCBs/PCTs) Directive 76/769/EEC on the approximation of the laws, regulations and administrative provisions of the Member States relating to restrictions on the marketing and use of certain dangerous substances and preparations

[14] Stockholm Convention on Persistent Organic Pollutants, Stockholm, 22 May 2001. A treaty of the United Nations.

their stability, PFAS remain in the environment for a long time and can end up in seaweed from the surface water.

PFAS are not acutely toxic. Therefore, EFSA did not derive an ARfD. For chronic effects, EFSA derived a TWI for the sum of four PFAS (EFSA-4): perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS), perfluorononanoic acid (PFNA) and perfluorohexane sulfonic acid (PFHxS) based on immunotoxicity as the critical effect (EFSA CONTAM Panel, 2020a). Currently, these are the four PFAS that contribute the most to the levels measured in human serum.

In humans, these four PFAS have similar toxicokinetic properties, similar accumulation, and long half-lives. EFSA concluded that the effect on the immune system is the critical effect, with exposure to PFAS associated with a reduced immune response (i.e. a reduction in post-vaccination antibody production) and derived a TWI of 4.4 ng/kg body weight per week based on a reduced vaccination response in children aged 1 year. This TWI is also protective against other described health effects (such as elevated cholesterol and serum ALT concentration and reduced birth weight) (EFSA CONTAM Panel, 2020a).

EFSA based its derivation of the TWI on equipotence. However, there are probably differences in potential of the four PFAS, which are not now reflected in this TWI. EFSA indicates that there is currently insufficient data to correct this.

The TWI, based on the sum of four PFAS, raises questions regarding the application of this health-based limit value in the risk assessment. The four PFAS are not the only PFAS found in seaweed.

There are two options for dealing with the sum TWI in the risk assessment. First, assume equal toxicity (equipotency) of the PFAS (EFSA-4 or all measured PFAS). For this purpose, the individual levels of the PFAS are added up and this summed concentration is used for testing against the health-based limit value (TWI).

The second possibility is the use of relative potency factors (RPFs). RPFs represent the toxic potency of individual PFAS relative to PFOA (index substance). RIVM has currently derived an RPF based on liver effects for 23 PFAS (Bil et al., 2021; RIVM, 2021b; Bil et al., 2022; Bil et al., 2023). This is a different effect from the immune effects (the most critical effect) on which EFSA-TWI is based. With the RIVM RPFs, an individual PFAS content in seaweed can be converted into PFOA equivalents (PEQ), which are then added up for a review against the EFSA TWI.

As there is currently no consensus on the approach for calculating the sum of the PFAS levels found, BuRO will estimate exposure using both concentration addition and the RPF method in this risk assessment. For further explanations and comments, see the BuRO opinion on PFAS in eggs from private chickens (BuRO, 2024a).

(Veterinary) medicines

Residues of (veterinary) medicines can end up in surface water via effluents from sewage treatment plants or by leaching from animal manure. There are a large number of different substances: medicines such as antibiotics, painkillers and antidepressants, but also, for example, estrogens from humans and animals (Lahr et al., 2014; Moermond et al., 2020). In larger waters, such as the Eastern Scheldt, the Wadden Sea or the North Sea, concentrations will be lower due to strong dilution than in small waters such as rivers.

Plant protection products

Plant protection products are found in surface water as a result of their application in agriculture and by private individuals. In addition to the intended effect of combating the pest, the active substance of a plant protection product may also have undesirable or harmful effects. Although these effects are taken into account in the authorisation procedure of the products, adverse effects on humans and the environment may occur. The active substances do not have a necessary chemical relationship and several chemical groups can be distinguished. Due to the large variation in chemical structure between the individual active substances, the toxic effects for humans are very diverse. Possible toxic (long-term) effects of plant protection products described in the literature are: various forms of cancer, neurodegenerative diseases such as Parkinson's, amyotrophic lateral sclerosis (ALS) and Alzheimer's, respiratory, reproductive, developmental and metabolic diseases and congenital abnormalities (Gezondheidsraad, 2020).

Health based guidance values (ARfD and ADI) for European approved active substances (including those that had a European approval but are now banned) can be found in the pesticide database of the European Commission (Eurostat, 2023).

Mineral oils

Mineral oil is a collective term for thousands of hydrocarbons, the so-called MOHs (Mineral Oil Hydrocarbons). Three groups can be distinguished: paraffins, (ii) naphthenes (cycloalkanes) and (iii) aromatics. The first two classes are called MOSH (Mineral Oil Saturated Hydrocarbons) and the last group MOAH (Mineral Oil Aromatic Hydrocarbons). The exact composition depends on the origin of the mineral oil (EFSA CONTAM Panel, 2012a).

There is no clear critical effect for MOSH. Based on a NOAEL value, EFSA derived a reference point of 236 mg/kg body weight per day for a MoE approach to adverse health effects (EFSA CONTAM Panel et al., 2023).

MOAH can be mutagenic and carcinogenic depending on its composition. For the fraction with three or more aromatic rings, EFSA provides a reference point of 0.49 mg/kg body weight per day, based on an increase in tumor formation from polycylic hydrocarbon carcinogenicity studies (EFSA CONTAM Panel et al., 2023).

(Heavy) metals

(Heavy) metals occur naturally in the soil. In addition, (heavy) metals can be present as contamination in the soil after the use of fertilisers (animal manure, artificial fertilisers and the use of sewage sludge) and plant protection products or as a result of (regional) atmospheric deposition from industrial activities. The use of leaded petrol has been a major source of environmental pollution with lead in the past. The main heavy metals are arsenic, cadmium, lead and mercury. By leaching (heavy) metals enter the surface water.

Some metals are essential, and necessary for the proper functioning of seaweed, such as copper, iron and zinc. Other metals (lead, mercury, arsenic) may be toxic to seaweed at low concentrations (Moennea et al., 2016). Seaweed has several mechanisms to keep the concentrations in the cells as low as possible: from excretion from the cell to binding to the seaweed component carrageenan. Factors that influence the occurrence of metals in seaweed are: environment in which seaweed grows (salt content of the water, temperature, pH, oxygen content), seaweed species, age and condition of the seaweed (FSAI Sci. Com., 2020; Faassen et al., 2022).

Arsenic

For arsenic, two forms can be distinguished; organic arsenic and inorganic arsenic. Especially inorganic arsenic is very toxic to humans. For most organic forms there are insufficient toxicological data to derive the critical effect and associated reference point, For two organic arsenic compounds, monoethyl arsenic acid (MMA(V)) and dimethyl arsenic acid (DMA(V)), with an incomplete toxicological dataset, a MoE approach is used. EFSA gives DMA(V) a BMDL10 of 1.1 mg per kg body weight per day based on an increase in bladder tumours in rats. And states that DMA(V) is genotoxic and carcinogenic. For MMA(V), a BMDL10 of 18.2 mg per kg body weight per day is given, based on diarrhoea in rats as a critical effect (EFSA CONTAM Panel et al., 2024).

The main effects of short-term human exposure to inorganic arsenic are effects on the gastrointestinal system, haematological, dermal and neurotoxic effects. For short-term exposure to inorganic arsenic (up to 14 days), the US Agency for Toxic Substances and Disease Registry (ATSDR) has derived an oral 'minimal risk level' of 5 µg/kg body weight per day, based on a LOAEL of 0.05 mg/kg body weight per day for gastrointestinal effects in humans (ATSDR, 2007).

The main health effects associated with long-term intake of inorganic arsenic in humans are skin abnormalities, skin, lung and bladder cancer, developmental toxicity, neurotoxicity, cardiovascular disease, abnormal glucose metabolism and diabetes. There is also some evidence that inorganic arsenic negatively affects the development of the fetus and young child (EFSA CONTAM Panel, 2009a).

EFSA derived a BMDL05 of 0.06 µg/kg body weight per day as a reference point (EFSA CONTAM Panel, 2024). This BMDL05 is the relative increase of 5% in cancer incidence relative to background incidence. The BMDL05 comes from an American case-control study of skin cancer (squamous cell carcinomas). EFSA concluded that the reference point also applies to other adverse effects of long-term exposure to inorganic arsenic, such as lung and bladder cancer, skin lesions, ischaemic heart disease, chronic kidney disease, respiratory disease, spontaneous abortion, stillbirth and effects on neurological development. Because inorganic is a genotoxic carcinogen, EFSA applies a margin of exposure (MoE) approach. A MoE equal to 1 corresponds to an exposure level corresponding to a 5% relative increase in cancer incidence relative to background incidence. This is a cause for concern for consumer health. A MoE in which there is no or little cause for concern (MoE or low concern) for consumer health has not been derived by EFSA. There is no precedent that EFSA can use when identifying a MoE or low concern when using a BMDL based on human cancer incidence data (EFSA CONTAM Panel, 2024). As a result, if the MoE is less than 1, BuRO cannot rule on the potential risks to the health of the consumer.

Cadmium

Prolonged exposure to cadmium can cause kidney damage. Cadmium has been classified as a human carcinogen (category 1) by the WHO International Agency for Research on Cancer (IARC) (Nijkamp et al., 2017). The Joint Research Centre of the European Commission (JRC) concluded that there is no evidence that cadmium is carcinogenic after oral exposure but that there is strong evidence that cadmium oxide is carcinogenic after inhalation (Nijkamp et al., 2017).

EFSA concluded in 2011 (EFSA CONTAM Panel, 2011) that the TWI for oral cadmium intake of 2.5 µg/kg bw per week (0.36 µg/kg bw per day), as established on the basis of renal toxicity in 2009, should be maintained.

Mercury

Methylmercury is the most toxic and also most common form of mercury in food, and is found mainly in fish. Prolonged oral exposure to methylmercury may lead to adverse effects on neurodevelopment (EFSA CONTAM Panel, 2012b).

EFSA derived a TWI of 1.3 µg/kg bw per week (0.18 µg/kg bw per day) for methylmercury (expressed as mercury) and of 4 µg/kg bw per week (0.57 µg/kg bw per day) for inorganic mercury (EFSA CONTAM Panel, 2012b).

Lead

Lead can accumulate in the human body and cause damage to the developing nervous system. Furthermore, lead causes high blood pressure and kidney toxicity in adults.

EFSA concluded that the previously derived provisional TWI (PTWI) of 25 µg/kg body weight per week was no longer appropriate because there was no evidence for a threshold for a number of critical endpoints including neurotoxicity at the developmental stage and renal toxicity. The BMDL for neurotoxicity in the developmental phase (BMDL01) corresponds to a dose of 0.50 µg/kg body weight per day, which is used for children. For adults, where neurotoxicity no longer plays a role in the developmental phase, a BMDL10 of 0.63 µg/kg body weight per day is applied. A MoE of 10 is used (EFSA CONTAM Panel, 2010).

Nickel

Nickel is present naturally or as a result of human activity everywhere in soil, water and air. Nickel is most commonly found in food and drinking water as nickel (II). In general, total nickel is measured, without taking into account the speciation. However, organic nickel can have both different physicochemical properties and different biological properties than inorganic nickel. The speciation affects the degree of absorption of nickel from the gastrointestinal tract (EFSA CONTAM Panel, 2020b).

The main effects of nickel after short repeated oral exposures were weight loss, effects on liver, kidneys, bones and gut microbiota (rodents and dogs) and effects on reproduction (mice). No tumour formation was observed in animal carcinogenicity studies after oral exposure (EFSA CONTAM Panel, 2020b).

The critical acute effect after oral exposure to nickel is eczema reaction on the skin in nickel-sensitive individuals. A LOAEL of 4.3 µg/kg body weight per day was chosen as the reference point (EFSA CONTAM Panel, 2020b).

EFSA gave a TDI of 13 µg/kg body weight per day, the critical effect of which was the effect on reproduction (increased post-implantation loss) in rats with a BMDL10 of 1.3 mg/kg body weight per day (EFSA CONTAM Panel, 2020b).

Radioactive substances

Every day, humans are exposed to low levels of radioactive radiation from soil, space, building materials, medical examinations or air travel. The amount of natural radioactive radiation in the human body is around 120 Bq/kg, mainly due to potassium-40 and carbon-14. Thus, the average human being is a radioactive source of approximately 8500 Bq (Aristoteles Consulting, 2023).

As a result of a radiation accident, radioactive substances can enter the environment in increased concentrations, such as after the accident at the Fukushima nuclear power plant. The main effect of radioactive radiation is the damage that can be done to the DNA, resulting in an increased risk of cancer. Radiation sickness occurs at extremely high doses that can lead to death after a number of weeks (RIVM, 2021c).

Regulation (Euratom) 2016/52[15] sets maximum permitted levels of radioactive contamination in foodstuffs in Bq/kg, as follows:

- Total strontium isotopes, in particular Sr-90: 750 Bq/kg.
- Total iodine isotopes, in particular I-131: 2000 Bq/kg.
- Total alpha-radiation isotopes of plutonium and transplutonium elements, in particular Pu-239 and Am-241: 80 Bq/kg.
- Total all other nuclides with a half-life of more than 10 days: 1250 Bq/kg.

For imports of foods originating in or consigned from Japan, following the accident at the Fukushima nuclear power plant, the maximum concentration for total caesium 134 and caesium-137 for most foods was 100 Bq/kg (Implementing Regulation (EU) No 322/2014[16]). That implementing regulation was valid until 8 January 2016.

4.5.2.3 *Exposure assessment*

Fresh unprocessed seaweed from Dutch seaweed farms

To gain insight into the occurrence of chemical contaminants in seaweed grown in the Netherlands, WFSR sampled seaweed at seaweed farms in the Eastern Scheldt estuary, Wadden Sea and North Sea in 2018, 2019 and 2020. In addition, seaweed was also sampled in land-based basins receiving seawater via a pipeline (Faassen et al., 2022). The most widely grown seaweed species in the Netherlands are sea lettuce (*Ulva* spp.) and sugar kelp (*Saccharina latissima*) (Faassen et al., 2022). There are alien sea lettuce species. It is not known which *Ulva* species have been analysed. Sugar kelp is a native species in the Netherlands (Gittenberger et al., 2020b). Only a few samples of other species of seaweed have been taken, therefore the risk assessment is based on the study on *Ulva* spp. and *Saccharina latissima*, abbreviated to sea lettuce and sugar kelp .

Sea lettuce is seaweed that grows in summer (May-October). Several harvests are possible per season. Sugar kelp is a seaweed that grows in winter (November-June) and is harvested in spring. For both species, samples were taken at different locations at different points in the seaweed bed during the growing season to track contaminant levels over time (Faassen et al., 2022).

Not all seaweed currently grown is used for consumption. A part is used for research which may cause different growing conditions and influence the contaminant concentration. For the exposure assessment, no distinction was made between cultivated seaweed for research purposes or consumption.

The following contaminants have been analysed in the seaweed samples: iodine, mercury, lead, cadmium, arsenic, nickel, dioxins, PCBs, PAHs, PFAS, mineral oils, plant protection products, radioactivity and algae toxins (see also Table 9). A total of 122 samples were taken and analysed (51 sea lettuce and 71 sugar kelp). Due to the small number of samples per sampling site and per sampling period, no subdivision in location and growing season of the samples shall be made.

The study covered two growing seasons per seaweed species. All 122 samples from the study were analysed for the presence of iodine, total arsenic, lead, mercury and cadmium. When the total

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[15] Regulation (Euratom) 2016/52 laying down maximum permitted levels of radioactive contamination of food and feed following a nuclear accident or any other case of radiological emergency and repealing Regulation (Euratom) No 3954/87 and Commission Regulations (Euratom) No 944/89 and (Euratom) No 770/90

[16] Implementing Regulation (EU) No 322/2014 imposing special conditions governing the import of feed and food originating in or consigned from Japan following the accident at the Fukushima nuclear power station

arsenic content was greater than 0.1 mg/kg wet weight, the inorganic arsenic content was also determined. The samples from the second growing season (22 sea lettuce and 38 sugar kelp) were also analysed for the presence of nickel. In addition, some of the samples from both growing seasons (16 sea lettuce and 13 sugar kelp) analysed for the presence of dioxins, dioxin-like PCBs (DL-PCBs) and non-dioxin-like PCBs (NDL-PCBs), PAHs, PFAS, mineral oils, algae toxins, plant protection products and radioactivity.

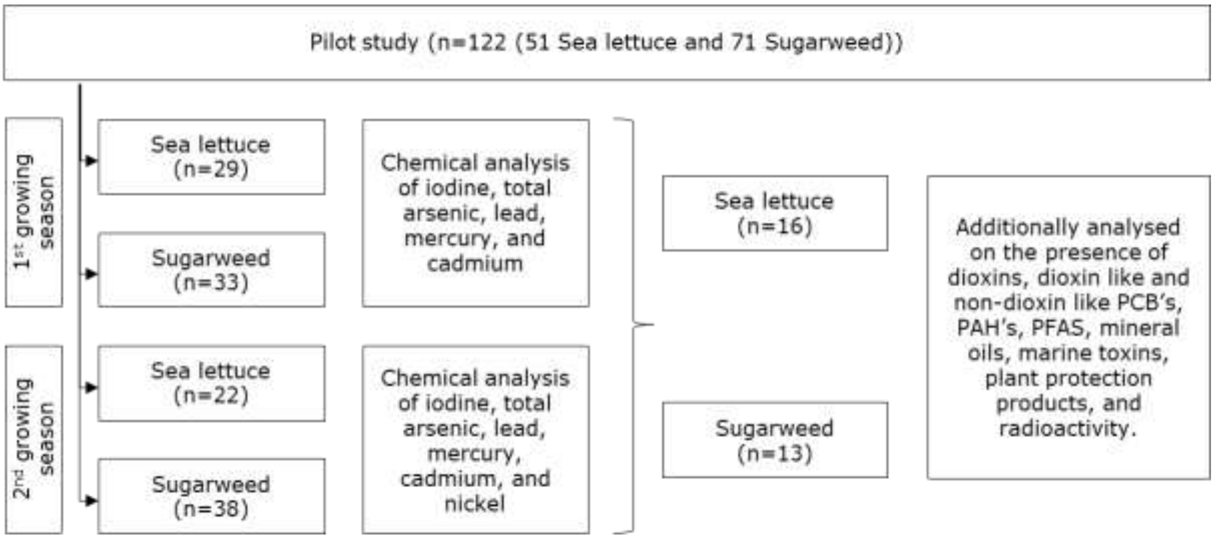

Figure 6 An overview of the number of samples analysed and the associated substances on which these samples were analysed.

Annex IV provides an overview of the individually analysed dioxins, DL-PCBs and NDL-PCBs. The selection of these samples was made on the basis of the widest possible representation of both types of seaweed, harvesting/cultivation techniques, locations and harvesting moments. Figure 6 gives an overview of the number of samples analysed and the associated substances on which these samples were analysed. Due to the relevance of and current concerns about PFAS compounds as widespread environmental contaminants, a method of analysis for seaweed has been developed and validated for these substances. As a result, the analyses of the PFAS compounds took place at a later date (2023) in the preserved original seaweed samples (14 seaweed and 12 sugar kelp) (Krätschmer, 2024). The individual PFAS are described by an abbreviation. The list of abbreviations and full names can be found in Annex V.

Contaminants in fresh unprocessed seaweed

Table 11 gives an overview of the number of samples analysed and the number of samples with a value below the quantification limit (LOQ) for the substances detected in sea lettuce and sugar kelp. For details on the LOQ, see Annex VI. In two samples of sea lettuce, the algae toxins cylindrospermopsin and 7-epi-cylindrospermopsin were detected but the concentration of these substances could not be determined. No algae toxins were found in the sugar kelp samples. Mineral oils, plant protection products and radioactivity were not found in any of the samples analysed.

In the PFAS analyses, the following individual PFAS were analysed: PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFTrDA, PFTeDA, PFBS, PFHxS, PFHpS, PFOS, PFDS, GenX, NaDONA, 9Cl-PF3ONS. It was not possible to determine PFBA, PFPeA, PFHxDA, PFODA, PFOSA and 11Cl-PF3OUdS.

For the individual PFAS found, Table 10 summarises the number of samples analysed and the number of samples measured below the quantification limit (LOQ) measured in sea lettuce and sugar kelp. PFOS has been found in almost all samples of sea lettuce and in all samples of sugar kelp in concentrations greater than the LOQ. For details on the LOQ, see Annex VI.

For a number of substances, the analytical result was below the quantification limit (Table 11, Table 10). In order to take this into account in the risk assessment, BuRO used two calculation methods for the exposure levels (P50 and P95), namely lower bound (LB) and upper bound (UB). When using LB, the reported levels <LOQs are replaced by the value 0 and at UB the reported levels

<LOQ are replaced by the corresponding LOQs. The results with LB and UB are the same if there are no or relatively few analytical results for a substance that are smaller than the LOQ.

Table 10 An overview of the number of samples analysed and the number of samples smaller than the quantification limit (LOQ) for the individual PFAS found in sea lettuce and sugar kelp.

Individual PFAS*	Sea lettuce		Sugar kelp	
	Samples analysed (N)	Samples <LOQ (N)	Samples analysed (N)	Samples <LOQ (N)
PFHxA	14	14	12	12
PFHpA	14	12	12	9
PFOA	14	14	12	12
PFNA	14	6	12	9
PFDA	14	5	12	9
PFUnDA	14	6	12	10
PFDoDA	14	8	12	10
PFTrDA	14	11	12	11
PFTeDA	14	14	12	11
PFBS	14	14	12	12
PFHxS	14	14	12	11
PFHpS	14	14	12	12
PFOS	14	2	12	0
PFDS	14	14	12	12
GenX	14	14	12	12
NaDONA	14	14	12	12
9Cl-PF3ONS	14	14	12	12

* See Annex V for the explanations of the abbreviations.

Table 11 An overview of the number of samples analysed and the number of samples below the quantification limit (LOQ) for the substances found in sea lettuce and sugar kelp. The LOQ has been estimated by correcting the wet LOQ for the moisture content of the sample (Faassen et al., 2022).

Substance	Sea lettuce		Sugar kelp	
	Samples analysed (N)	Samples <LOQ (N)	Samples analysed (N)	Samples <LOQ (N)
Iodine	51	0	71	0
Cadmium	51	10	71	28
Mercury	51	26	71	45
Lead	51	11	71	4
Nickel	22	0	38	3
Total arsenic	51	5	71	0
Inorganic arsenic	41	13	70	33
Total dioxins	16	0*	13	0*
Total DL PCBs	16	0*	13	0*
Total NDL PCBs	16	1	13	2
Benzo(a)anthracene	16	4	13	5
Chrysene	16	4	13	4
Benzo(b)fluoranthene	16	4	13	4
Benzo(a)pyrene	16	4	13	4

* This is based on the total content of the dioxins analysed; individual dioxins or DL-PCBs (see Annex IV) may be below the LOQ.

Table 12 Overview of the P50 and P95 concentration (mg/kg) of iodine and the different metals found in the studied seaweeds sea lettuce and sugar kelp.

Substance	Sea lettuce				Sugar kelp			
	Wet seaweed		Dry seaweed		Wet seaweed		Dry seaweed	
	LB	UB	LB	UB	LB	UB	LB	UB
	P50 concentration (mg/kg)							
Iodine	6.2	6.2	27	27	560	560	3483	3483
Cadmium	0.0075	0.011	0.038	0.049	0.019	0.021	0.12	0.14
Lead	0.26	0.26	1.3	1.3	0.29	0.29	1.8	1.8
Mercury	0	0.0047	0	0.028	0	0.015	0	0.091
Nickel	0.59	0.59	2.7	2.7	0.48	0.48	3.2	3.2
Inorganic arsenic	0.11	0.11	0.46	0.53	0.12	0.12	0.78	0.83
	P95 concentration (mg/kg)							
Iodine	31	31	161	161	1150	1150	6925	6925
Cadmium	0.022	0.066	0.089	0.31	0.049	0.066	0.24	0.39
Lead	1.65	1.65	6.4	6.4	1.3	1.3	6.9	6.9
Mercury	0.016	0.016	0.041	0.048	0.018	0.018	0.11	0.12
Nickel	1.5	1.5	6.0	6.0	1.8	1.8	12	12
Inorganic arsenic	0.28	0.28	1.3	1.3	0.39	0.39	2.08	2.08

For the exposure calculation of PFAS, only LB-based calculations were performed. The PFAS results show that levels below the LOQ are reported in a relatively large number of samples (Table 10). An UB-based calculation gives fictitious PFAS levels as levels of undetected PFAS are based on the quantification limit of the analytical method. The sum of the individual PFAS levels used in the risk characterization is therefore determined to a large extent by the level of the PFAS analysed below the quantification limit. Upper bound levels are therefore not realistic for the risk assessment and only show the uncertainty that PFAS levels below the LOQ can maximally introduce.

The total PFAS content in sea lettuce and sugar kelp has been calculated in four ways:

1. The sum EFSA-4 (based on equipotency)
2. The sum EFSA-4 (based on relative potency)
3. The sum of all measured PFAS (based on equipotency)
4. The sum of all measured PFAS (based on relative potency).

Table 13 Overview of P50 and P95 levels of total dioxins + total DL-PCBs (ng WHO(2005)-PCB-TEQ/kg) and the sum of PAH4 (µg/kg) found in the studied seaweeds sea lettuce and sugar kelp.

Substance	Sea lettuce				Sugar kelp			
	Wet seaweed		Dry seaweed		Wet seaweed		Dry seaweed	
	LB	UB	LB	UB	LB	UB	LB	UB
	P50 concentration (ng WHO(2005)-PCDD/F-TEQ/kg))							
Total dioxins + DL-PCBs	0.046	0.073	0.16	0.32	0.021	0.071	0.14	0.41
	P50 concentration (µg/kg)							
Sum PAH4	0.82	0.82	4.0	4.0	1.03	1.03	4.7	4.7
	P95 concentration (ng WHO(2005)-PCDD/F-TEQ/kg))							
Total dioxins + DL-PCBs	0.13	0.20	0.61	0.99	0.18	0.21	0.96	1.2
	P95 concentration (µg/kg)							
Sum PAH4	3.8	3.8	16	16	7.9	7.9	44	44

In calculating the sum of EFSA-4 and the sum of all measured PFAS, both based on relative potency, BuRO used RPFs as proposed by RIVM (Bil et al., 2021; RIVM, 2021b) (Annex VII).

Table 12, Table 13 and Table 14 provide an overview of the P50 and P95 levels of iodine and the other contaminants found in the studied seaweeds sea lettuce and sugar kelp. As no health based guidance value is available for total NDL-PCBs, it has not been included in the calculations.

All levels are calculated for both wet and dry seaweed. The basis for these calculations was the levels analysed by WFSR in both wet and dry seaweed. In its report, WFSR expressed all analysis results in dry weight. Where analyses have been carried out on wet samples, the dry weight levels have been calculated by correcting for the moisture content of the sample (Faassen et al., 2022).

Annex VIII contains three tables showing, in addition to the P50 and P95 levels, a mean, minimum and maximum level of iodine, the different metals and other contaminants.

The total PFAS levels in sea lettuce and in sugar kelp are calculated and presented in Annex VIII in four ways. Table 14 summarises the total PFAS levels calculated according to Method 1 (sum of EFSA-4 based on equipotency) and Method 4 (sum of all measured PFAS based on relative potency). The results of these two methods are

shown because method 1 allows a direct comparison with the TWI and because method 4 considers all measured PFAS. Methods 2 and 3 are a combination of method 1 and method 4 and are set out in the Annex for readability.

Table 14 The total PFAS levels calculated by BuRO (ng PFAS/kg or ng PEQ/kg for the calculations based on RPFs) in the studied seaweeds sea lettuce and sugar kelp. The P50 and P95 levels are calculated on the basis of a lower bound scenario. Two different methods have been used to add the individual PFAS levels; sum of EFSA-4 based on equipotency and sum of all measured PFAS based on RPFs.

PFAS	Sea lettuce		Sugar kelp	
	Wet seaweed	Dry seaweed	Wet seaweed	Dry seaweed
	P50 concentration			
Sum EFSA-4 (ng PFAS/kg)	161	211	35	1,505
Sum all measured PFAS (ng PEQ/kg)	825	3,373	80	4,615
	P95 concentration			
Sum EFSA-4 (ng PFAS/kg)	619	3,804	270	2,280
Sum all measured PFAS (ng PEQ/kg)	2,480	14,489	1,400	9,830

Processing of seaweed

The number of studies in the literature on the effects of seaweed processing on the presence of iodine or metals has increased (strongly) in recent years. Washing/rinsing, soaking and/or cooking can lead to a decrease in iodine (60 – 80%) (FAO & WHO, 2022). The extent to which iodine or metal levels decrease after rehydration or cooking depends on the type of seaweed (Correia et al., 2021). Blanching and then fermenting *S. latissima* led to an 81% decrease in iodine levels (Banach et al., 2024). Blanching in water (80 °C for 120 seconds) of *S. latissima* led to a 94% decrease in iodine content (Nielsen et al., 2020). Rinsing (three times) and soaking (15 min) of *S. latissima* led to a similar decrease (85%) in iodine levels (Blikra et al., 2021).

Washing and soaking seaweed can reduce total arsenic levels by up to 60% of the original content (FAO & WHO, 2022). Heating in water (90 °C) can reduce the arsenic content by up to 80%. When this treatment was followed by soaking (20 minutes) in water with 2% sodium chloride (NaCl, table salt), the arsenic content decreased further by 5 to 20% (Park et al., 2019). Blanching and then fermenting *S. latissima* led to a 46% decrease in the total arsenic content (Banach et al., 2024). Rinsing (three times) and soaking (15 min) of *S. latissima* resulted in a 43% decrease in total arsenic content (Blikra et al., 2021).

Cadmium, chromium and lead can be removed by immersion of fresh algae (genera *Porphyra* and *Pyropia*) in an acid solution (pH 2,5-4,0) for 20 minutes. The presence of lead, mercury and cadmium in processed algae (roasted or seasoned) may be reduced by cooking (Cho & Rhee, 2020). After blanching, the cadmium content did not decrease. If blanching was followed by fermentation, cadmium levels decreased by 35% (Banach et al., 2024). By contrast, blanching and then fermentation led to an increase in the content of copper and zinc (Banach et al., 2024).

WFSR conducted two studies looking at the effect of different processing steps on the presence of iodine and a number of heavy metals in sea lettuce and sugar kelp (Van Tuinen et al., 2023) and sugar kelp (Gsell et al., 2025) from Dutch seaweed farms. Factors that may reduce levels include washing fresh seaweed in ample amounts of freshwater and rehydrating dry seaweed with ample amounts of hot to boiling water. By contrast, drying fresh seaweed increases the contaminant levels in the dried product (Van Tuinen et al., 2023). When sugar kelp was washed with artificial seawater at 60 °C, iodine and arsenic levels decreased. The addition of an additional processing step did not contribute (iodine) or hardly (arsenic) to further reductions in the levels. Copper and, to a lesser extent, mercury content increased after applying a second wash/rehydration step with tap water. The researchers recommend that more research needs be done into the use of washing water with different salinity levels. Lead levels were not affected by the processing steps examined (Gsell et al., 2025).

The above results indicate that various processing steps can contribute to the decrease of (heavy) metals and iodine in seaweed. The degree of the decrease varies. It should be borne in mind that this may not apply to all (heavy) metals and that the decrease depends on, among other things, the type of seaweed and the (combination of) processing steps. Therefore, this risk assessment by BuRO does not include the possible decreases of (heavy) metals and iodine due to processing steps. It has been assumed in the calculation of the risk that all (heavy) metals and iodine in the seaweed are also available for absorption; a worst-case scenario.

No information has been found in the literature on the influence of processing steps on the presence of PFAS in seaweed.

Exposure assessment

In the exposure assessment, the exposure was calculated for 18- to 80-year-olds on the basis of the consumption quantities as defined in the RIVM consumption study (see section 3.4.2) (Dinnissen et al., 2020). The exposure assessment was carried out in two steps (Figure 7). The consumption data of 1 to 17-year-old seaweed users in this study are based on a small number of consumers. As a result, these data are not representative and are therefore not used for the exposure estimate. Alternatively, BuRO calculated the maximum safe consumption of seaweed by toddlers (1- to 3-year-olds; 12 kg) to make a rough estimate of potential risks for children.

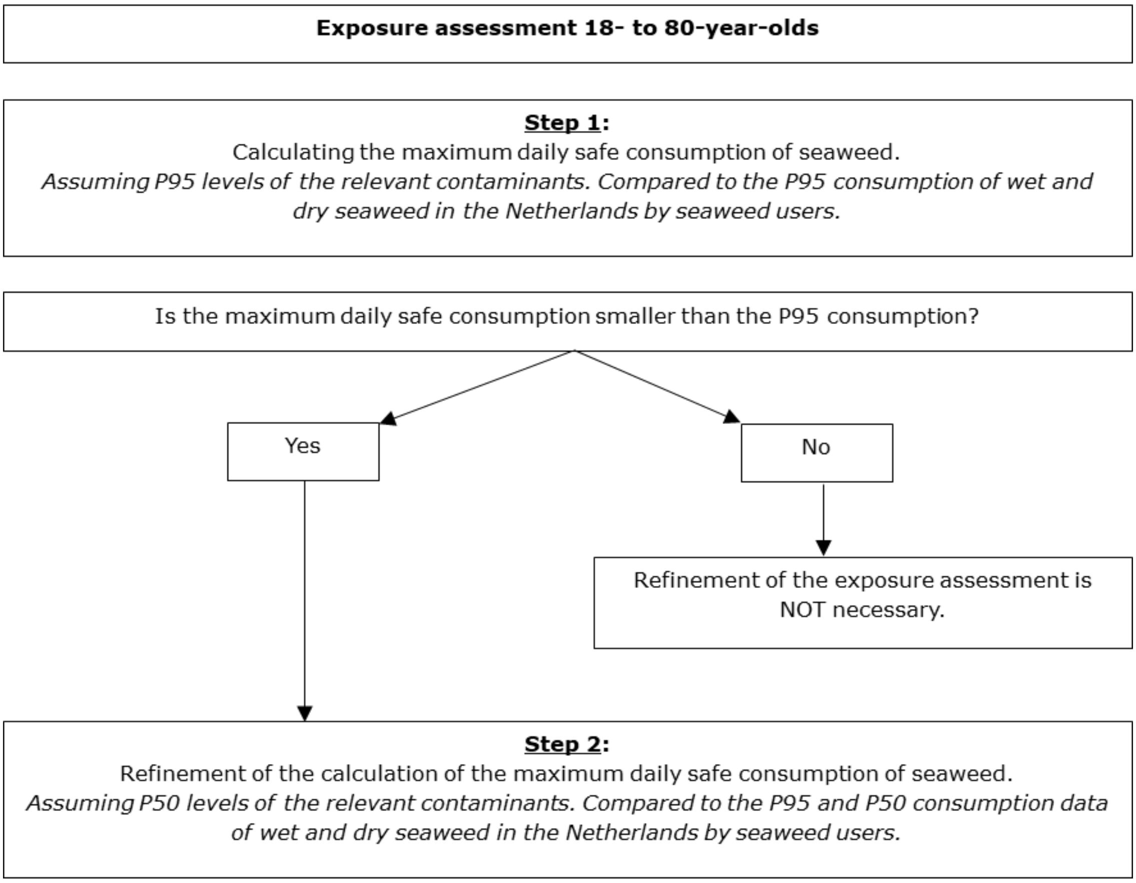

Figure 7 Summary of the steps taken in the exposure assessment for 18- to 80-year-olds.

Maximum safe consumption of seaweed
First of all was calculated, based on the P95 levels of the contaminants in Table 12, Table 13 and Table 14, how much wet and dry seaweed 1- to 3-year-olds (12 kg) and 18 to 80-year-olds (60 kg) may consume per day before the relevant health based guidance values are exceeded. Results for iodine, cadmium, mercury, lead, nickel and inorganic arsenic are shown in Table 15. The results for total dioxins + DL-PCBs and sum PAH4 are presented in Table 16 and the results for PFAS are presented in Table 17. Subsequently, the results were compared with the P95 consumption of wet and dry seaweed in the Netherlands.

The P95 consumption of wet seaweed in the Netherlands by seaweed users (18 to 80-year-olds) is estimated by RIVM at 93.3 grams per day, with a 95% confidence interval of 25.1 − 161.4 grams per day. This corresponds to a daily consumption of 13.3 grams of dry seaweed (P95), with a 95% confidence interval of 3.6 − 23.1 grams per day (Table 3) (Dinnissen et al., 2020). P95 consumption is influenced by the measurements of individuals with extreme consumption reporting. This is an overestimation of consumption, a worst-case consumption. In Table 15, Table 16 and Table 17, the maximum quantities of seaweed below the upper limit of the 95% confidence interval of P95 consumption are indicated in bold (i.e. <161.4 grams per day and <23.1 grams per day, respectively for wet and dry seaweed). These values indicate a potential health risk because the maximum safe intake for an adult is lower than a realistic amount of consumption. For 1- to 3-year-olds this indication cannot be given due to the lack of reliable consumption data for this group.

Annex IX provides an overview of the maximum daily safe consumption of the examined seaweeds sea lettuce and sugar kelp before the health based guidance value for PFAS is exceeded for all four methods used to calculate the total PFAS content.

Based on the calculated maximum daily safe consumption of seaweed (Table 15, Table 16, Table 17), BuRO concludes that 18- to 80-year-olds can consume (very) large amounts of the studied wet or dry seaweed (both sea lettuce and sugar kelp) before exceeding the health based guidance values for cadmium, mercury, nickel and the sum of PAH4. The intake of these contaminants from other sources has not been taken into account. BuRO considers it unlikely that these maximum safe amounts are eaten daily by a consumer, as they are above the upper limit of the 95% confidence interval of P95 consumption (values not indicated in bold in Table 15, Table 16, Table 17). For toddlers (1- to 3-year-olds) no consumption data are available so that no comparison can be made with the calculated maximum safe consumption. However, the picture for toddlers seems to be similar to that of adults for these contaminants based on the estimates: the portions are so large that it is unlikely that they are eaten daily by toddlers. Therefore, the degree of presence of the contaminants mentioned in the seaweed under investigation does not pose a risk to the health of consumers (both toddlers and adults). This does not apply to the consumption of seaweed with respect to iodine, lead, inorganic arsenic, dioxins (total dioxins + DL-PCBs) and PFAS. Maximum safe consumption is below the upper limit of the 95% confidence interval of P95 consumption of 18- to 80-year-olds (values in bold in Table 15, Table 16, Table 17). This calculation of maximum safe consumption is based on P95 concentration data and then compared to P95 consumption data, this is a worst-case scenario. Refinement to a more realistic exposure scenario is necessary to better assess any risks related to exposure to iodine, lead, inorganic arsenic, dioxins (total dioxins + DL-PCBs) and PFAS. This refinement is elaborated below.

Table 15 The maximum daily safe consumption of the studied seaweeds sea lettuce and sugar kelp before the health based guidance values of iodine, cadmium, mercury, lead, nickel, and inorganic arsenic are exceeded by 1- to 3-year-olds (12 kg) and 18- to 80-year-olds (60 kg). Values printed in bold: the calculated maximum daily safe consumption is lower than the upper limit of high consumption (95% confidence interval of P95 consumption; i.e. <161.4 grams per day and <23.1 grams per day, respectively for wet and dry seaweed). Exposure from other sources has not been taken into account.

Seaweed		Substance	Health based guidance value (µg/kg body weight per day)	P95 concentration (mg/kg)		Maximum daily safe consumption (g/day)			
						1- to 3-year-olds		18- to 80-year-olds	
				LB	UB	LB	UB	LB	UB
Sea lettuce	Wet	Iodine	17 (toddlers)[a] 10 (adults)[b]	31	31	6.5	6.5	19	19
		Cadmium	0.36[c]	0.022	0.066	196	65	982	327
		Mercury	0.18[d]	0.016	0.016	135	135	675	675
		Lead	0.06[e]	1.7	1.7	0.42	0.42	2.1	2.1
		Nickel	13	1.5	1.5	104	104	520	520
		Inorganic arsenic	0.06[f]	0.28	0.28	3	3	13	13
	Dry	Iodine	17 (toddlers) 10 (adults)	161	161	1.2	1.2	3,7	3,7
		Cadmium	0.36	0.089	0.31	49	14	243	70
		Mercury	0.18	0.041	0.048	53	45	263	225
		Lead	0.06	6.4	6.4	0.11	0.11	0.56	0.56
		Nickel	13	6.0	6.0	26	26	130	130
		Inorganic arsenic	0.06	1.3	1.3	0.6	0.6	3	3
Sugar kelp	Wet	Iodine	17 (toddlers) 10 (adults)	1150	1150	0.17	0.17	0.52	0.52
		Cadmium	0.36	0.049	0.066	88	65	441	327
		Mercury	0.18	0.018	0.018	120	120	600	600
		Lead	0.06	1.3	1.3	0.55	0.55	2.8	2.8
		Nickel	13	1.8	1.8	87	87	433	433
		Inorganic arsenic	0.06	0.39	0.39	1.8	1.8	9	9
	Dry	Iodine	17 (toddlers) 10 (adults)	6925	6925	0.029	0.029	0.087	0.087
		Cadmium	0.36	0.24	0.39	18	11	90	55
		Mercury	0.18	0.11	0.12	20	18	98	90
		Lead	0.06	6.9	6.9	0.1	0.1	0.52	0.52
		Nickel	13	12	12	13	13	65	65
		Inorganic arsenic	0.06	2.08	2.08	0.3	0.3	1.7	1.7

[a] For toddlers (1- to 3-year-olds), the health based guidance value for iodine is based on a tolerable upper level of 200 µg/day and a body weight of 12 kg.

[b] For adults, the health based guidance value for iodine is based on a tolerable upper level of 600 µg/day and a body weight of 60 kg.

[c] The health based guidance value of cadmium is based on a TWI of 2.5 µg/kg body weight per week.

[d] The health based guidance value of mercury is based on a TWI of 1.3 µg/kg body weight per week.

[e] Applying a factor of 10 (MoE) to a BMDL_{10} of 0.63 µg lead/kg body weight per day results in a health guidance value of 0.06 µg lead/kg body weight per day.

[f] Applying a factor 1 (MoE) to a $\text{BMDL}_{0.5}$ of 0.06 µg inorganic arsenic/kg body weight per day results in a health based guidance value of 0.06 µg inorganic arsenic/kg body weight per day.

Table 16 The maximum daily safe consumption of the studied seaweeds sea lettuce and sugar kelp before the health based guidance value of dioxins and PAH4 are exceeded by 1- to 3-year-olds (12 kg) and 18- to 80-year-olds (60 kg). Values printed in bold: the calculated maximum daily safe consumption is lower than the upper limit of high consumption (95% confidence interval of P95 consumption; i.e. <161.4 grams per day and <23.1 grams per day, respectively for wet and dry seaweed). Exposure from other sources has not been taken into account.

Seaweed		Substance	Health based guidance value (µg/kg body weight per day)	P95 concentration (µg/kg)		Maximum daily safe consumption (g/day)			
						1- to 3-year-olds		18- to 80-year-olds	
				LB	UB	LB	UB	LB	UB
Sea lettuce	Wet	Total dioxins + DL-PCBs	0.00000028[a]	0.00013	0.000204	26	17	129	84
		Sum PAH4	0.034[b]	3.8	3.8	108	108	537	537
	Dry	Total dioxins + DL-PCBs	0.00000028	0.00061	0.00099	5.5	3.4	28	17
		Sum PAH4	0.034	15.7	15.7	27	27	136	136
Sugar kelp	Wet	Total dioxins + DL-PCBs	0.00000028	0.00018	0.00021	19	16	93	80
		Sum PAH4	0.034	7.9	7.9	52	52	258	258
	Dry	Total dioxins + DL-PCBs	0.00000028	0.00096	0.0012	3.5	2.8	18	14
		Sum PAH4	0.034	44	44	9.3	9.3	46	46

[a] The health based guidance value (TDI) for total dioxins + DL-PCBs is based on a TWI of 2 pg WHO-TEQ/kg body weight per week.

[b] Applying a factor of 10,000 (MoE) to a $BMDL_{10}$ of 0.34 mg sum PAH4/kg body weight per day results in a health based guidance value of 0.034 µg sum PAH4/kg body weight per day.

Intake of iodine, lead, arsenic, dioxins and PFAS

In Table 18, Table 19 and Table 20 the intake of contaminants by 18- to 80-year-olds through the consumption of the studied wet or dry seaweed were calculated for iodine, lead, inorganic arsenic, dioxins (total dioxins + DL-PCBs) and PFAS . For this purpose, the P50 levels (Table 12, Table 13, Table 14) and the P50 and P95 consumption data as reported by RIVM (Table 3) (Dinnissen et al., 2020) were used. With regard to the contaminant levels in seaweed, a realistic scenario has been chosen (P50 levels), because it is unlikely that most consumers in the Netherlands consume seaweed grown with (very) high concentrations of iodine, metals or other contaminants for an extended period of time (chronic exposure). With regard to consumption data, two scenarios were used: worst-case scenario ((P95 consumption); consumers consuming large quantities) and a more realistic scenario (P50 consumption).

Table 17 The maximum daily safe consumption of the studied seaweeds sea lettuce and sugar kelp before the health based guidance value for PFAS is exceeded by 1- to 3-year-olds (12 kg) and 18- to 80-year-olds (60 kg). Values printed in bold: the calculated maximum daily safe consumption is lower than the upper limit of high consumption (95% confidence interval of P95 consumption; i.e. <161.4 grams per day and <23.1 grams per day, respectively for wet and dry seaweed). Exposure from other sources has not been taken into account.

Seaweed		Substance	Health based guidance value (ng/kg body weight per day)	P95 concentration	Maximum daily safe consumption (g/day)	
					1- to 3-year-olds	18- to 80-year-olds
Sea lettuce	Wet	Sum EFSA-4 (ng PFAS/kg)	0.63[a]	619	12	61
		Sum all measured PFAS (ng PEQ/kg)		2,480	3	15
	Dry	Sum EFSA-4 (ng PFAS/kg)		3,804	2	10
		Sum all measured PFAS (ng PEQ/kg)		14,489	1	3
Sugar kelp	Wet	Sum EFSA-4 (ng PFAS/kg)		270	28	140
		Sum all measured PFAS (ng PEQ/kg)		1,400	5	27
	Dry	Sum EFSA-4 (ng PFAS/kg)		2,280	3	17
		Sum all measured PFAS (ng PEQ/kg)		9,830	1	4

[a] The health based guidance value (TDI) of PFAS is based on a TWI of 4.4 ng/kg body weight per week.

Table 18 The intake (µg/kg body weight/day) of iodine, lead and inorganic arsenic of 18- to 80-year-olds (60 kg) by P50 and P95 consumption (seaweed users) of the studied wet and dry seaweed (both sea lettuce and sugar kelp).

Seaweed		Substance	P50 concentration (mg/kg)		Intake (µg/kg body weight/day)				Health based guidance value (µg/kg body weight per day)
					P50 consumption		P95 consumption		
			LB	UB	LB	UB	LB	UB	
Sea lettuce	Wet	Iodine	6.2	6.2	0.34	0.34	9.6	9.6	10[a]
		Lead	0.26	0.26	0.014	0.014	0.404	0.404	0.06[b]
		Inorganic arsenic	0.11	0.11	0.0061	0.0061	0.17	0.17	0.06[c]
	Dry	Iodine	27	27	0.23	0.23	6.0	6.0	10
		Lead	1.3	1.3	0.011	0.011	0.29	0.29	0.06
		Inorganic arsenic	0.46	0.53	0.0038	0.0044	0.102	0.12	0.06
Sugar kelp	Wet	Iodine	560	560	31	31	871	871	10
		Lead	0.29	0.29	0.016	0.016	0.45	0.45	0.06
		Inorganic arsenic	0.12	0.12	0.0066	0.0066	0.19	0.19	0.06
	Dry	Iodine	3483	3483	29	29	772	772	10
		Lead	1.8	1.8	0.015	0.015	0.40	0.40	0.06
		Inorganic arsenic	0.78	0.83	0.0065	0.0069	0.17	0.18	0.06

[a] For adults, the health based guidance value for iodine is based on a tolerable upper level of 600 µg/day and a body weight of 60 kg.

[b] Applying a factor of 10 (MoE) to a $BMDL_{10}$ of 0.63 µg lead/kg body weight per day results in a health based guidance value of 0.06 µg lead/kg body weight per day.

[c] Applying a factor 1 (MoE) to a $BMDL_{0.5}$ of 0.06 µg inorganic arsenic/kg body weight per day results in a health based guidance value of 0.06 µg inorganic arsenic/kg body weight per day.

Table 19 The intake (pg/kg body weight/day) of dioxins (total dioxins + DL-PCBs) of 18- to 80-year-olds (60 kg) by P50 and P95 consumption (seaweed users) of the studied wet and dry seaweed (both sea lettuce and sugar kelp).

Seaweed		Substance	P50 concentration (ng WHO(2005)-PCB-TEQ/kg)		Intake (pg/kg body weight/day)				Health based guidance value (pg WHO-TEQ/kg body weight per day)
					P50 consumption		P95 consumption		
			LB	UB	LB	UB	LB	UB	
Sea lettuce	Wet	Total dioxins + DL-PCBs	0.046	0.073	0.0025	0.0040	0.072	0.11	0.28[a]
	Dry		0.16	0.32	0.013	0.0027	0.035	0.071	
Sugar kelp	Wet		0.021	0.0705	0.0012	0.0039	0.033	0.11	
	Dry		0.14	0.41	0.0012	0.0034	0.031	0.091	

[a] The health based guidance value (TDI) for total dioxins + DL-PCBs is based on a TWI of 2 pg WHO-TEQ/kg body weight per week.

Table 20 The intake (ng PFAS/kg body weight/day or ng PEQ/kg body weight/day for RPF calculations) of PFAS of 18- to 80-year-olds (60 kg) by P50 and P95 consumption (seaweed users) of the studied wet and dry seaweed (both sea lettuce and sugar kelp).

Seaweed		Substance	P50 concentration	Intake (ng PFAS/kg body weight/day or ng PEQ/kg body weight/day)		Health based guidance value (µg/kg body weight per day)
				P50 consumption	P95 consumption	
Sea lettuce	Wet	Sum EFSA-4 (ng PFAS/kg)	161	0.0089	0.25	0.63[a]
		Sum all measured PFAS (ng PEQ/kg)	825	0.045	1.3	
	Dry	Sum EFSA-4 (ng PFAS/kg)	211	0.0018	0.047	
		Sum all measured PFAS (ng PEQ/kg)	3373	0.028	0.75	
Kelp weed	Wet	Sum EFSA-4 (ng PFAS/kg)	35	0.0019	0.055	
		Sum all measured PFAS (ng PEQ/kg)	80	0.0044	0.12	
	Dry	Sum EFSA-4 (ng PFAS/kg)	1505	0.013	0.33	
		Sum all measured PFAS (ng PEQ/kg)	4615	0.038	1.02	

[a] The health based guidance value (TDI) of PFAS is based on a TWI of 4.4 ng/kg body weight per week.

Annex X provides an overview of the PFAS intake via P50 and P95 consumption of the studied wet and dry seaweed for all four methods used to calculate the total PFAS content. Table 21, Table 22 and Table 23 then calculate the ratio between the daily intake of iodine, lead, inorganic arsenic, dioxins and PFAS and the maximum safe intake (i.e. the health based guidance value) from the consumption of the studied seaweed. If the ratio is greater than 1, this means that the intake is greater than the health based guidance value and that daily intake of the various contaminants due to the consumption of the studied seaweed for a longer period of time may lead to health risks. In the tables, these values are indicated in bold. The intake of these contaminants from other sources has not been taken into account.

Table 21 The ratio of daily intake (μg/kg body weight/day) of iodine, lead and inorganic arsenic from 18- to 80-year-olds (60 kg) by P50 and P95 consumption (seaweed users) of the studied wet and dry seaweed (both sea lettuce and sugar kelp). Ratios >1 are shown in bold. The starting point is a P50 content of iodine, lead and inorganic arsenic.

Seaweed		Substance	Ratio between daily contaminant intake (μg/kg body weight/day) and health based guidance value			
			P50 consumption		P95 consumption	
			LB	UB	LB	UB
Sea lettuce	Wet	Iodine	0.034	0.034	0.96	0.96
		Lead	0.24	0.24	6.7	6.7
		Inorganic arsenic	0.101	0.101	2.9	2.9
	Dry	Iodine	0.023	0.023	0.599	0.599
		Lead	0.18	0.18	4.8	4.8
		Inorganic arsenic	0.064	0.074	1.7	1.96
Sugar kelp	Wet	Iodine	3.08	3.08	87	87
		Lead	0.27	0.27	7.5	7.5
		Inorganic arsenic	0.11	0.11	3.1	3.1
	Dry	Iodine	2.9	2.9	77	77
		Lead	0.25	0.25	6.7	6.7
		Inorganic arsenic	0.11	0.12	2.9	3.1

Table 22 The ratio of daily intake (pg/kg body weight/day) of dioxins (total dioxins + DL-PCBs) from 18- to 80-year-olds (60 kg) by P50 and P95 consumption (seaweed users) of the studied wet and dry seaweed (both sea lettuce and sugar kelp). Ratios >1 are shown in bold. The starting point is a P50 level of dioxins (total dioxins + DL-PCBs).

Seaweed		Substance	Ratio between daily contaminant intake (pg/kg body weight/day and health based guidance value			
			P50 consumption		P95 consumption	
			LB	UB	LB	UB
Sea lettuce	Wet	Total dioxins + DL-PCBs	0.0090	0.014	0.26	0.405
	Dry		0.0048	0.0095	0.13	0.25
Kelp weed	Wet		0.0041	0.014	0.12	0.39
	Dry		0.0042	0.012	0.11	0.32

Table 23 The ratio of daily intake (ng/kg body weight/day) of PFAS of 18- to 80-year-olds (60 kg) by P50 and P95 consumption (seaweed users) of the studied wet and dry seaweed (both sea lettuce and sugar kelp). Ratios >1 are shown in bold. The starting point is a P50 content of PFAS.

Seaweed		Substance	Ratio between daily contaminant intake (ng/kg body weight/day) and health based guidance value	
			P50 consumption	P95 consumption
Sea lettuce	Wet	Sum EFSA-4 (ng PFAS/kg)	0.014	0.40
		Sum all measured PFAS (ng PEQ/kg)	0.072	2.04
	Dry	Sum EFSA-4 (ng PFAS/kg)	0.0028	0.074
		Sum all measured PFAS (ng PEQ/kg)	0.045	1.2
Sugar kelp	Wet	Sum EFSA-4 (ng PFAS/kg)	0.0031	0.087
		Sum all measured PFAS (ng PEQ/kg)	0.0070	0.20
	Dry	Sum EFSA-4 (ng PFAS/kg)	0.020	0.53
		Sum all measured PFAS (ng PEQ/kg)	0.061	1.6

Annex XI provides an overview of the ratio of daily PFAS intake by P50 and P95 consumption of the studied wet and dry seaweed and the maximum safe intake (i.e. health based guidance value) for all four methods used to calculate the total PFAS content.

Table 24 gives an overview of Table 21, Table 22 and Table 23, the intake of iodine and contaminants from fresh unprocessed Dutch seaweed relative to the health based guidance value. This is further explained in the risk characterisation (4.5.2.4).

Seaweed products from the supermarket

Contaminants in seaweed products from the supermarket

In the period 2018 and 2019, following the call of the European Commission (Recommendation (EU) 2018/464), 31 seaweed-based products were sampled by the NVWA in supermarkets and at wholesalers.

Table 24 Intake of iodine and contaminants from Dutch seaweed relative to the health based guidance value.

Contaminants in unprocessed Dutch seaweed (sea lettuce & kelp weed)			
Analysed	Detected	Quantified	Exposure
Iodine	Yes	Yes	🟥
Cyanotoxins	Yes	No	🟨
Dioxins & DL-PCBs	Yes	Yes	🟩
PAHs	Yes	Yes	🟩
PFAS	Yes	Yes	🟥
Plant protection products	No	No	🟩
Mineral oil	No	No	🟩
Inorganic arsenic	Yes	Yes	🟥
Cadmium	Yes	Yes	🟩
Lead	Yes	Yes	🟥
Mercury	Yes	Yes	🟩
Nickel	Yes	Yes	🟩
Radioactive substances	No	No	🟩

* red: Intake above the health based guidance value
green: Intake below the health based guidance value
yellow: no intake calculation possible

These sampled products are probably imported seaweed products. During sampling, not all product data were well documented. In most cases, for example, it was not described whether the product was dried or fresh. Often it was also unknown how much seaweed was incorporated into the product. The samples were analysed for the presence of arsenic (total and inorganic), cadmium, mercury, lead, nickel (only samples from 2019) and iodine, dioxins and PCBs, PAHs, mineral oils, pesticide residues, toxins produced by algae and plants, pharmaceuticals and radioactivity. The concentrations are determined on the basis of the product as supplied and concern both dried and fresh products. Concentrations are expressed on a product basis (unit mass per quantity of dried or wet product). It was not possible to calculate back to wet or dry weight because the moisture content was not determined and the percentage of seaweed in the product was not known (Faassen, 2020).

None of the seaweed products examined contained mineral oils, toxins or pharmaceutical substances produced by algae and plants. Only naturally occurring radioactive substances (nuclides) have been demonstrated. In addition, iodine, various heavy metals, dioxins, dioxin-like and non-dioxin-like PCBs, PAHs and pesticide residues were found. For details of the measured levels, see the WFSR report (Faassen, 2020).

Exposure assessment

Because it is unclear exactly which seaweed-based products have been sampled, no distinction can be made on, for example, dry versus wet seaweed or percentage of seaweed in the product. What remains is a general group of 'seaweed products' so that it is not possible to perform an exposure assessment for the various contaminants analysed.

In 2023, EFSA published an opinion looking at the exposure of the European population to heavy metals and iodine from the consumption of seaweed, seaweed-based products and halophytes (EFSA, 2023). Exposure has not been calculated for the general population but only specifically for seaweed consumers as this is a small group. EFSA concluded that:

- The average adult intake of cadmium from the consumption of seaweed, seaweed-based products and halophytes is comparable to the intake of cadmium from the total diet of all adults. So seaweed consumers have a double cadmium intake.
- Exposure to lead and inorganic arsenic from the consumption of seaweed, seaweed-based products and halophytes by seaweed consumers corresponds to 10 to 30% of the exposure to these substances from the total diet (without seaweed).
- Exposure to mercury from the consumption of seaweed, seaweed-based products and halophytes by seaweed consumers corresponds to 10% of the exposure to mercury from the total diet (without seaweed). EFSA assumes that all mercury present consists of methylmercury.
- The P90 intake of iodine from the consumption of seaweed, seaweed-based products and halophytes by seaweed consumers is 32.7 µg/kg body weight per day (adults). This corresponds to an intake of 1,962 to 2,289 µg of iodine per day for adults from 60 to 70 kg. For comparison: The tolerable upper intake level (UL) is 600 µg/day for an adult.

4.5.2.4 Risk characterisation

Fresh unprocessed seaweed from the seaweed farms

Seaweed (sea lettuce and sugar kelp) grown and studied in the Netherlands contains iodine, metals and other contaminants such as dioxins, PAHs and PFAS. When considering the risks to consumer health based on the individual contaminants (P95 concentration and P95 consumption; worst-case scenario), BuRO concludes that the presence of cadmium, mercury, nickel and the sum of PAH4 does not lead to a health risk. The amounts of seaweed (sea lettuce and sugar kelp) that a consumer may eat daily before the relevant health based guidance values are exceeded are (very) large and are above the upper limit of the 95% confidence interval of P95 consumption as reported by RIVM (Table 15, Table 16). The intake of these contaminants from other sources has not been taken into account. For the consumption of seaweed with respect to iodine, lead, inorganic arsenic, dioxins (total dioxins + DL-PCBs) and PFAS, it cannot be concluded that there is no health risk. In order to assess the health risks of these substances, the exposure assessment has been refined. When estimating long-term (chronic) exposure, a P50 level gives a more realistic scenario than a P95 level, because a consumer is unlikely to consume seaweed containing contaminants at the level of the P95 level for an extended period of time. Based on P50 levels and P50 and P95 consumption data (median and large portions) of seaweed, BuRO concludes that the consumption of seaweed does not pose a health risk in terms of intake of dioxins (total dioxins + DL-PCBs). The ratio of daily dioxin intake to maximum safe intake (i.e. health based guidance value) is less than 1 (Table 22).

By contrast, based on P50 levels and P50 and P95 consumption data, BuRO concludes that seaweed consumption may lead to a health risk related to the intake of iodine, lead, inorganic arsenic and PFAS. The ratio of daily iodine, lead, inorganic arsenic or PFAS intake to maximum safe intake of those contaminants is greater than 1 in the following scenarios (Table 21, Table 23):

- Iodine: P50 consumption and P95 consumption of wet and dry seaweed (sugar kelp).
- Lead: P95 consumption of wet and dry seaweed (sea lettuce and sugar kelp).
- Inorganic arsenic: P95 consumption of wet and dry seaweed (sea lettuce and sugar kelp).
- PFAS: P95 consumption of dry seaweed (sea lettuce) (only if calculated on the basis of PFAS content using RPFs).

Based on the risk assessment above, BuRO concludes that daily consumption of large quantities of raw (fresh) wet and dry seaweed (sea lettuce and sugar kelp) grown in the Netherlands may lead to a risk to consumer health due to the presence of iodine, lead, inorganic arsenic and PFAS. Possible decreases in (heavy) metals and iodine due to the processing and/or preparation steps are not included, a worst-case scenario.

A nuance of this conclusion is also appropriate due to uncertainties in the assessment. With regard to the data on the levels of the substances in the seaweed samples, no distinction has been made between the location of sampling, the sampling site in the seaweed bed and the moment of sampling. As a result, the levels in the samples can be both underestimated and overestimated. For iodine, 100% availability for uptake has been assumed, although this may also be lower depending on the seaweed species (Beerman & Van Tuinen, 2023; Hogstad et al., 2023; Van Tuinen et al., 2023). For PFAS, the conclusion on a potential risk to consumer health depends on how the total PFAS content is calculated (concentration addition versus the use of RPFs). The food consumption data used show a large dispersion so that both the 50th and 95th percentiles of the consumption distribution were used in this assessment. In addition, the 95th percentile is probably an overestimation (worst-case) by the measurements of persons with extreme consumption. In addition, representative consumption data for children and adolescents are lacking, so that it was not possible to assess the risk for this group. Furthermore, this assessment does not take into account possible cumulative effects of exposure to multiple substances at the same time and a possible decrease in the levels of contaminants by seaweed processing.

Seaweed products from the supermarket

Because it is not possible to perform an exposure assessment for the different contaminants present in the 31 sampled seaweed-based products from supermarkets and wholesalers, no risk characterisation can be performed for these products. However, the EFSA study on seaweed-based products (EFSA, 2023) shows that the consumption of seaweed, seaweed-based products and halophytes by seaweed consumers can greatly contribute to the maximum safe intake of iodine and metals.

4.5.2.5 Conclusion on chemical risks

Seaweed (sea lettuce and sugar kelp) grown and studied in the Netherlands contains iodine and other contaminants. The degree of presence of iodine and contaminants in seaweed may vary. This depends, among other things, on the type of seaweed. The literature shows that the location, and season in which harvesting takes place also have an influence. In addition, processing steps often result in a reduction in concentrations.

Based on the performed risk assessment, BuRO concludes that daily consumption of large quantities of raw (fresh) wet (over 90 grams) and dry (over 13 grams) seaweed (sea lettuce and sugar kelp) grown in the Netherlands may lead to a risk to consumer health due to the presence of iodine, lead, inorganic arsenic and PFAS (based on the calculated PFAS content using RPFs). Possible decreases in (heavy) metals and iodine due to the processing and/or preparation steps are not included, a worst-case scenario. There are also a number of other uncertainties − in the levels of contaminants and iodine, in the calculated total PFAS levels, in the consumption data for Dutch consumers − that need to be taken into account for a correct interpretation of this conclusion.

Excessive intake of iodine can lead to a disruption of thyroid function. However, iodine deficiency can also lead to thyroid dysfunction and stunted growth in children. The iodine intake of Dutch adults is (just) sufficient. A decrease in salt intake could lead to an iodine deficiency in consumers (Gezondheidsraad 2008; De Jong et al., 2023). In order to prevent shortages, seaweed is mentioned as a possible substitute iodine-rich food. However, be careful as iodine levels in seaweed can vary greatly (Geziondheidsraad, 2008; Voedingscentrum, 2022; De Jong et al., 2023). When seaweed is consumed as an iodine source, there is a risk of an excessive intake of iodine, as this risk assessment confirms.

In addition, the consumption of raw (fresh) wet and dry seaweed grown in the Netherlands can contribute (substantially) to the total intake of various heavy metals via food. It is noted that the intake of cadmium, mercury, arsenic and lead via food generally leads to exposure around the health based guidance value (EFSA CONTAM Panel, 2009b; EFSA, 2012b;2014; Sprong & Boon, 2015; Boon et al., 2017). Consumption of seaweed grown in the Netherlands contributes (extra) to this.

The intake of dioxins and DL-PCBs from food (calculations from 2014 for the Dutch population (Boon et al., 2014) exceeds the TWI established by EFSA in 2018 (EFSA CONTAM Panel, 2018). The intake of PFAS from food and drinking water exceeds the health based guidance value for a large part of the European population (EFSA CONTAM Panel, 2020a) and for the Dutch population (RIVM, 2021b; Schepens et al., 2023). Consumption of seaweed grown in the Netherlands contributes (extra) to this.

The EFSA study on seaweed-based products shows that the consumption of seaweed, seaweed-based products and halophytes by seaweed consumers can make a major contribution to the maximum safe intake of iodine and heavy metals (notably cadmium).

4.6 Food safety microbiological risks

4.6.1 Approach and scope of microbiological risk assessment

A qualitative (descriptive) approach has been followed when assessing the risk to public health (food safety) of the various microbiological hazards that may occur on seaweed. This approach was chosen because of the lack of sufficient (prevalence) data to provide a more quantitative assessment of the risk. The risk assessment focuses in particular on the exposure assessment , i.e. on the extent to which microorganisms occur in the chain and can survive or grow out. This means that the risk assessment focuses on the chance of infection and not so much on the severity of the infection. This has been done because there is no reason to believe that seaweed affects the extent to which a pathogen causes disease (severity of the disease) and this information can be found, among other sources, in previous BuRO risk assessments. In order to characterise the risk, a comparison has been made with the risk of fishery products. Of these products, a more quantitative risk assessment has been performed for the situation in the Netherlands (BuRO, 2022). In this risk assessment of seaweed, the four steps of the risk assessment have been followed in the following way:

1. Hazard identification: inventory of the microorganisms that can reach humans from the cultivation phase through the consumption of seaweed and cause disease in humans (pathogens).
2. Hazard characterisation: relevant characteristics of the inventoried microorganisms for survival/growth in seaweed(products).
3. Exposure assessment: data on the detection of pathogenic microorganisms on seaweed(s) and on outbreaks caused by seaweed(s).
4. Risk characterisation: assessment of the risk to public health in the Netherlands caused by the consumption of seaweed (products) contaminated with microorganisms from the cultivation phase (conclusion of the risk assessment).

In carrying out this risk assessment, various sources were used, such as scientific and grey literature, databases and notifications on food-borne outbreaks, data from the Rapid Alert System for Food and Feed (RASFF) and research data from the NVWA (samples analysed by WFSR).

For the assessment of the microbiological risks that can be related to seaweed, in addition to the WFBR report (Rodríguez Illera & Van Bokhorst-Van de Veen, 2019), the previously published risk assessments of the food safety authorities from Ireland (FSAI Sci. Com., 2020), Scandinavia (Norway, Denmark, Sweden, Iceland and the Faroe Islands; Hogstad et al. (2023)) and New

Zealand (Cressey et al., 2023) which emerged from the literature review were used in particular. These are supplemented with data from the other literature and data from the NVWA.

This risk assessment uses the term microorganisms as adopted in the Regulation on microbiological criteria for foodstuffs (Regulation (EC) No 2073/2005). This includes bacteria, viruses, prions, yeasts, fungi, algae, parasitic protozoa and microscopic parasitic helminths, as well as toxins and metabolites of these organisms. Not included in this assessment are opportunistic pathogens, fungal enterotoxins and marine biotoxins. These toxins are part of the risk assessment of chemical hazards. Antibiotic resistance is not part of this risk assessment.

Contamination with pathogenic microorganisms during the processing of the product is not specific to seaweed and is not part of this assessment. This also applies to the introduction of pathogens by sick staff (harvesting, processing and handling, food preparation). This assessment focuses on the hazards introduced at the primary stage − during cultivation.

The risk assessment is limited to exposure (probability) and does not address the severity of infection (effect).

4.6.2 Risk assessment of microbiological hazards

Seaweed grows in nature and carries a rich palette of micro-organisms on the leaves and stems. Most types of microorganisms found in nature are not harmful to human or animal health. However, there is a limited group of microorganisms capable of causing disease in humans. The latter group, also known as pathogenic microorganisms, is considered a microbiological hazard.

Table 25 Overview of publications (until and including September 2023) with quantitative data on the occurrence of (potentially) pathogenic microorganisms on seaweed (products).

Microorganism (genus)	Microorganism (species)	#Npos[1]	N[2]	Reference
Aeromonas spp.		20	20	(Ziino et al., 2010)
Bacillus spp.	*B. Cereus*	25	57	(Choi et al., 2014; Son et al., 2014; Lytou et al., 2021; Martelli et al., 2021; Banach et al., 2024)
		0	5	(Blikra et al., 2019; FSAI Sci. Com., 2020)
Campylobacter spp.		0	24	(Moore et al., 2002; Zolkifly et al., 2012)
Clostridium spp.	*C. perfringens*	1	2	(FSAI Sci. Com., 2020)
Cronobacter spp.		3	24	(EFSA BIOHAZ Panel, 2013)
E. coli	STEC O157:H7	10	30	(Moore et al., 2002; Barberi et al., 2020)
		14	144	(Ziino et al., 2010; Zulkifly et al., 2012; Choi et al., 2014; FSAI Sci. Com., 2020; DVFA, 2021; Lytou et al., 2021; Moreira-Leite et al., 2023)
Listeria spp.	*L. monocytogenes*	4	112	(Moore et al., 2002; EFSA BIOHAZ Panel, 2013; Choi et al., 2014; Son et al., 2014; Blikra et al., 2019; Panebianco et al., 2019; FSAI Sci. Com., 2020; Lytou et al., 2021; Martelli et al., 2021; Moreira-Leite et al., 2023)
		0	6	(FSAI Sci. Com., 2020)
Pseudomonas spp.	*P. aeruginosa*	1	19	(EFSA BIOHAZ Panel, 2013)
Salmonella spp.	*S.* Typhimurium	14	18	(Barberi et al., 2020)
		0	186	(Moore et al., 2002; Alsulaiman, 2011; Zulkifly et al., 2012; Choi et al., 2014; Son et al., 2014; Panebianco et al., 2019; FSAI Sci. Com., 2020; DVFA, 2021; Lytou et al., 2021; Moreira-Leite et al., 2023; Sørensen et al., 2023; Banach et al., 2024)
Shigella spp.		0	14	(Alsulaiman, 2011)
Staphylococcus spp.	*S. aureus*	0	74	(Moore et al., 2002; Alsulaiman, 2011; Choi et al., 2014; Son et al., 2014; FSAI Sci. Com., 2020; Lytou et al., 2021; Moreira-Leite et al., 2023)
Vibrio spp.	*V. cholerae*	0	26	(Panebianco et al., 2019)
	V. parahaemolytic	100	182	(Mahmud et al., 2006; Ziino et al., 2010; Choi et al., 2014; Son et al., 2014; Panebianco et al., 2019; Barberi et al., 2020)
	V. vulnificus	24	101	(Mahmud et al., 2008; Panebianco et al., 2019)
		31	90	(Moore et al., 2002; Ziino et al., 2010; Blikra et al., 2019; Panebianco et al., 2019; Lytou et al., 2021; Moreira-Leite et al., 2023; Banach et al., 2024)
Norovirus		0	5	(Banach et al., 2024)

[1] #Npos: number of samples positive for the pathogen under investigation

[2] N: Number of samples examined

4.6.2.1 Hazard identification

The relevant publications from the literature study have been used to make an overview of hazards found on seaweed (worldwide). This shows that on seaweed many different bacterial genera can occur containing human pathogenic species (Table 25, Table 26). Of the food-borne viruses (norovirus (NoV), hepatitis A virus (HAV), Hepatitis E virus (HEV), rotavirus), only norovirus is associated with seaweed from literature.

Table 26 Overview of publications (until and including September 2023) with qualitative data on the occurrence of pathogenic microorganisms on seaweed (products). Pathogens (genera, species) that are opportunistic pathogens or whose infections occur rarely or are particularly associated with hospitalisation (nosocomial) and for which food is (in most cases) not the route of exposure are marked with a *.

Microorganism (genus)	Microorganism (species)	Reference
Acinetobacter	*A. urginsii* *	(Kreissig et al., 2023)
Aeromonas	*A. hydrophila* *	(Vairappan & Suzuki, 2000)
	A. eucrenophila *	(Kreissig et al., 2023)
Bacillus	*B. cereus*	(Wiese et al., 2009; Singh et al., 2015; Thilakan et al., 2016; Del Olmo et al., 2018)
	B. licheniformis *	(Wiese et al., 2009; Singh et al., 2015; Del Olmo et al., 2018)
	B. megaterium *	(Del Olmo et al., 2018)
	B. (pseudo)mycoides *	(Del Olmo et al., 2018)
	B. pumilus *	(Wiese et al., 2009; Del Olmo et al., 2018)
	B. thuringiensis *	(Wiese et al., 2009)
	spp.	(Beleneva & Zhukova, 2006; Albakosh et al., 2016)
Citrobacter	*C. freundii* *	(Kreissig et al., 2023)
Clostridium	spp.	(Choi et al., 2014)
Escherichia	*E. coli*	(Vairappan & Suzuki, 2000; Musa & Wei, 2008; Barberi et al., 2020)
Enterobacter	*E. cloacae* *	(Musa & Wei, 2008; Kreissig et al., 2023)
Enterobacteriaceae		(Bolinches et al., 1988)
Klebsiella	*K. pneumoniae* *	(Singh et al., 2015)
	K. oxytoca *	(Musa & Wei, 2008; Kreissig et al., 2023)
Pasteurella	*P. haemolytica* *	(Musa & Wei, 2008)
Proteus	*P. vulgaris* *	(Vairappan & Suzuki, 2000)
Pseudomonas	*P. aeruginosa* *	(Singh et al., 2015)
	P. fulva *	(Del Olmo et al., 2018)
	P. putida *	(Del Olmo et al., 2018)
	spp.*	(Wiese et al., 2009; Albakosh et al., 2016; Thilakan et al., 2016)
Shewanella	spp.*	(Albakosh et al., 2016)
Staphylococcus	*S. saprophyticus subsp.* *	(Albakosh et al., 2016)
	S. hominis *	(Lytou et al., 2021)
	S. epidermis *	(Lytou et al., 2021)
	spp.	(Bolinches et al., 1988; Choi et al., 2014)
Streptomyces	spp.*	(Wiese et al., 2009)
Vibrio	*V. alginolyticus*	(Vairappan & Suzuki, 2000; Musa & Wei, 2008; Barberi et al., 2020)
	V. cholerae	(Musa & Wei, 2008)
	V. parahaemolyticus	(Vairappan & Suzuki, 2000; Singh et al., 2015)
	spp.	(Beleneva & Zhukova, 2006; Albakosh et al., 2016; Thilakan et al., 2016)
Yersinia	*Y. intermedia* *	(Kreissig et al., 2023)

No publications were found on research on food-borne parasites (*Cryptosporidium* spp., *Giardia* spp. and *Toxoplasma gondii*) on seaweed or products made thereof (Table 32).

In addition, opportunistic toxin-producing dinoflagellates and cyanobacteria have been identified by EFSA as a potential hazard associated with seaweed (EFSA et al., 2017; Cressey et al., 2023). The marine biotoxins produced by these dinoflagellates and cyanobacteria have been included in the risk assessment of chemical hazards.

The published studies include a (very) limited number of samples per pathogen (Table 25). The absence of a pathogen on seaweed or products made from seaweed is therefore not evidence that this pathogen cannot occur on seaweed. The general assumption is that human pathogenic microorganisms found in seaweed growing water can also be found on the seaweed itself (Løvdal et al., 2021). Thus, seaweed that grows in water exposed to human activity (raw water, recreation, agriculture) will contain microorganisms derived from humans and farm animals (Duinker et al., 2016; FSAI Sci. Com., 2020; Cressey et al., 2023).

This risk assessment therefore takes into account, in addition to the pathogenic microorganisms actually found on seaweed (based on the aforementioned sources), the other pathogens that can be transmitted via food − usually with humans or animals as a source − and that cause a relevant disease burden in the Netherlands (Benincà et al., 2024).

The hazard characterisation and exposure assessment will be used to provide an overview of the hazards that are most relevant for public health in the Netherlands with regard to the consumption of seaweed (products).

4.6.2.2 Hazard characterisation

Of the bacterial genera found on seaweed (products) and containing species that can cause disease in humans, the majority are genera whose pathogenic species are opportunistic pathogens. That is, they are particularly pathogenic in people with weak immune systems (immune compromised). The risk of these opportunistic pathogens is limited to a specific part of the population, with the risk arising from the health status of this consumer. They are also bacteria that are mainly related to hospital infections or have only very rarely been reported as a human pathogen. In addition, with regard to these pathogens, food is not (always) the route of infection along which the infection is sustained. The genera and/or species in question are marked with a * in Table 26. *Cronobacter* spp. (Table 25) can also be added to this list. This pathogen is particularly a risk for neonates and associated with infant formula. The bacteria selected in this way do not pose a risk to food safety with regard to the consumption of food, or of seaweed in particular, and have therefore − as previously indicated (4.6.1) − been excluded from the scope of this risk assessment.

The role of *Aeromonas* as an agent of food-related infections has long been under discussion. It now has been shown that some *Aeromonas* spp. can cause disease in humans (in particular *A. hydrophila*, *A. veronii* biovar *sobria* and *A. caviae*). *Aeromonas* is an opportunistic pathogen, but does not only cause disease in people with a weak immune system. *Aeromonas* is therefore sometimes called an emerging pathogen (ESR (FSANZ), 2010; Teunis & Figueras, 2016; Pessoa et al., 2022). However, this pathogen has not been included in this risk assessment. The reason for this is that it is generally unclear how many cases of disease this pathogen causes by food consumption. Therefore, it is also not clear what role seaweed plays in this. Should more clarity on this become available in the future, it will be relevant to review this assessment.

Several food-borne pathogenic bacteria have been found on seaweed. These are both pathogens naturally occurring in the environment (such as *Vibrio* spp., *Bacillus cereus*), and pathogens (also) associated with humans and animals (such as *Listeria monocytogenes*, *Salmonella*, STEC, *Clostridium perfringens*). An overview of relevant characteristics of these hazards can be found in Table 43 (Annex XII) as well as the characteristics of pathogens for which it is not implausible that they can occur on seaweed on the basis of similarity in the original reservoir and route of infection of the pathogens that have been found.

Of these pathogens, *B. cereus* and the clostridia are spore-formers, these pathogens survive processes used during seaweed processing, such as blanching, cooking, salting and drying. However, humans do not get sick from the spores of these pathogens, but from the toxins produced by the vegetative cells of these pathogens. However, spores of these pathogens must first germinate and then the formed vegetative cells must grow into numbers sufficient to produce either toxin in the food (*B. cereus*, *C. botulinum*) or to survive the gastric passage and then produce toxin in the intestines (*B. cereus*, *C. perfringens*). Also *S. aureus* is a toxin-former (in the food) and must first grow in the food in order to be able to proceed to toxin production.

Cooling (<7 °C) inhibits or prevents outgrowth and/or toxin formation of *B. cereus*, *C. perfringens* and *S. aureus*. This also applies to the outgrowth of most other pathogens. Exceptions are *L. monocytogenes*, *C. botulinum* and some *Vibrio* spp. which may develop at lower temperature (<5 °C) (Table 43).

Specifically for *Vibrio* spp. it applies they are quite sensitive to heating, freezing, drying and various other preservation techniques and also to the acidity in the stomach (Duinker et al., 2016; FSAI Sci. Com., 2020; US FDA, 2022). Not all *Vibrio* strains within a potentially human pathogenic species are capable of causing infection in humans. As with other pathogens (*E. coli*, *C. perfringens*, *B. cereus*), only part of the strains possess the correct combination of virulence genes (Baker-Austin et al., 2010; Nigro et al., 2011; Tamplin et al., 2011; Duinker et al., 2016). For example, in a study from Japan, only 18 of the 6,000 *V. parahaemolytic isolates* - derived from seawater and seaweed - were found to have virulence genes (Mahmud et al., 2006).

Viruses cannot grow outside their host, where human pathogenic viruses originate from humans themselves (NoV, HAV, rotavirus, HEV (genotypes 1 and 2)) or from farm animals (HEV genotypes 3 and 4). However, these viruses are quite stable in the environment and survive cooling and freezing. NoV, HAV and HEV are also fairly resistant to heating (Johne et al., 2024). With a heat treatment of 2 minutes at 70-72 °C, often only a reduction of less than 4 logs is achieved. This contains some degree of uncertainty, because it depends on the product, the virus strain, the type of heat treatment and also on the analytical method used to determine the virus inactivation.

Like viruses, parasites cannot grow outside their host or intermediate host. However, the parasitic food-borne protozoa (Cryptosporidium spp., *Giardia* spp. and *Toxoplasma* spp.) can survive in the environment (water) or in food. These parasites do not survive heating or freezing (BuRO, 2022).

4.6.2.3 Exposure assessment

To gain an insight into the extent to which pathogenic microorganisms occur on seaweed (products), data from prevalence studies have been collected from the (grey) literature, monitoring data from the NVWA have been requested and the RASFF database has been consulted. Data on outbreaks of food poisonings and infections caused by seaweed consumption were also sought. Finally, the effect of processing processes on any pathogenic microorganisms present on seaweed was investigated.

However, seaweed is a product that in the Netherlands, but also in many other countries in Europe or countries with a Western diet, has only relatively recently become of interest to being eaten and produced on a larger scale. The amount of data in the English-language literature on the microbiological safety of seaweed is therefore not as extensive as that of other foodstuffs. This is also endorsed by others (FSAI Sci. Com., 2020; FAO & WHO, 2022).

Data literature

Seaweed contains a wide variety of microorganisms, just like all other macroscopic eukaryotes. On the surface of seaweed is a layer of exopolysaccharides (excreted organic compounds) which enables microorganisms to attach themselves (bacteria, parasites) and sometimes even grow out (bacteria) (Hannah & Cowie, 2009;Mazzillo et al., 2013; Duinker et al., 2016). There is no mention of the adhesion of viruses to seaweed in the collected literature. On the other hand, it is noted that seaweed itself and the natural microbiota present on seaweed actually hinder the adhesion and growth of other bacteria (Hannah & Cowie, 2009; Duinker et al., 2016). For example, it is known that seaweed may have antibacterial properties (species dependent), which may also inhibit growth of human-relevant pathogens (including *L. monocytogenes*, *S. aureus* and *E. coli*) (Hannah & Cowie, 2009; Gupta et al., 2010; Duinker et al., 2016; Hogstad et al., 2023).

Seaweed naturally contains bacteria that occur in the surrounding water, or that are associated with soil/sediment. The numbers found on seaweed range from 10^1-10^8 CFU/cm2 (colony-forming units/cm2) and are higher in summer than in winter. However, the natural microbiota of salt or brackish water − and therefore of seaweed − are not pathogenic to humans. Exceptions to this are the pathogenic species of the genus *Vibrio* and *C. botulinum*, *C. perfringens* and *Aeromonas* spp.

A number of studies investigating the presence of human pathogenic microorganisms on seaweed have been published. This concerns both studies with quantitative data (Table 25, Table 31, Table

32) and studies with a qualitative perspective (Table 26). Half of the studies (n=21) only looked qualitatively or did not describe sample numbers (Table 26). The studies in which quantitative data have been reported often involve studies with few samples. Of the quantitative studies found (n=19), 5 examined more than 20 samples, totalling more than 400 samples (Table 44).

The data concern samples of freshly harvested seaweed and processed seaweed. Some studies involving sampling in the cultivation phase have been carried out at clean locations and/or at locations where human influence is greater (and therefore exposure to pathogens may also be higher) (near, for example, sewage discharge). It is therefore not always seaweed that has been or will be placed on the market as a food, but also more worst-case scenarios. The data are therefore not suitable for providing a quantitative estimate of the occurrence of pathogens on seaweed as a food. However, the data do provide insight into whether human pathogenic microorganisms can occur on seaweed.

Bacillus cereus

Bacilli generally occur as spores in the environment, including soil (Iwamoto et al., 2010; US FDA, 2012). Pathogenic *B. cereus* strains can also be found in surface water (rivers) (Østensvik et al., 2004). A number of studies have looked at the presence of *Bacillus* spp. or more specifically *B. cereus* on seaweed. *B. cereus* is regularly found (25/57 samples) (Table 25, Table 26). The study by Lytou et al. (2021) carried out storage tests. On fresh *Alaria esculenta,* the initial concentration of *Bacillus* spp. was 1-3 log CFU/g and this increased by 1-4 log at 5 °C in 7 days. Growth was also observed at 0 °C (2 log increase). This is probably not (only) *B. cereus* sensu stricto, because this pathogen has a higher growth temperature. However, *B. cereus* was found on the samples (end of storage) at 5 °C. On *Saccharina latissima* low numbers of *Bacillus* spp. were found (<2 log CFU/g) and these numbers did not increase or hardly increased (<1 log). On dried algae (both species) 4.5-5 log CFU/g was found by these authors. In the studies of Choi et al. (2014) and Martelli et al. (2021), (sometimes) *B. cereus* was found on dried seaweed (9/32 samples), where the numbers found were between 1-4 log (spores)/g. In a storage trial, *B. cereus* was subsequently found not to grow on rehydrated product (4 days stored in the refrigerator) (Martelli et al., 2021). *B. cereus* can therefore occur on seaweed, *Bacillus* spp. can grow on seaweed. Presumably *B. cereus* will also be able to do that at a suitable temperature.

Campylobacter spp.

Campylobacter spp. have not been detected on seaweed (0/24 samples, Table 25). A previous BuRO literature study showed that − based on the combined data from the literature (approximately 1,500 samples) - the calculated prevalence of *Campylobacter* spp. in fish was 1% and in shellfish 30% (Arumugaswamy & Proudford, 1987; Wilson & Moore, 1996; Daczkowska-Kozon, 1998; Whyte et al., 2004; Ibrahim et al., 2014; Kim et al., 2017). In the Netherlands, no campylobacteriosis outbreaks attributed to shellfish have been described, but source attribution estimates based on food-borne outbreaks (excluding dairy-related outbreaks) in the US in the period 1998-2017 attribute 3% of campylobacteriosis cases to fish and 13% to other fishery products (IFSAC, 2019). *Campylobacter* spp. therefore occur in seawater and can therefore also be present on seaweed.

Clostridium spp.

Very limited literature has been published on the occurrence of *C. perfringens* on seaweed, but this pathogen was found (1/2 samples (Table 25)). No data on the presence of *C. botulinum* were found. *C. botulinum* is common in the environment, including in soil, water and ocean sediment. In particular, type E is common in freshwater and saltwater sediment (EFSA BIOHAZ Panel, 2005; Iwamoto et al., 2010; RIVM, 2011a; US FDA, 2012). It therefore seems plausible that C. *botulinum* can be found on seaweed. *C. botulinum* only grows under anaerobic conditions, something that can occur when using *modified atmosphere packaging* (MAP).

Listeria monocytogenes

L. monocytogenes is widespread in the environment and water and soil and is considered to be a source of infection for animals and plants. Usually this is in low numbers (RIVM, 2016). Seaweed - just like fish, crustaceans and shellfish - can become infected with *L. monocytogenes* if the aquatic environment is contaminated. This can play a role in coastal waters or in aquaculture if hygiene standards are low. In open sea water this plays a lesser role (US FDA, 2019a). The main route by which ready-to-eat products become infected with *L. monocytogenes* is through post-contamination from the process environment (EFSA BIOHAZ Panel, 2018). *L. monocytogenes* has been found in seaweed products (4/104 samples). This concerned fresh seaweed suspected to have become infected after harvesting (Lytou et al., 2021) and processed seaweed (EFSA BIOHAZ Panel, 2005).

Salmonella and STEC

In a study from the USA, STEC O157 and *Salmonella* were commonly found (56% and 83% of sampling moments, respectively) on seaweed (kelp) (PCR detection method, presence per approximately 8 g of algae) (Barberi et al., 2020). This was in a bay where a lot of human activity takes place and there are various anthropogenic and natural polluting (point) sources. However, based on the amount of *E. coli* in the water, the water quality at the seaweed cultivation site almost always met the standard for shellfish farming water (<12 CFU/100 ml). In the other studies looking at *Salmonella* on seaweed, this pathogen was not found (0/186 samples, Table 25). No other studies have been found that looked at STEC on seaweed. *E. coli* in general is found regularly on seaweed (14/136 samples, Table 25).

Shigella spp.

Humans are the only reservoir of significance for *Shigella* spp. *Shigella* spp. are therefore not specifically found in particular foods. Often the source is an infected food handler who has not worked hygienically. *Shigella* spp. have been regularly detected in water contaminated with human faeces. Water (drinking water, swimming water, seawater) is a well-known source of shigellose outbreaks (Iwamoto et al., 2010; RIVM, 2011b; US FDA, 2012; CDC, 2018). However, fish or shellfish are rarely a source of outbreaks (CDC, 2018). And in the Netherlands, hardly any food-borne shigellosis outbreaks are observed at all (shigellose is notifiable) (RIVM, 2011b). Seaweed could therefore be contaminated by contaminated seawater. In the limited published research, this pathogen was not detected (0/16 samples, Table 25).

Staphylococcus aureus

S. aureus is part of the skin microbiota (throat, nose, hands) of many people. The main source of food contamination is through hand contact during food processing by a food handler (Argudin et al., 2010). In a previous literature study commissioned by BuRO into the occurrence of pathogens in the fish supply chain (Hayrapetyan & Van Bokhorst-Van de Veen, 2018; Hayrapetyan et al., 2018; Van Bokhorst-Van de Veen & Hayrapetyan, 2018; Van Bokhorst-Van de Veen et al., 2018) it was shown that *S. aureus* was only found after processing and handling of fishery products, and therefore not in the primary phase (fish, cultivation water) (Ibrahim et al., 2014; Edris et al., 2017). In the study described in the literature on the occurrence of *S. aureus* on seaweed, this pathogen was not found (0/74 samples, Table 25). However, other human-associated staphylococci were found on freshly manually harvested seaweed. The contamination was suspected to have occurred during harvesting (Lytou et al., 2021). Contamination of the seaweed with *S. aureus* could therefore take place during harvesting if this were not done by machine.

Vibrio spp.

Vibrio spp. (155/399 sample in total) are regularly found on seaweed. This may include species that are pathogenic to the seaweed itself (Albakosh et al., 2016; Blikra et al., 2019), but also to species that may cause gastrointestinal complaints in humans (such as *V. parahaemolyticus* (100/182 samples) and *V. vulnificus* (24/101 samples) *(*Table 25, Table 26). The concentrations found on seaweed range from <1 log CFU *V. parahaemolyticus*/g (USA), 1- >2 log CFU *V. parahaemolyticus* or *V. vulnificus*/g (Japan) (Mahmud et al., 2006; Mahmud et al., 2008) and 1-4 log CFU *Vibrio* spp./g (Italy) (Ziino et al., 2010) to 8 log CFU *Vibrio* spp./g (Malaysia) (Musa & Wei, 2008). Without further specification of the species, it is unclear whether these are also human-pathogenic species and to what extent they are part of the total number of *Vibrio* cells counted.

Vibrio spp. occur naturally in salt and brackish water. Optimal growing conditions for certain *Vibrio* spp. are a higher water temperature (especially >20 °C) and water with a low salt concentration (<30 ppt). These situations occur mainly in the summer months in estuaries and enclosed water bodies with moderate salinity. The open sea is not very suitable for *Vibrio* spp. The temperature is too low, the salinity too high and there are too few nutrients (Lowry & Smith, 2007; Baker-Austin et al., 2010; Ellis et al., 2012; ECDC, 2019). In the colder months, *Vibrio* spp. survive in the soil sediment and are hardly observed in the water (EC, 2001; Clemence & Guerrant, 2015). Especially for *V. parahaemolyticus* the concentration drops sharply when the water temperature drops below 14-15 °C (Tamplin et al., 2011).

There is a lack of data on the occurrence of *Vibrio* spp. on seaweed grown in the Netherlands. However, there are data on the extent to which *Vibrio* spp. occurs at various Dutch swimming water sites and in water from shellfish production areas (2019-2021) (Schets et al., 2023). This gives an indication of the extent to which this pathogen could occur on seaweed. This research shows that *Vibrio* spp. is found in most water samples. Depending on the location, the highest observed concentrations in the water range from 10^4 to 10^6 MPN/L (10^1-10^3 MPN/ml; MPN: *most probable number*). The distribution of species varies by location, but on average *V. alginolyticus* is most common (77%), followed by *V. parahaemolyticus* (29%) and *V. vulnificus* and *V. cholerae* non-O1/O139 (both 1%). It is unclear what proportion of the *Vibrio* isolates have virulence genes and can therefore cause disease in humans (Schets et al., 2023). Research from Germany shows that *Vibrio* strains isolated from shellfish in Germany were rarely positive for toxin genes. For the most common species – *V. parahaemolyticus* – this was 2% (BfR, 2022). In Norway, no toxin genes were found in the isolated *Vibrio* strains (Duinker et al., 2016). However, it has been shown for *V. parahaemolyticus* that with the increase in water temperature relatively more pathogenic isolates are found compared to the total of *V. parahaemolyticus* isolates (Mahmud et al., 2006), so that this situation may change in the future (climate change).

Vibrio spp. can grow at low temperature (from 5-8 °C) (Table 43). However, for fishery products, the FDA (Food and Drug Administration, US) maintains that growth is prevented for 21 days when stored at 10 °C for *V. cholerae*, at 5-10 °C for *V. parahaemolyticus* and at 8-10 °C for *V. vulnificus* (US FDA, 2022). It is unknown what the growth characteristics of *Vibrio* spp. on seaweed are. It is BuRO's estimate that at these temperature-growth extremes, the growth temperature has more influence than the matrix. It can be assumed that the growth of *Vibrio* spp. on refrigerated seaweed (storage phase) is limited to a similar extent as in fishery products.

Fecal indicator organisms

Studies have looked at indicators of faecal pollution on seaweed. For example, enterococci (approximately 2-7 log CFU/g) were found on fresh seaweed in Italy (retail) in all samples examined (n=20) (Ziino et al., 2010). A part (6/20 samples) of this was also positive for *E. coli* (0.7-2.7 log CFU/g). In Denmark, more than 2 log CFU *E. coli*/g were detected on freshly harvested seaweed in a number of samples (8/65 samples) (DVFA, 2021). In Malaysia, even 8 log CFU *E. coli*/g were found on fresh seaweed (Musa & Wei, 2008). These indicator organisms are also found on dried seaweed. On dried (roasted or unroasted) seaweed in Italy, enterococci (approximately 2,4 log CFU/g) and *Enterobacteriaceae* (maximum 2,7 log CFU/g) were detected on some of the samples (3-4 out of 26 samples) (Panebianco et al., 2019). In another study, this was 2.5-5 log CFU/g coliforms and *E. coli* (4/14 samples) (Martelli et al., 2021). These results show that seaweed can be contaminated with faecal bacteria and thus be a source of enteral pathogens.

Viruses

Of the food-borne viruses (NoV, HAV, HEV, rotavirus (group A)), only norovirus is associated with seaweed and only as an agent of outbreaks (Table 25, Table 29, Table 32). Data on research on norovirus on seaweed (immediately after harvesting) was published in one of the publications within the search strategy followed. No norovirus was found in the five samples examined (Banach et al., 2024). Furthermore, no data were found on the occurrence of viruses on seaweed (products). The literature review looked broadly for microbiological hazards, but did not specifically look for viruses, unlike the four viruses mentioned above.

Seaweed may become contaminated with human pathogenic viruses during the growing phase if the cultivation water is contaminated with human faeces/vomitus (sewage water; NoV, HAV, rotavirus, HEV-1, HEV-2) or animal manure (HEV-3, HEV-4). In a food-borne outbreak or disease case caused by NoV, HAV or rotavirus, the source is usually a diseased food handler who infects the ready-to-eat product (prepared food, food eaten raw). As far as rotavirus is concerned, the main route of infection in humans (risk groups: child, elderly) is not food, but direct hand-mouth-contact. This is also due to the fact that adults have built up immunity in childhood, while in the elderly that immunity has decreased again (RIVM, 2017). As for the different genotypes of HEV, HEV-1 and HEV-2 are not endemic in Europe. The transmission route of these genotypes is not food-related, but mainly water-related. The hepatitis E virus that is relevant for humans in the Netherlands comes mainly from pigs (HEV-3). In the Netherlands, hepatitis A is not an endemic disease, which means that HAV will be found less in water.

It is known that filter-feeding shellfish eaten raw or not properly cooked (oysters, mussels) are a source of virus outbreaks (BuRO, 2022). Filter-feeding shellfish accumulate the virus particles from the water, while seaweed does not. Viruses that are involved in the aforementioned shellfish outbreaks are mainly NoV, but also HAV. In Europe − and thus the Netherlands − no outbreaks of HAV caused by the consumption of shellfish (2013-2017 period) are known in the period 2013-2017 (BuRO, 2022). However, there was a mussel-related HAV outbreak in the Netherlands in 2012 (Boxman et al., 2016). And although HEV can occur in water and shellfish, (global) consumption of filter-feeding shellfish is hardly associated with hepatitis E (1 described outbreak) (Treagus et al., 2021; BuRO, 2022). However, norovirus does occur in shellfish originating from Dutch farming areas and outbreaks have been frequently described worldwide (BuRO, 2022).

Parasites

No publications were found on the occurrence of food-borne parasites (*Cryptosporidium* spp., *Giardia* spp. and *Toxoplasma gondii*) on seaweed or products made thereof (Table 32). However, research on the infection route of the California sea otter with *T. gondii* shows that *T. gondii* can attach to seaweed (kelp) through the layer of exopolysaccharides on the seaweed (Mazzillo et al., 2013). It is not known whether this also applies to *Cryptosporidium* spp. and *Giardia* spp.

However, it is known that C*ryptosporidium* spp. and *Giardia* spp. can occur in (sea) water and that these parasites cause infection in humans via water (drinking water, swimming water). Little information is known about the occurrence of *T. gondii* in coastal waters (BuRO, 2022), except for the above-mentioned situation of California sea otters, where snails foraging on the seaweed would be a source of infection for the sea otter. *Cryptosporidium* spp. and *Giardia* spp. are found in shellfish and − albeit to a lesser extent − also on fish. *T. gondii* has also been detected in shellfish (BuRO, 2022).

Outbreaks caused by *Cryptosporidium* spp., *Giardia* spp. and *T. gondii* due to shellfish or fish consumption are not or hardly described. This while shellfish in particular are regularly consumed raw (oysters) or less well-cooked (mussels). It is unknown whether this is because fishery products are actually a rare source of these parasitic infections or whether there is underreporting (or both).

Seaweed-seawater relationship

Human pathogenic microorganisms are assumed to occur on seaweed to the same extent and composition as in the water in which the algae grows (Løvdal et al., 2021). There are studies that have looked at the relationship between seaweed and seawater with regard to the finding of different microorganisms. A study from Greenland looked at the effect of seaweed farming site (near small hamlet or near village) on the occurrence of faecal indicator bacteria (*E. coli*, coliforms) on seaweed (Kreissig et al., 2023). These indicator organisms only occurred in the water and on the seaweeds near the village (greater human influence). Also, only bacteria that could be associated with humans were found on that seaweed (Table 26). Barberi et al. (2020) saw that the presence of *E. coli* in the water usually correlated with the presence of this bacterium on kelp. And that *V. parahaemolyticus* and *V. alginolyticus* occurred in water in significantly higher numbers than on seaweed (kelp). However, the observed concentration of both species of *Vibrio* on kelp was low with less than 8 CFU/100 ml of rinsing water (8 g of seaweed). This low concentration may have to do with the growing season of kelp. Kelp grows in the winter-spring period when the water has not yet warmed strongly (research data were from February-May) and the amount of vibrios in the water is still low. For *V. vulnificus,* Mahmud et al. (2008) observed that the concentration on the seaweed (in CFU/g; various species, especially *Porphyra*, *Undaria*, *Laminaria* and *Fucus*) are always higher than in the seawater (in CFU/ml). It was striking that no culturable *Vibrio* spp. could be detected in seawater in winter, while 3-4 log CFU/g was found on the seaweed (Mahmud et al., 2008). Research from Scotland showed that no *E. coli* was found on seaweed (different species) at a concentration of <10 CFU *E. coli*/100 ml seawater (Swinscoe et al., 2020). While in other research by these authors *E. coli* was found on seaweed at the same maximum concentration of *E. coli* in the seawater (<10 CFU/ml). There seems to be a difference in the type of seaweed. *E. coli* was not found on *Laminaria* (<10 CFU/g) and on *Palmaria* and *Ulva* (30 CFU /g and 11 CFU/g respectively) (Swinscoe et al., 2019).

Research by Lytou et al. (2021; 2022) showed that the year of harvest, the site of cultivation and the seaweed species have an impact on the microbiological quality (bacterial count) of seaweed (1,5-3 log CFU/g difference) and even on the extent to which the bacterial count can increase during the storage of seaweed. In addition, the microbiota on both species of seaweed (*A. esculenta* and *S. latissima*) appeared to be different in composition, which according to the authors is also supported by other research.

Swinscoe et al. (2020) investigated the change of the concentration of pathogens (*E. coli* and STEC O157, *L. monocytogenes* and *V. parahaemolyticus*) on seaweed (5 species) during the cultivation phase and during various processing and handling steps of the seaweed. Exposure (24 h at 20 °C) of the algae (cut pieces) to seawater contaminated with these pathogens resulted in contamination of the algae. On the seaweed, the concentration (in CFU/g) was higher than in the water (in CFU/ml), which was caused by growth. However, it is unclear whether growth can also take place on intact seaweed.

These data show that there can be a large variation in the relationship between microorganisms that occur in seawater and those that are on the seaweed, and that there are many factors that influence this relationship, such as the species of seaweed and the bacterium species. The assumption that human pathogenic microorganisms occur on seaweed to the same extent and composition as in the water in which the algae grows (Løvdal et al., 2021) therefore appears to be less valid. More relevant to the risk is the fact that bacteria (and viruses) that occur in the water can also occur on seaweed even if the concentration of these microorganisms in the seawater is low.

Data NVWA

In the period 2019-2021, the NVWA sampled various types of seaweed products and sea vegetables (final product/food; 533 samples) (Table 27). The samples came from retail (89%) and wholesalers and food producers (11%). About half (52%) of the samples were seaweed.

Of the seaweed products studied, the majority were wakame (82%), mostly in the form of salad (86%). It is not known what the origin (cultivation area) of the seaweed is. Wakame salad is often, if not always, sold as an thawed product in the supermarket. The majority of the seaweed products examined were salad (82%, 227 samples). Partly this was 'seaweed salad' without mentioning the species of seaweed. Most likely it is all about wakame. Dried seaweed was barely sampled. It is unclear to what extent it concerns fresh, blanched or salted seaweed. Seaweed is very perishable and therefore often undergoes a conservation step, such as blanching or salting.

In addition to seaweed, sea vegetables were also sampled, mainly samphire (95%). Sea vegetables grow on land and can come into contact with seawater, but that is not always the case. Sea vegetables are not part of the scope of this risk assessment and have only been taken into account as a comparison.

Seaweed and sea vegetables were examined for the presence of *B. cereus*, *L. monocytogenes*, *Salmonella*, STEC and *Vibrio* spp. (Table 28). *B. cereus* was found on both seaweed and sea vegetables (0.7% and 3.9% respectively). For seaweed, the numbers were between 10^2 and 10^3 CFU/g. For sea vegetables, the range was somewhat wider, namely between 10^2 and 10^4 CFU/g (7 samples 10^2-10^3 CFU/g, 3 samples 10^3-10^4 CFU/g). *L. monocytogenes*, *Salmonella*, STEC and *Vibrio* spp. were not found on the seaweed(s). *L. monocytogenes (1.2%)* and *Vibrio* spp. (2.8%) were found on sea vegetables. These were 2 *L. monocytogenes* isolates of serotype '4b, 4d, 4e' and one with serotype 1/2a,3a. The *Vibrio* isolates were non-pathogenic species of *V. cholerae* and *V. parahaemolyticus.*

Table 27 Overview of samples of seaweed and sea vegetables examined by the NVWA (2019-2021).

Product	Number of samples	Product	Number of samples
Seaweed	277	Sea vegetables	256
wakame salad	194	samphire	244
wakame	32	other[2]	12
seaweed (salad)	32		
other[1]	19		

[1] dulse, hijiki, hijiki (salad), kombu, red hornweed, green sea fingers, sea oak, sea lettuce, sea spaghetti and seaweed (dried); 1-4 samples per species.

[2] sea banana, sea fennel and seagrass (salad); 1-7 samples per species

Table 28 Overview of pathogens found in seaweed and sea vegetables sampled in Dutch retail and wholesale (including food industry) (2019-2021).

	Seaweed			Sea vegetables		
Number of samples	Positive	Total		Positive	Total	
B. cereus	2	276	0,7%	10	256	3,9%
L. monocytogenes	0	276		3	254	1,2%
Salmonella	0	265		0	248	
STEC	0	250		0	244	
Vibrio spp.	0	263		7	246	2,8%

Recalls

In the period 2003 to 2024, 10 notifications were registered in RASFF in the EU regarding the finding of a microbiological deviation in seaweed (Table 4). These included 2 notifications on mould formation on dried seaweed, 1 on a 'microbiological complaint' and 7 notifications on pathogenic microorganisms. Two of these notifications concerned the finding of *Salmonella*, one on dried seaweed (*S*. Idikan) and one on seaweed salad (*Salmonella* spp.). One notification concerned HEV in seaweed salad (wakame, via the Netherlands). The other four notifications concerned norovirus, two of which were outbreaks caused by seaweed salad (frozen) and two notifications of finding norovirus on frozen seaweed (wakame, seaweed salad).

Cressey et al. (2023) provide an overview of international recalls. In New Zealand, no recalls were notified regarding microbiological abnormalities in seaweed (2016-August 2022). This was also not the case in Australia (June 2019 – September 2022) and Canada (2019 – June 2022). In the US, one *border rejection* report was made in the period 2015-2021, concerning the finding of *L. monocytogenes* in seaweed with sauce.

Outbreaks

The sources consulted (literature, outbreak reports Netherlands, EU, USA, Australia, New Zealand) described 14 outbreaks caused by the consumption of seaweed. These were 2 outbreaks by *Salmonella*, 1 by STEC, 10 by norovirus (of which 7 outbreaks clustered) and 1 vibriosis outbreak in which seaweed was the suspected source (Table 29).

In the Netherlands, no outbreaks were recorded in the period 2017-2023 where seaweed was the source. In EFSA's data reporting, the data is aggregated on food groups, with seaweed falling into the category of vegetables. There is no breakdown by specific products, so there is no insight into the number of outbreaks caused by, for example, a product such as seaweed. There is also no mention of seaweed (wamake) in the text of the reports themselves.

Of the outbreaks described in the literature (Table 29), it is partly known what the (possible) source of contamination of the seaweed was. Of the 10 norovirus outbreaks, seven were clustering in Japan, and a symptomatic worker was the source of the infection. In a norovirus outbreak in South Korea, among other things, the seawater (production site) and the washing water (seawater) proved positive for norovirus. The production site was near a sewer drain. In the US, one outbreak of *Salmonella* occurred in the period 1998-2021 through consumption of seaweed. The cause of this salmonellosis outbreak turned out to be an unhygienic cultivation and process environment of the seaweed. Of the other outbreaks, no information is known on how the seaweed became infected.

Table 29 Overview of outbreaks caused by seaweed consumption.

Pathogen	Country	Year	Product	Sick	H$^{\$}$	Reference*
Salmonella	Wales	2014	Laverbread (cooked, chopped seaweed)	17	3	(Anonymous, 2014; Public Health Wales, 2014)
S. Weltevreden	USA (Hawaii)	2016	Seaweed, unspecified	16	4	NORS, (Nichols et al., 2017)
STEC O7:H4	Japan	2020	Seaweed salad (*Gigartina tenella*)	2958	-	(Kashima et al., 2021)
Vibrio spp.	Japan	-	possibly seaweed	-	-	(Kudaka et al., 2008)
Norovirus	South Korea	2012	Green seaweed, seasoned (Enteromorpha spp.)	91	-	(Park et al., 2015)
Norovirus	Japan	2017	Laver, dried and minced (7 different outbreaks)	2094	-	(Kusumi et al., 2017; Sakon et al., 2018)
Norovirus	Spain	2019	wakame salad, frozen from China	-	-	RASFF (2019.2938)
Norovirus	Norway	2019	wakame salad, frozen from China	>100		RASFF (2019.3003), (Whitworth, 2019; FAO & WHO, 2020)

$^{\$}$H: hospitalizations

* References from FSAI Sci. Com. (2020) and Cressey et al. (2023)

No seaweed-related outbreaks were reported in Australia (2009-2020) and New Zealand (2006-2022). The latter is confirmed by Cressey et al. (2023) (1997-2022 period). Information on food-borne outbreaks is available on the government's website in Hong Kong at an aggregate level, but necessary detailed information was not found. The websites consulted from Taiwan provided two English-language publications on outbreak surveillance in the period 1991-2000 (Chang & Chen, 2003) and 2014-2018 (Yu et al., 2021). In both publications, seaweed is not mentioned as a source of an outbreak.

From the literature studies, *B. cereus* and *Vibrio* spp. emerged as pathogens that were relatively common − compared to the other pathogens − on seaweed (products). In terms of outbreaks, the picture is different.

The FSAI report notes that outbreaks of food-related vibriosis are occasionally observed in Ireland, but have so far never been associated with seaweed (FSAI Sci. Com., 2020). In the literature searched by Cressey et al. (2023), only an abstract of a Japanese article mentioned a *Vibrio* outbreak possibly related to seaweed consumption. None of the articles in English mentioned seaweed as a source of vibriosis. Also Løvdal et al. (2021) note in their review that vibriosis outbreaks by seaweed seem rare. There are few (suspected) vibriosis outbreaks in the EU. In the period 2018-2022, 9 *strong evidence* and 23 *weak-evidence* vibriosis outbreaks were reported to EFSA (EFSA, 2021). The majority (23/32 outbreaks) of fishery products; Not by seaweed.

Outbreaks and cases of disease caused by *B. cereus* are associated with food stored for too long at a too high cooling temperature or a too low keeping-warm temperature, which allowed growth and/or toxin formation in the product. These are always products that have been heated. If seaweed is blanched, this could lead to the germination of spores of *B. cereus.* Therefore, the growth of these germinated spores should be prevented. There have been no known outbreaks where seaweed is the source and *B. cereus* the pathogen.

Effect processing and handling on pathogens in the chain

Seaweed contains many nutrients and moisture and is therefore a suitable breeding ground for bacteria. The shelf life of products based on fresh seaweed is therefore roughly between 1 to 2 weeks, but depends on the type of seaweed and the harvest season (Cressey et al., 2023).

The most commonly used processes that take place in the processing and handling of seaweed in relation to extending shelf life are drying, freezing, blanching, salting or fermentation. In addition, seaweed is first rinsed clean. Before consumption, rehydration (weeks) of dried algae or heating may still take place (3.2.3). In the supermarket, seaweed is mainly sold as a wakame salad. This appears (often) to be packaged under a protective atmosphere (MAP, modified atmosphere packaging). For this risk assessment, literature on the impact of different processes on microbial food safety was initially not specifically sought, but the topic was addressed in a number of the selected articles. In addition, specific literature has been sought on the effect of various processing processes on the microbiological quality and/or safety of seaweed. However, the overview given below does not pretend to be complete.

Rinsing

Seaweed is rinsed with (sea) water to remove pollution that is on the seaweeds. It may also remove microorganisms (Cressey et al., 2023). However, experiments show that after washing artificially contaminated seaweed (5 species) with drinking water, the amount of pathogens (*E. coli* and STEC O157, *L. monocytogenes* and *V. parahaemolyticus*) does not decrease, but may increase slightly (<1 log CFU /g) (Swinscoe et al., 2020). While other research shows that on naturally contaminated seaweed (≤ 30 CFU *E. coli*/g*)* no detectable amount of *E. coli* was present after washing (tap water) (Swinscoe et al., 2019). And in yet another study, there was no effect (<0.5 log CFU/g difference) of both washing with drinking water and washing with UV-treated seawater on the aerobic plate count (Mariene Agar, incubating 7 days at 15 °C) of seaweed (*S. latissima*) (Wirenfeldt et al., 2022). This study also showed that washing had no effect on the observed increase in aerobic plate count during refrigerated storage (16 days, 2.8 °C).

Research on the production of nori (dried laver of *Porphyra yezoensis*; three production sites) shows that washing (sea water) and then rinsing (tap water) has no or limited (3 log CFU/g decrease) on the aerobic plate count of seaweed (Wang et al., 2023).Also , the number of coliforms also increased (approximately 2 log CFU/g) at two of the production sites, which is an indication that the water used for washing and rinsing was probably not of good quality.

Use of freshwater instead of seawater may improve the ability of any pathogenic bacteria present to grow on the seaweed (FAO & WHO, 2022). On the other hand, the use of water that is not clean can lead to possible microbial contamination.

Drying

Drying is the most common technique used to extend the shelf life of seaweed (Løvdal et al., 2021; FAO & WHO, 2022). Seaweed can be dried in different ways. Traditionally, sun drying is done in the open air. This is slow and is therefore only suitable for small-scale production. It can lead to contamination with faeces from birds and pests and is therefore the least hygienic way of drying. Given the climate, this method of drying is not very relevant for seaweed grown in the Netherlands. Drying with air under controlled conditions and freeze drying are other drying techniques used. However, drying in an oven is most commonly used (FSAI Sci. Com., 2020; Cressey et al., 2023). Common temperatures are between 25 and 60 °C (Martelli et al., 2021; Sørensen et al., 2023). Water activity (Aw; a value (between 0 and 1)) indicating how much free water is present in a product) of dried seaweed (nori) is around 0.65 (Cressey et al., 2023).

Drying can reduce the amount of microorganisms present. This depends, in addition to the properties of the microorganism, on the technique used, the temperature, time and speed applied and the reduction in moisture content achieved (Cressey et al., 2023). It is known that, among others*, Salmonella* can also be found on dried products (e.g. herbs and milk powder), survives drying processes and can cause outbreaks by 'low moisture foods' (FAO & WHO, 2014), as well as spores of bacilli and clostridia.

Research by Vorse et al. (2023) shows that air drying and freeze drying of seaweed (*Saccharina latissima* and *Ascophyllum nodosum*) can lead to a reduction (2-4 log CFU/g) of (pathogenic) bacteria (*L. monocytogenes*, *V. parahaemolyticus*, *V. vulnificus*, *Salmonella, S. aureus* and *E. coli*). Air drying has more effect than freeze drying. Drying of seaweed (*Alaria esculenta*) by convection heat (hot air oven; 40 °C) resulted in a reduction (approximately 4 log CFU/g) of *Salmonella* (*S. typhimurium*) in research by Sørensen et al. (2023). However, research by Lytou et al. (2021) shows that drying at 40 °C can increase the plate count (2 log CFU/g increase), while at 50 °C and 60 °C a 2 log decrease was achieved.

Swinscoe et al. (2020) also see that drying at 40 °C does not always lead to a reduction of pathogens. Drying at 40 °C (7 days) had no effect on cell numbers of *E. coli* and *L. monocytogenes*, but this process was effective against STEC O157 (approximately 8 log CFU/g reduction), while *V. parahaemolyticus* grew the first 24 h before dying off (approximately 5 log CFU/g relative to initial concentration). *E. coli* was significantly reduced when dried at 50 °C (approximately 8 log CFU/g reduction). *L. monocytogenes* proved to be the most robust and unpredictable. A 5 log CFU/g reduction was achieved at 50 °C, while drying at 60 °C had no significant effect (Swinscoe et al., 2020).

Research on the effect of the drying process on the aerobic plate count of seaweed (three commercial production sites) shows that during the drying of nori (ground, mixed and pressed in blocks (approximately 20x20x10 cm); 40-50 °C for 2.5 hours) bacterial outgrowth may occur (1.9-3.3 log CFU/g increase in aerobic plate count) (Wang et al., 2023). A second drying step (gradual temperature of 35-90 °C, 3-4 hours) had no effect on the aerobic plate count. As regards coliforms, the first drying step resulted in approximately 2 log CFU/g reduction. The second drying step had no germ-reducing effect at two of the production sites, while at the other site a 2 log CFU/g increase was observed (Wang et al., 2023). Research on an additional drying step shows that drying nori blocks (10 layers) for 1 hour at 100 °C, 125 °C or 150 °C resulted in an approximately 1.3 and 3.5 log CFU/g decrease respectively.

Drying at 40-60 °C can therefore cause a decrease in the amount of bacteria, but is not necessarily considered to be an adequate germ-reducing step. Under less suitable production conditions, the drying process can result in the outgrowth of bacteria.

No outgrowth shall occur in dried seaweed (Aw 0.65) (Table 43). And at an Aw below 0.6, fungi and yeasts cannot grow out either (Løvdal et al., 2021; Cressey et al., 2023). During the storage of dried algae (6 weeks), the amount of pathogens seems to decrease (Vorse et al., 2023). However, during longer-term storage of dried algae (6 months), the number of culturable microorganisms (germ number, *Enterobacteriaceae, Bacillus* spp., *Pseudomonas* spp., *Vibrio* spp., yeasts and fungi) decreases significantly (depending on species and type of microorganism) (Lytou et al., 2021). The microorganisms remaining on dried seaweed can regrow after rehydration (Byappanahalli et al., 2003; Lytou et al., 2021). Norovirus also remains infectious on dried nori sheets after two months (Kusumi et al., 2017; Sakon et al., 2018).

Freezing and cooling

Seaweed/wakames salads sold in retail often have been frozen. Freezing can damage bacteria and thus reduce bacterial contamination. As with drying, this depends on the temperature and speed at which this happens as well as on the sensitivity of the microorganism to this. Bacterial spores are insensitive to freezing. Research shows that seaweed that has been frozen has less bacterial outgrowth (both in quantity and speed) than fresh seaweed (Jönsson et al., 2023). In this study, the variation in bacterial genera and species within this genera was also reduced by freezing compared to fresh seaweed.

Vibrio spp. are quite sensitive to stress and also to freezing (NZFS, 2017; US FDA, 2022). The effect of freezing on pathogens on seaweed is unknown (Cressey et al., 2023). Freezing seaweed (*S. latissima*; individual quick-freezing: 30 min at -42 °C, then at -20 °C) showed an unclear picture of the effect on the aerobic plate count. No bacteria were recovered after 11 days of storage (4.2 log CFU/g reduction), while aerobic bacteria were found after 457 days, albeit approximately 1.5 log CFU/g less than before freezing (Stévant et al., 2024). It is unclear what is causing this.

Cooling (<7 °C) inhibits or prevents outgrowth and/or toxin formation of *B. cereus*, *C. perfringens* and *S. aureus* in the final product. This also applies to the growth of most other pathogens. Preventing outgrowth is particularly essential for pathogens where ingestion of a low amount of cells gives a reasonable chance of infection (C. *jejuni*, STEC, *Salmonella*). But also to control pathogens that can grow at low temperature (<7 °C), such as *L. monocytogenes* and *C. botulinum*. *Vibrio* spp. are quite sensitive to refrigerated storage (0-5 °C) and may die (*V. parahaemolyticus*), but can also exist in a viable but non-culturable (VBNC) state (NZFS, 2017).

Research on (cooled) storage of fresh seaweed (knotted wrack (*Ascophyllum nodosum*) and sugar kelp (*Saccharina latissima*) shows that various (pathogenic) bacteria (*L. monocytogenes*, *V. parahaemolyticus*, *V. vulnificus*, *Salmonella, S. aureus* and *E. coli*) remain stable for 2 days or show a (small) decrease at 4 °C and 10 °C. The largest decrease (over 1 log CFU /g) was seen for *V. vulnificus* at 4 °C (Vorse et al., 2023). None of the pathogens grew to knotted wrack at 20 °C during the 2-day storage period, while sugar kelp showed an increase in *Salmonella*, *V. parahaemolyticus* and *E. coli* and, remarkably, a decrease in *L. monocytogenes*. On the contrary, other studies with sugar kelp showed a decrease in *Salmonella*, *L. monocytogenes*, STEC and *Vibrio* spp. during storage at 22 °C (8 hours) of whole and sliced sugar kelp (0.7-3 log CFU/g reduction) (Akomea-Frempong et al., 2023). Also at 4 °C and 10 °C, the concentration of these pathogens decreased during storage (7 days). *Salmonella* and STEC were found to be the most robust (3-3.6 log CFU/g reduction), while for *Vibrio* spp. (*V. parahaemolyticus* and *V. vulnificus*) the largest reduction was observed (at 4 °C this was more than 5 log CFU/g). Possibly this could also be VBNC cells, so that it is not a real reduction in risk. Research on *B. cereus* showed that this pathogen could not grow on rehydrated seaweed (*Palmaria palmata*, *Undaria pinnatifida*) stored at refrigerator temperature (4 days) (Martelli et al., 2021). Lytou et al. (2021) in their study saw an increase in the germ count on *Alaria esculenta* at 5 °C of around 4 log CFU/g in 4 days and at 10 °C of around 6 log CFU/g.

Packaging under protective atmosphere

Research by Moreira-Leite et al. (2023) looked at the effect of MAP and vacuum packaging on the microbiological quality of seaweed (*Porphyra umbilicalis*, *Ulva lactuca*) during refrigerated storage (6 °C). Packaging under MAP and vacuum prevented bacterial outgrowth (marine bacterial count) on *Porphyra umbilicalis* and resulted in a decrease from 6 days (>0.5 log CFU/g reduction), to even below the detection limit at day 15 (>4 log CFU/g reduction). Packaging had no effect on the bacterial count (marine bacteria) on *Ulva lactuca,* which remained stable (packaged, unpackaged).

Heating

Various heating processes are used in the production of processed seaweed, such as blanching, cooking, roasting, frying and frying. These processes inactivate to a greater or lesser extent the microorganisms present on the seaweed. Blanching is a fairly mild heat treatment (short time in hot water) and seems to be frequently applied (extends quality and shelf life), including in the production of seaweed/wakames salad (Banach et al., 2022; Cressey et al., 2023). Little is known about the extent to which the applied heating processes have an effect on the reduction of pathogenic microorganisms and which products (by default) undergo a heating step (Cressey et al., 2023).

Research shows that blanching seaweed may not be very effective. A 2-minute treatment in water of 60 °C resulted in approximately 1 log CFU/g reduction of the aerobic plate count on *S. latissima* (Stévant et al., 2024). The study of Zhu et al. (2022) on the effect of, among others, blanching (70 °C, 5 min) of seaweed (*Alaria esculenta, Ascophyllum nodosum*) does not allow a conclusion on the absolute effect (number of log reductions) of the treatment. However, blanching appears to result in a greater reduction in aerobic plate count than salts (1% w/w) and HPP (500 MPa, 3 min).

In research by Wirenfeldt et al. (2022), *S. latissima* was blanched in drinking water (2 min, 76 °C) or seawater (2 min, 80 °C). This resulted in a reduction of 3-3.5 log CFU/g of the aerobic plate count (on Marine Agar, 7 days at 15 °C). In another study, a blanching step (1-3 minutes at 100 °C) resulted at most in a reduction in aerobic plate count of 0.5 log CFU/g (Cressey et al., 2023). In research by Banach et al. (2024), *B. cereus* (1/5 versus 0/5 samples) and *Vibrio alginolyticus* (2/5 versus 5/5 samples) were more commonly found after blanching (no time temperature indicated). The latter may indicate post-infection.

Heating seaweed (various species available in Ireland, heating in an autoclave (steam)) at 85 °C for 15 minutes resulted in activation and germination of bacterial spores, raising the temperature to 95 °C caused complete inactivation of the bacteria present (Gupta et al., 2010). It was striking that in the study of Gupta et al. (2010) no bacteria (aerobic plate count, halophilic and extreme halophilic plate count) were found on raw seaweed (brown seaweeds: *Himanthalia elongata, Laminaria sachharina* and *Laminaria digitata*). Also in the limited microbiological study of Banach et al. (2024) *B. cereus* was found more frequently (1/5 vs 0/5 samples) after blanching. Other studies showed steaming of fresh seaweed (15 minutes at 95 °C; *S. latissima*) but have limited effect on aerobic platelet count (1.5 log CFU/g reduction) (Stévant et al., 2024).

Fresh seaweed has the property of being able to clump during heating, which can adversely affect the effectiveness of the heat treatment. This property differs per seaweed species (Løvdal et al., 2021).

Also dried seaweed can still be heated, for example by roasting. Applying a second roasting step (260-400 °C, 2-10 s) to dried nori appears to be quite effective in reducing microbial contamination (up to almost 5 log CFU/g reduction in total plate count) (Choi et al., 2014).

Salting

Seaweed has traditionally been salted to extend its shelf life. This can involve very high amounts of salt (40% on a weight basis). The addition of salt reduces the Aw, limiting or preventing the growth of microorganisms. When salted with 30% salt, seaweed (kelp) can be stored without cooling (25 °C) for 30 days without loss of quality (Løvdal et al., 2021). Salting can lead to a reduction in microorganisms, but it is unclear whether it achieves a sufficient level of reduction of pathogens to ensure the safety of the product (Cressey et al., 2023). Quantitative data on this were published in research by Stévant et al. (2024). In that study, salts of seaweed were used as a process step. Seaweed was salted for 1 hour (2:3 weight ratio salt:seaweed) resulting in approximately 2 log CFU/g reduction of the aerobic plate count. This treatment was more effective than blanching (2 min, 60 °C) and steaming (15 min, 95 °C).

Zhu et al. (2022) investigated the effect of dry salts (1% by weight) of seaweed (*Alaria esculenta, Ascophyllum nodosum*) on aerobic plate count. Dry salting has an effect on the aerobic plate count and its increase during refrigerated storage (4 °C). It is unclear what the magnitude of the effect is (initial concentration is lacking). It is clear that salting reduces the plate count during the first days (3 days) of refrigerated storage, after which the plate count increases. This differs per seaweed, on *Ascophyllum nodosum* the level after 7 days of storage is 6 log CFU/g, while on *Alaria esculenta* after 14 days is still <4 log CFU/g present (Zhu et al., 2022).

Fermenting

Fermentation of seaweed could reduce the risk of pathogens, due to the low acidity of the final product (Hogstad et al., 2023). However, fermentation (by lactic acid bacteria) of seaweed is a fairly recent application, probably due to the fact that on and in seaweed no lactic acid bacteria and simple fermentable sugars occur naturally (Løvdal et al., 2021). Research by Banach et al. (2024) shows that fermentation (blanched seaweed) reduced the frequency at which *V. alginolyticus* was found on seaweed (from 5/5 samples positive before fermentation to 1/26 samples positive after fermentation). The fermentation process had no effect on *B. cereus* (before and after fermentation 1/5 and 2/26 samples positive, respectively). In another study on seaweed fermentation, seaweed was first heated for fermentation (100 °C, 3-5 minutes), resulting in a pathogen-free product. No pathogens (*B. cereus, C. perfringens*, pathogenic staphylococci, coagulase-positive staphylococci, *Vibrio* spp. and *Enterobacteriaceae*) were found after fermentation either (Maiorano et al., 2022).

High Pressure (HPP)

Another technique for preserving seaweed is high-pressure processing (HPP). Research conducted by Jönsson et al. (2023) on the effect of HPP on the microbiological quality of seaweed showed that HPP (180 sec at 200 MPa, 400 MPa or 600 MPa) has a large effect on the texture and structure of seaweed. It was not possible to observe an effect of the HPP treatments on the microbiological quality of seaweed, because the initial contamination was too low. In research by Zhu et al. (2022), brown seaweed (*Alaria esculenta*, *Ascophyllum nodosum*; Ireland) treated with high pressure (500 MPa, 3 min). After 30 days of storage at 4 °C, the product still had an acceptable level of aerobic plate count (approximately 3 log CFU/g).

4.6.2.4 Risk characterisation

Seaweed has a long tradition as a food in countries in Asia, such as China, Japan and South Korea. In Europe − but also in the USA and Canada − the consumption and cultivation of seaweed has only recently come to the attention, including research into its food safety. Data on the occurrence of most food-related pathogens is virtually missing. The same applies to data on the impact of the different processing steps that seaweed undergoes on microbiological food safety and to shelf life studies. As a result, the risk characterisation has a high degree of uncertainty. In order to understand the risk, a comparison has been made with fishery products because they are harvested from the same environment.

For fish, crustaceans and shellfish, microbial contamination is influenced by the type of product (in this case the type of seaweed), the aquatic environment in which the product is grown or grows, the season in which it grows and is harvested and the way it is harvested, prepared and eaten (Reilly & Kaferstein, 1999; Iwamoto et al., 2010). These factors also emerge as being of importance for seaweed based on the publications selected for this risk assessment, such as by the FAO and WHO (2022), among others.

As with fish, there will be other factors that affect the microbiota of seaweed. For fish, one of the important factors is whether it concerns wild catch or aquaculture (Reilly & Kaferstein, 1999). For seaweed, the possible parallel herein is growth in nature (wild harvest and cultivation in open water) versus cultivation in saltwater basins on land. However, Cavallo et al. (2021), in their review on the food safety of seaweed, specifically mention open basins as a risk of introducing pathogens from, among others, pests and birds, while Winkel (2022) indicates that when seaweed is grown in tanks on land conditions can be controlled and thus the risk of many hazards (including *Vibrio* spp. and *C. botulinum*) is controlled.

Other factors that play an important role for fish in terms of the occurrence of pathogens are the water temperature, the salinity of the water, the proximity of humans to the harvesting area and the region where the fish comes from (Reilly & Kaferstein, 1999). In general, fish, crustaceans and shellfish originating from colder waters contain lower amounts of pathogenic bacteria than fish, crustaceans and shellfish originating from warmer waters (Hastein et al., 2006; Iwamoto et al., 2010). All these factors also seem to apply to seaweed.

The pathogenic microorganisms found in particular on seaweed originate from the aquatic environment: *B. cereus* and *Vibrio* spp. (30-40% positive). It therefore seems plausible that other environment-related pathogens such as *C. perfringens* and *C. botulinum* will also be found on seaweed.

Indicator organisms of exposure to faecal contamination (enterococcal, coliforms) are regularly found on seaweed. Pathogens originating from humans and/or animals, such as *Salmonella*, STEC, norovirus and − also from the process environment − *L. monocytogenes* have also been detected on seaweed. These pathogens can therefore end up on seaweed from the water, with proximity to human activity being the main cause. In particular, proximity to sewage discharge is a risk factor.

No studies have been found with data on food-borne parasites on seaweed. Only one publication on viruses is available with very limited research on viruses (norovirus) and also publications on a number of norovirus outbreaks. This shows that norovirus and *T. gondii* can occur on seaweed. However, it is known that *Giardia* and *Cryptosporidium* occur in (sea) water and cause disease through exposure to water. HAV is not endemic in the Netherlands and for rotavirus food does not play an important role in the transfer, so the role of seaweed from the Netherlands in the exposure to these viruses is not important. Also, the share of seaweed in the exposure to HEV is estimated by BuRO as very small, because even shellfish that accumulate viruses (oysters, mussels) do not give relevant exposure to HEV. For seaweed grown in the Netherlands, only norovirus may be relevant, because it is known that this virus is found in shellfish originating from Dutch farming areas.

Seaweed can be eaten raw, but usually undergoes some form of processing before it is placed on the market as a food, such as rinsing, heating (including blanching), drying or salting whether or not in combination with refrigerated storage (refrigerator). These steps can have a germ-reducing effect, with the degree of reduction depending on the process, the species of seaweed and the pathogen. It is unclear whether these steps provide an adequate germ reduction for any pathogenic microorganisms present.

Data from the NVWA show that on fresh samphire (unprocessed vegetables*)* from the retail/wholesale trade *Vibrio* spp. is found (3%), but that this pathogen was not demonstrated on seaweed. The seaweed was largely (95%) wakame/salad. This is a processed product, which is often first frozen and then is sold thawed and can contain, among others, preservative and salt. This is very likely to have an effect on the survival of *Vibrio* present on raw seaweed. In addition, the products come from different locations, so that making a comparison is not possible. However, it is clear that *Vibrio* spp. can be found on plant products grown in (near) the sea.

Fresh seaweed (not dried or salted) has a short shelf life and should be kept refrigerated. The very limited data available on the survival/growth of pathogens on seaweed shows that various pathogens may die during refrigerated storage of seaweed. On the basis of these data, it is not possible to determine whether pathogens − and in particular *L. monocytogenes* − can grow on fresh seaweed within the shelf life.

Outbreaks caused by the consumption of seaweed are not often described and appear to be mainly caused by microorganisms originating from humans and/or animals. The source of contamination is often contaminated seawater or an infected food handler. The food safety of seaweed itself (product specific risk) seems to be strongly associated with the quality of the water in which it is grown.

Vibrio spp., *B. cereus*, *C. perfringens* and probably *C. botulinum* occur naturally on seaweed. The risk of *B. cereus* and *C. perfringens* is particularly associated with heated products that have not cooled adequately. Control of the risk therefore lies with the food preparer. *C. botulinum* is assessed as a relevant hazard to seaweed because it is likely to occur naturally on seaweed and there are storage conditions that may be beneficial for growth of *C. botulinum* (including MAP packaging).

Vibrio spp. occur naturally on seaweed due to contamination from the environment (water). *Vibrio* spp. is also found in Dutch waters. In summer, the concentration of *Vibrio* spp. in Dutch waters can reach 10^1-10^3 MPN/ml. The chance of infection by *Vibrio* spp. is only reasonably plausible when ingesting a higher concentration of cells and this differs per *Vibrio* species (10^3-10^6 CFU/g). For example, for *V. parahaemolyticus,* the ID50 (the dose at which 50% of those exposed will become ill) is 10^8 CFU/consumption (US FDA, 2005). And although this dose for *V. vulnificus* for healthy people is not known, the assumption is that less than 100 cells cause disease (blood poisoning) in susceptible people (weakened immune system, liver disease) (ESR (MPI), 2001). However, not all isolates of a pathogenic *Vibrio* species contain virulence genes. Research shows that virulent strains are rarely found in Europe (0-2%). This can change if the average water temperature rises (climate change). Vibriosis outbreaks are not yet common in Europe and fishery products are the main source. It therefore seems that the consumption of seaweed grown in the Netherlands does not currently lead to a high level of exposure to pathogenic amounts of *Vibrio* spp.

The occurrence of pathogenic microorganisms on seaweed cannot be properly estimated on the basis of available data. As a result, the risk characterisation has a high degree of uncertainty. It was therefore decided to compare the risk of seaweed consumption with a product group with a known risk. For the purpose of the risk assessment, a comparison was therefore made, as an indication, with the risk of the consumption of fish, crustaceans and shellfish previously assessed by BuRO (BuRO, 2022). After all, products from the fish, crustacean and shellfish supply chain come from the same environment (seawater) and partly have the same hazards. For the situation in the Netherlands, BuRO assessed that the probability of contracting a *Vibrio* infection (symptomatic) due to consumption of fishery products (in particular shellfish) is currently low. For infection with *Salmonella* and STEC, that probability was assessed as low and very low, respectively. Viruses mainly play a role in shellfish. Viruses involved in shellfish-related outbreaks are primarily NoV, but also HAV. HEV does not play a role. The risk of the protozoan parasites *Cryptosporidium* spp., *Giardia* spp. and *T. gondii* via consumption of fishery products is estimated to be limited. Although no estimate of the risk of infection was given (BuRO, 2022), it is estimated to be very low based on the available data. Compared to fishery products, seaweed − like fish − does not seem to accumulate microorganisms, as filter-feeding shellfish can. Possible exception to this could be *Vibrio* spp.. For consumption of seaweed, it is assessed on the basis of available data that the chance of contracting an infection by pathogenic microorganisms is very likely to be lower than the chance of infection by these hazards through consumption of shellfish (oyster, mussels) and that the chance is likely to be comparable to the risk of these pathogens through consumption of raw fish. As a result, the chance of contracting an infection through consumption of seaweed will be low to very low.

Based on the available data, any microbiological hazards from the environment (seawater, soil sediment) that may be present on seaweed do not appear to contribute significantly to the risk to human health (population level) or to consumers (consumption level). However, *C. botulinum* is a relevant hazard.

The food safety risk of seaweed comes mainly from pathogens associated with humans and/or animals. In addition to applying the standard hygiene measures during the preparation and storage of food, managing the risk is preventing the water in which the seaweed is grown from being contaminated with faeces (sewage water, run off of agricultural land, recreation).

4.6.2.5 Conclusion on microbiological risks

A wide variety of microorganisms occurs on seaweed. Seaweed can become contaminated with pathogenic microorganisms during cultivation, harvesting or further processing and handling. The latter route of contamination is not specific to seaweed and has therefore not been included in this risk assessment. Contamination during harvest can occur by hand contact (*Staphylococcus* spp.) or a sick worker and has been assessed as not a major source of infection. During the cultivation phase, contamination may occur with pathogens naturally occurring in seawater or seabed (in particular *Vibrio* spp, *B. cereus* and very likely *C. botulinum*) or with pathogens originating from humans and/or animals (in particular *Salmonella*, STEC, *L. monocytogenes* and norovirus). The main introduction route of this latter group of microorganisms is the proximity of a sewage discharge point or overflow to the farming or harvesting area. Data on the occurrence of parasites and viruses other than norovirus are largely missing, but seaweed does not appear to play a role in human exposure to these hazards (excluding norovirus). Seaweed can undergo various processing steps (e.g. washing, blanching, drying, salting, fermenting), but much is still unclear about the germ-reducing effect of these treatments, including for the different seaweed species. Although seaweed is consumed regularly in other countries (especially Asia), outbreaks have hardly been described in the literature. In some cases, it mainly concerns contamination by pathogens originating from humans and/or animals. It is therefore these pathogens (including *Salmonella*, STEC, norovirus) supplemented with *C. botulinum* that should be considered as a relevant hazard to seaweed.

4.7 Food safety physical risks

4.7.1 Approach and scope of physical risk assessment

In order to assess the physical risks related to the food safety of seaweed, the four steps of the risk assessment were followed:

1. Hazard identification: inventory of foreign objects and micro- and nanoplastics that could end up in seaweed and seaweed products.
2. Hazard characterisation: the effects that the foreign objects and micro- and nanoplastics in the seaweed chain can have on humans.
3. Exposure assessment: how often can foreign objects and micro- and nanoplastics end up in seaweed and seaweed products
4. Risk characterisation: assessment of the risk to public health in the Netherlands caused by the consumption of seaweed (products) containing foreign objects and micro- and nanoplastics (conclusion of the risk assessment).

This risk assessment is based on information from the literature. There are no data on physical hazards in Dutch-farmed seaweed or in seaweed products from Dutch supermarkets and wholesalers.

For the description of physical hazards in the seaweed chain related to food safety, this assessment makes a subdivision into two categories: foreign objects and micro- and nanoplastics. There are other physical hazards that are inherent to the product itself or the (method of) preparation. These are not included here, as this is generally part of the dangers of consuming food. Food can have a high temperature or have a shape or consistency that poses a risk of suffocation or injury when ingested.

The dangers associated with the work in the seaweed chain, such as cutting injuries, have also been disregarded, as have the dangers for the consumer in the preparation.

4.7.2 Risk assessment of physical hazards

Normally, within the food chain, all visible contaminants, living or non-living, are classified as physical hazards from the point of view of hazard analysis and critical control points (HACCP). The size of a foreign object is of greater importance for this definition than its properties (Batt, 2016). As a practical limit for the size of a foreign object in food that can cause health damage, the literature regularly cites a value proposed by Health Canada from 2 millimetres, with the note that this can also be smaller for infants (Health Canada, 1990). It is possible that foreign objects do not present a risk of physical injury, but of damage due to other hazards of a microbiological or chemical nature (e.g. insects or faeces).

Micro- and nanoplastics are considered as physical hazards in the literature when it comes to the seaweed chain (Banach et al., 2020b; FSAI Sci. Com., 2020; FAO & WHO, 2022). Therefore, as in the fish supply chain risk assessment (BuRO, 2022), they are treated for physical hazards, although these particles also have alleged chemical and microbiological hazards. Microplastics are particles of a size of 5 mm to 0.1 µm, and nanoplastics are smaller than 0.1 µm (EFSA CONTAM Panel, 2016; Garrido Gamarro & Costanzo, 2022). This partly overlaps the definitions of the size of plastic foreign objects. With regard to effects of plastics between 2 and 5 mm in size, they are included in the category of foreign objects.

4.7.2.1 Hazard identification

In the inventory of possible hazards that may occur in the seaweed chain, it was checked which processes and actions take place in the chain and which foreign objects can be introduced. In addition, we looked at the introduction of micro- and nanoplastics.

RASFF

Of the 275 notifications on seaweed in RASFF, two were notified on foreign objects (Table 4). Both notifications indicate that parts of shells were found in seaweed and are related to each other.

A search in the data of the Recalls, Market Withdrawals, & Safety Alerts of the FDA (Food and Drug Administration, US) has not resulted in reports of seaweed (products) with physical hazards.

Cultivation, harvesting, transport and storage

Several physical hazards have been identified or associated with the seaweed chain (EFSA CONTAM Panel, 2016; Cavallo et al., 2021; FAO & WHO, 2022). After harvesting seaweed, physical hazards may remain in the seaweed. This can include impurities such as sand and small stones, but also plastic and metal particles from the environment where the seaweed was farmed. In addition, pieces of molluscs and crustaceans can be transported. There are also marine animals that can attach to the surface of mainly older seaweed, such as barnacles (Hogstad et al., 2023). The lines on which the seaweed grows are often made of polymers such as polypropylene. When the seaweed is cut from the knots on the lines at harvest, fibres from these lines can end up in the harvested batch (Banach et al., 2022).

Plastic is widely present in the sea. These plastic particles can have different types and shapes and are divided into primary particles (manufactured as such) and secondary (caused by decomposition of larger objects) micro- and nanoplastics (EFSA CONTAM Panel, 2016). Micro- and nanoplastics are also added to personal care products such as shampoo, cosmetics and are found in clothing and packaging materials (KWR, 2021). They enter the aquatic environment via waste water. Antifouling materials on vessels also seem to be an important source for micro- and nanoplastics in the aquatic environment (Dibke et al., 2021). Finally, they are added to fertilising products (Bool, 2021) and can leach to surface water. Micro- and nanoplastics easily attach to seaweed (EFSA CONTAM Panel, 2016; Xiao et al., 2024) and can be introduced during breeding (hatchery) and farming (cultivation). Post-harvest treatment can remove microplastics. Microplastics that attach to seaweed can cause chemical or microbiological contaminants to be carried (FAO & WHO, 2022). In addition, micro- and nanoplastics may be enclosed in the seaweed during growth. No specific literature is available on this subject, but it has been demonstrated in other food crops (WHO, 2022). After treatment will not remove these plastics.

No data are available on introduction of physical hazards introduced during transport and storage of seaweed. The foreign objects and micro- and nanoplastics that came with the harvest are also transported in this phase. Based on data from other food chains (e.g. (BuRO, 2022)), it is not excluded that foreign objects may end up in the seaweed at this stage, for example due to improperly cleaned storage facilities. Depending on the circumstances, micro- and nanoplastics may be introduced.

Processing and packaging

During the processing of seaweed, foreign objects can be introduced in a number of ways. These are glass, plastic of packaging material and metal particles from cutting tools for cutting seaweed (Banach et al., 2020a; Concepcion, 2020). Furthermore, objects from the processor can come into the product (plasters, part mask, safety glasses). No incidents in the seaweed chain were found, but this has been described for other domains in the food industry, such as the meat industry (Christensen & Larsen, 2014). Another aspect at this stage is the introduction of insects and (parts and products of) pests as foreign objects. This has described for foods in general. For example, if hygiene is not guaranteed between harvest and consumption, insects can settle on the seaweed, or pests can reach the seaweed (Edwards, 2014).

The risk of physical hazards (foreign objects) is significantly reduced by sufficient rinsing of the seaweed, but the removal of barnacles will often have to be done mechanically (Hogstad et al., 2023).

The release of microplastics from food contact materials can also contribute to the prevention of micro- and nanoplastics in food (Garrido Gamarro & Costanzo, 2022).

The presence of foreign objects in seaweed products is shown, among other things, by the study by Fillipini (2020), which examined 72 samples of seaweed products purchased in Italy. The aim of the study was to analyse the content of heavy metals, iodine and arsenic. Contaminants, small crustaceans and (shells of) molluscs were found during the study of the samples. Another Italian study, focusing on imported products from the sea, found a shard of glass in a seaweed sample (Panebianco et al., 2019).

4.7.2.2 Hazard characterisation

The hazard characterisation consists of the effects that the foreign objects in the seaweed chain can have on humans, such as suffocation, cuts and other physical injuries. There are no health based guidance values with regard to physical hazards. There are also no well-described reports of illness or death due to these hazards in the literature. The rare reports of morbidity and mortality are related to microbiological and/or chemical hazards (Cheney, 2016).

Foreign objects

The hard objects under the foreign objects such as metal, hard plastic and glass can cause injuries such as cuts to lips, broken teeth, suffocation (blocked respiratory tract) and perforation of esophagus or respiratory tract (Edwards, 2014). Blockage of the respiratory tract can also play a role in softer objects, as well as blockage of the esophagus. The latter is often caused not by foreign objects but by the food itself (Ambe et al., 2012). For seaweed (kombu), a case has been described for a blocked esophagus in a vulnerable person (Kusaba et al., 2019). A systematic review of the literature on foreign objects in the esophagus of adults provides more than 10,000 cases (Aiolfi et al., 2018). Bone (fragments) are most often described as the cause of the problem, especially fish bones and chicken bones. Most of the objects could be removed endoscopically, in 3.4% of the cases surgery was necessary. In rare cases, the esophagus can be perforated, causing damage to vital organs such as the heart or blood vessels (aorta) (Ugenti et al., 2015; El-Matbouly et al., 2021). Another study describes a number of cases in which sharp foreign objects have caused injury further into the digestive tract, but this is also rare (Emir et al., 2013). Apart from the Kusaba seaweed casus, none of the sources cited here describe a direct link with seaweed (products).

Micro- and nanoplastics

Much remains unclear about the potential health effects (hazards) of micro- and nanoplastics (Garrido Gamarro & Costanzo, 2022; WHO, 2022). Micro- and nanoplastics also form a complex and diverse group of particles with different properties that can affect them. A distinction can be made between physical, chemical and microbiological effects of micro- and nanoplastics. Factors that may play a role in the effects include particle size, shape, type of material (and the substances that can migrate from it), additives used and physico-chemical properties of the surface of the particle (density, hydrophobicity, charge and functional groups). In addition, the hazard properties can change due to environmental influences, for example because the material weathers, substances adsorb to the plastic or because a biofilm forms on the surface of the particle.

Additional information is necessary for hazard characterisation, including understanding the potential to function as a vector for chemical contaminants and pathogens (Banach et al., 2020a). As a result of this missing information, there is currently no legal or health based guidance value for these particles (FSAI Sci. Com., 2020).

4.7.2.3 Exposure assessment

In order to get an impression of whether and how often foreign objects can end up in seaweed and seaweed products, data on the occurrence of these objects in seaweed have been searched. For this purpose, databases with reports on foreign objects in food were consulted, RASFF and the FDA's Recalls, Market Withdrawals, & Safety Alerts. In addition, relevant scientific literature and verifiable reports via Google have been used.

For micro- and nanoplastics, literature and reports on the occurrence of these particles have been used.

Foreign objects

Data on exposure to foreign objects from seaweed are scarcely available. There are hardly no notifications in either RASFF or FDA data base. Reports in scientific literature and in media reports about physical contaminants found are also limited. Based on the few reports, no estimation of the exposure can be made.

Micro- and nanoplastics

In light of the impact of micro- and nanoplastics as a potential contaminant in seaweed, the concern is focused on the huge amounts of plastic in the oceans and how it can affect marine food chains and public health. Research of Xiao indicates that in East Asian countries, seaweed is the main source of consumer intake of micro- and nanoplastics (Xiao et al., 2024). For the Dutch situation, this is not (yet) clear.

A major limitation in current exposure data is that data on the occurrence of particles smaller than 10 µm in foods are limited, whereas these are precisely the particles that can pass through the human intestinal wall (WHO, 2022). Currently, analytical methods are still insufficient to measure the more relevant nanoplastics in food (WHO, 2022). The same applies to seaweed. At the moment, there is insufficient insight into the intake of micro- and nanoplastics via food.

4.7.2.4 Risk characterisation

The basis for the risk assessment of the physical hazards caused by foreign objects is that there is no safe limit to consumer exposure to foreign objects in seaweed and seaweed products. In practice, this means that the products must be free of foreign objects when they reach the consumer. However, a foreign object in food does not directly poses a risk to the consumer. For example, if there is a risk of suffocation, this is related to the size of the object, and if there is a risk of cutting this is related to the edges and points of an object.

Foreign objects

The presence of physical hazards in the form of foreign objects in seaweed and seaweed products occurs. Control measures in the chain prevent the consumer from being exposed to physical hazards. Notifications of foreign objects in the seaweed chain are limited. However, if only traditional detection methods such as metal detection are used, it is possible that foreign objects end up with the consumer. This is particularly the case with fresh seaweed. Due to the lack of sufficient data on exposure, a risk assessment is not possible.

In food production in general, foreign objects are the main source of consumer complaints (Edwards & Stringer, 2007). Detection is used to prevent these foreign objects from reaching the consumer. Examples are metal detection, X-ray detection and infrared detection, but visual inspection is also used (Panebianco et al., 2019). The effectiveness of these detection methods varies according to the food concerned and the expected foreign objects. In addition, the extent to which maintenance of detection and compliance is taken into account in the business operations is important, something that according to Panebianco in the Asian food industry may be substandard. This is based on a limited sample (Panebianco et al., 2019).

According to Kwak et al., detecting foreign objects in seaweed is not easy because of variation in colour and the uneven, greasy surface. This is why in the Korean seaweed industry, the effectiveness of conventional foreign object detection is only 80% (Kwak et al., 2021).

Micro- and nanoplastics

Management measures to prevent of micro- and nanoplastics in the chain are limited. The main measure is the washing or rinsing of seaweed. This can significantly reduce the amount of microplastics on the seaweed (Sundbæk et al., 2018). However, it is not clear whether this is also the case for the particles with a size <10 µm, given the use of larger particles in this study. In addition, it has no effect on micro- and nanoplastics that may be included in the seaweed (enclosed plastics).

4.7.2.5 Conclusion on physical risks

The main physical hazards in seaweed are (pieces of) crustaceans and small stones to which the spores of seaweed have attached to grow. These physical hazards may remain undetected during processing or consumption of fresh seaweed (FAO & WHO, 2022). The main method of removing the foreign objects that came with the seaweed harvest is rinsing, although the removal of barnacles often have to be done mechanically (Hogstad et al., 2023).

Given the lack of information on the effects of micro- and nanoplastics on the human body and data on the occurrence of plastic particles <10 µm in seaweed, a risk assessment of this hazard is currently not possible.

5 Risks to nature– alien species

5.1 Introduction

The cultivation of seaweed in open water may change the aquatic ecosystem where cultivation takes place. Seaweed beds may alter currents and affect sedimentation (Gittenberger, 2025). In addition, seaweed competes with other organisms for light, space and nutrients. Seaweeds can also be a soure of nutrients themselves, provide shelter or be a habitat for other organisms. This can increase their number as a result (Campbell et al., 2019; FAO, 2022).

When assessing the risks of seaweed cultivation to Dutch nature, the focus of this risk assessment is on alien species and the effects of these species on biodiversity and the aquatic ecosystem in the Netherlands. Alien species are species that do not occur naturally in the Netherlands. In this case, the Netherlands refers to Dutch marine and brackish water areas: the Dutch section of the North Sea, the Dutch section of the Wadden Sea and the Southwest Delta.

Alien species can be harmful to Dutch nature, but also to human health, safety and the economy. When an alien species has been identified as adversely affecting or threatening biodiversity and related ecosystem services, it is called an invasive alien species.

If alien species are used in seaweed cultivation or if alien species hitchhike with the starting material (the cultivated species), then there is a possibility that these species are introduced in natural ecosystems and establish there. In addition, a seaweed bed may be a place where (other) alien species can establish. Some alien species, but certainly not all, can have a negative impact on nature. This is the case, for example, when they are invasive and outcompete native species.

5.2 Scope

This risk assessment concerns the possible risks to Dutch nature due to the introduction, establishment and spread of alien species (seaweeds or other organisms) as a result of seaweed cultivation. It concerns alien seaweed species that are deliberately brought to the Netherlands for seaweed cultivation, alien seaweed species that have previously been introduced by other human activities and alien seaweed species that naturally wash ashore here. It also concerns alien species that occur in the cultivated seaweed. The species are alien to the Netherlands. They may be alien or native to other parts of Northwest Europe.

This risk assessment does not address other potential impacts of seaweed cultivation on nature, such as disruption of ecosystems due to noise from activities during seaweed cultivation and/or harvesting, or a reduced availability of nutrients due to seaweed cultivation (Campbell et al., 2019; Tonk & Jansen, 2019). This risk assessment also does not address the risks to nature in nearby countries. The conditions in these countries do not always correspond to those in the Netherlands.

5.3 Approach

5.3.1 Collection of Dutch data

In order to assess the risks of seaweed cultivation regarding alien species, BuRO commissioned research agency GiMaRIS to carry out a field study at Dutch seaweed farms (including wild harvest). In this field study, the cultivated alien seaweed species and other alien species present in the cultivation were inventoried. Subsequently, for these alien species, an assessment was made of the increased chance of introduction, establishment and spread, and of the impact of these alien species on the aquatic ecosystem as a result of the seaweed cultivation activities carried out at the time of the study (Gittenberger et al., 2020b). GiMaRIS also carried out a desk research on behalf of BuRO, together with WMR, into the risks of potential future seaweed cultivation in wind farms in the North Sea (Gittenberger et al., 2020a). GiMaRIS has also been commissioned by BuRO to assess the impact of a number of alien seaweed species with commercial value on nature in the Netherlands (Gittenberger, 2025). For this assessment, a limited literature study has been carried out, which has been combined with previous observations and expert judgement. Changes in the origin of the starting material used for seaweed cultivation in 2025 compared to 2019 were also assessed (Gittenberger, 2025).

The present risk assessment is based on the results of the GiMaRIS and WMR studies. BuRO also made an inventory of the existing laws and regulations applicable to seaweed cultivation and related to potential risks posed by alien species.

5.3.2 Risk assessment methodology

A number of steps have been taken to assess the risks posed by alien species. These steps can be linked to the four steps of risk assessment as used by BuRO: hazard identification, hazard characterisation, exposure estimation and risk characterisation. The first step is the inventory of seaweed species grown in the Netherlands or potentially suitable for cultivation in Dutch wind farms, supplemented by an inventory of seaweed species and other species found in Dutch seaweed cultivation. Subsequently, for all these species it was assessed whether they were native or alien to the Netherlands and/or North-Western Europe ('hazard identification'). It was then assessed whether the alien species could have an adverse impact on Dutch nature, focusing more extensively on the potential adverse impact of alien seaweed species that are already cultivated and/or potentially suitable for cultivation in wind farms ('hazard characterisation'). Finally, it was estimated to what extent the current seaweed cultivation activities and potential future cultivation of seaweed in wind farms increase the chance of introduction, establishment and spread of alien species ('exposure estimation') and thus the impact of these species. When assessing the risk ('risk characterisation') of seaweed cultivation, the alien seaweed species, the origin of the starting material, the cultivation system used and the area where the seaweed is grown have been taken into account.

5.4 European and Dutch laws and regulations

5.4.1 Marine Strategy Framework Directive

The European Marine Strategy Framework Directive (2008/56/EG[17]) (MSFD) requires each Member State to develop its own Marine Strategy with measures to achieve a so-called 'good environmental status'. Non-indigenous (alien) species are explicitly mentioned. In order to achieve good environmental status, the number of alien species newly introduced via human activities should be minimised and where possible reduced to zero (Decision (EU) 2017/848[18]). In accordance with the advice of the Joint Research Centre (JRC) (EC et al., 2021), marine alien species in the Dutch section of the North Sea, the Dutch section of the Wadden Sea and the Southwest Delta (the coastal waters) are included in the number of newly introduced species. In accordance with the MSFD, the Dutch Marine Strategy describes measures to achieve good environmental status for alien species. It states that initiatives concerning the cultivation of alien species and improved native seaweed species (i.e. cultivars or hybrids) in the open sea are considered undesirable also due to the precautionary principle (IenW & LNV, 2022).

5.4.2 Water Framework Directive

One of the objectives of the European Water Framework Directive (2000/60/EC[19]) (WFD) is to achieve good ecological and chemical status of surface water by 2027. It applies to fresh surface waters (including rivers and lakes), transitional waters (including the Wadden Sea and the Southwest Delta) and coastal waters (up to 12 miles from the coast). The WFD also sets targets for groundwater, but these are not addressed here.

When assessing the chemical status, a list of priority substances harmful to human health and the aquatic environment is considered. The ecological status assessment looks at four biological quality elements, different ecology-supporting physicochemical parameters and a list of specific pollutants.

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[17] Directive 2008/56/EC establishing a framework for Community action in the field of marine environmental policy

[18] Decision (EU) 2017/848 laying down criteria and methodological standards on good environmental status of marine waters and specifications and standardised methods for monitoring and assessment, and repealing Decision 2010/477/EU

[19] Directive 2000/60/EC establishing a framework for Community action in the field of water policy

Only when they all meet the standards set for the water body type in question a good chemical and ecological status is achieved.

Alien species are not mentioned in the WFD and are therefore not included in the quality standards used to assess the ecological status of the different water body types (with a few exceptions). Their presence may have an indirect effect on the ecological status of a water body type if they affect the biological quality elements (fish, macrofauna, phytoplankton and other water flora) or the ecology-supporting physicochemical parameters (nitrogen, phosphorus, oxygen content, pH, transparency, temperature and salinity).

5.4.3 Regulation on Invasive Alien Species

The European Regulation (EU)1143/2014[20] on invasive alien species, which has been implemented in the Dutch Environment and Planning Act ('Omgevingswet')[21], aims to prevent invasive alien species from causing serious adverse impacts on biodiversity and related ecosystem services. The core of this Regulation is a list of invasive alien species that are of concern to the European Union. Species on this list that may not be intentionally released into the environment and may not be propagated, grown, used or sold (Article 7). This so-called Union list applies to the entire European Union. A Member State may also establish a national list of invasive alien species of concern to that Member State. Within this Member State, the same prohibitions as described above will apply. The Union list includes one marine seaweed species (*Rugulopteryx okamurae*) (Implementing Regulation (EU) 2022/1203[22]). This species occurs in seawater with a relatively high temperature, such as in southern France and Spain (NVWA, 2022). This species is currently not relevant for the Netherlands, but this could change in the future. Recently, some other marine species (Japanese eelgrass (*Nanozostera japonica*), dwarf surf clam *(Mulinia lateralis),* North Pacific sea star (*Asterias amurensis*) have been added to the Union list (Implementing Regulation (EU) 2025/1422)[23]. There are no marine species on the national list of the Netherlands.

The Dutch policy on invasive alien species primarily aims to prevent introduction. If a species has been introduced nevertheless, the aim is to eliminate the species early or if elimination is not possible to isolate and control it (LNV, 2007). As marine species are difficult to eradicate or control, the Netherlands fully focuses on preventing their introduction.

5.4.4 Regulation on Alien Species in Aquaculture

The European Regulation (EC) 708/2007[24] on the use of alien and locally absent species in aquaculture (hereinafter: Regulation on alien species in aquaculture) aims to prevent impact from the use of these and any hitchhiking species (so-called non-target species) on aquatic habitats. This Regulation lays down requirements for closed aquaculture facilities in order to prevent species escaping from these facilities. For open aquaculture facilities, operators have to apply for a permit if they intend to introduce an alien species or a locally absent species in a Member State. Conditions are imposed on the species that may be released. Alien species (including seaweed species) may only be introduced into a Member State if the use of these species in an open aquaculture facility – possibly after risk mitigating measures have been taken – presents a 'low' risk. The same applies to so-called 'locally absent species', which do not occur in this part of their natural range, because the conditions here are not suitable for this species. In addition, certain artificially obtained organisms are within the scope of this Regulation. These are fertile artificially obtained hybrids between different species (e.g. offspring of artificial crosses between different species) and organisms where the number of chromosomes has been doubled through cell manipulation techniques ('polyploid organisms'). When assessing the risk of the above mentioned species and organisms the risks of potential hitchhiking species are also included in the assessment. The Regulation does, however, not apply to some alien species, such as the Pacific oyster and the Manila clam. As a result, the risks of alien (seaweed) species that may hitchhike with these species do not have to be assessed

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[20] Regulation (EU) No 1143/2014 on the prevention and management of the introduction and spread of invasive alien species

[21] Act of 23 March 2016 laying down rules on the protection and use of the physical environment (Environment Act)

[22] Implementing Regulation (EU) 2022/1203 amending Implementing Regulation (EU) 2016/1141 to update the list of invasive alien species of Union concern

[23] Implementing Regulation (EU) 2025/1422 amending Implementing Regulation (EU) 2016/1141 to update the list of invasive alien species of Union concern

[24] Regulation (EC) No 708/2007 on the use of alien and locally absent species in aquaculture

either. The Regulation requires aquaculture farmers to apply for a permit if they intend to introduce an alien species or a locally absent species in a Member State for farming or cultivation in an open aquaculture facility.

In the Netherlands, the Regulation has been implemented in the 'Regeling gebruik uitheemse en plaatselijk niet-voorkomende soorten in de aquacultuur'[25]. The Minister of LNV (now Ministry of Agriculture, Fisheries, Food Security and Nature, LVVN) is the competent authority for this Regulation. Permits are granted by the Director of Fisheries.[25] The authority to grant permits can, however, be delegated to another public body. According to the Ministry of LVVN, the Netherlands Enterprise Agency (RVO) is responsible for granting permits, but according to RVO they do not grant permits for the use of alien seaweed species in open aquaculture facilities. According to the explanatory memorandum of the Regulation, the General Inspection Service (now the Netherlands Food and Consumer Product Safety Authority (NVWA)) is responsible for supervising and enforcement of both open and closed aquaculture facilities[25]. Inquiries with the NVWA indicate that there is currently no supervision or enforcement of this Regulation.

5.4.5 Environmental law

5.4.5.1 Environmental impact assessments

In addition to the above-mentioned laws and regulations specifically aimed at alien species, there are several European Directives to protect nature and the environment. In the Netherlands, these Directives have been implemented in the Environment and Planning Act ('Omgevingswet'). This is also the case for Directives 2001/42/EG[26] and 2014/52/EU[27] and the environmental impact assessments required by them. As a result, in the Environment and Planning Act it is stated that an environmental impact assessment is required for certain activities in order to assess whether they have significant effects on the environment. Such an environmental impact assessment is required for 'intensive aquaculture of fish', but not for the cultivation of seaweed[28].

5.4.5.2 Birds Directive, Habitats Directive and Natura 2000 sites

In addition to the above-mentioned European directives, the Birds Directive (Directive 2009/147/EG[29]) and the Habitats Directive (Directive 92/43/EEG[30]) have also been implemented in the Environment and Planning Act. As a result, it contains rules to protect plant and animal species, Natura 2000 sites and special national nature conservation areas. For example, various activities with potential consequences for naturally occurring wild animals or plants (so-called flora and fauna activities) are subject to authorisation. This applies, for example, to the deliberate disturbance, capture or killing of protected species. Activities that may have adverse effects on Natura 2000 sites and special national nature conservation areas are also subject to authorisation. They may only be carried out if they do not have deteriorating or significantly disturbing effects, or do not adversely affect the integrity of the site (taking into account the conservation objectives). The Southwest Delta, the Wadden Sea and various parts of the North Sea are Natura 2000 sites. To cultivate seaweed in these areas, a Natura 2000 assessment will therefore be required. As all seaweed cultivation activities in the North Sea may have an effect on the Natura 2000 sites located in the North Sea, a Natura 2000 assessment will also be required for these activities.

In most cases, a permit is granted by the province and the province is also responsible for supervision and enforcement. For activities in the territorial sea (with the exception of the parts belonging to a province) and the so-called exclusive economic zone of the North Sea, permits are

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[25] Regulation of the Minister of Agriculture, Nature and Food Quality of 17 December 2008, No TRCJZ/2008/3516, laying down rules for the use of alien and locally absent species in aquaculture (Regulation on the use of alien and locally absent species in aquaculture).
Government Gazette 2008, No 252

[26] Directive 2001/42/EC on the assessment of the effects of certain plans and programmes on the environment

[27] Directive 2014/52/EU amending Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment

[28] Explanatory memorandum to the Decree of 3 July 2018 laying down procedural rules and rules on general topics concerning the protection and use of the physical environment (Environmental Decree). Government Gazette 2018, No 290

[29] Directive 2009/147/EC on the conservation of wild birds

[30] Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora

granted by the Ministry of LVVN. In these cases, Rijkswaterstaat is responsible for enforcement and supervision.

5.4.6 Private standard

In addition to laws and regulations, there is also a voluntary standard for sustainable production of seaweed, which has been drawn up by the Aquaculture Stewardship Council (ASC) and the Marine Stewardship Council (MSC). According to this standard, the use of alien seaweed species is only permitted if the seaweed is grown in closed facilities on land (completely separated from the aquatic environment) or when it has been introduced at least 20 years earlier (ACS/MSC, 2018). As far as is known, there are currently no Dutch seaweed companies with an ASC or MSC certification.

5.4.7 Discussion

The European Marine Strategy Framework Directive states that the number of 'non-indigenous species' (alien) species newly introduced by human activities should be minimised and, where possible, reduced to zero. The Dutch Marine Strategy describes measures to achieve this goal. Amongst other things, it states that cultivation of alien seaweed species in the open sea is considered undesirable also due to the precautionary principle. The same applies to the cultivation of improved native seaweed species. The Regulation on Alien Species in Aquaculture lays down rules for the introduction of alien or so-called 'locally absent' (seaweed) species into the Netherlands and also consider alien species that may hitchhike. Species may only be introduced for use in open aquaculture facilities if they pose a 'low' risk. This reduces the chance that risky alien species (both seaweed and potentially hitchhiking species) will be introduced in the Netherlands.

However, there are a number of situations which do not fall within the scope of the Regulation, but may pose a risk to nature. Because the Regulation only applies to the introduction of species, no permit and risk assessment are required for the cultivation of alien or 'locally absent' (seaweed) species that are already present in the Netherlands. This also applies to species that have only recently been found in the Netherlands. Once a species has been found in the Netherlands, no further authorisation is required on the basis of this Regulation. Even if the species is not or hardly present in the area where it will be grown and cultivation can therefore pose a risk to nature. For 'locally absent' species a permit requirement can be imposed, if, on the basis of scientific advice, there are grounds for foreseeing environmental threats. However, it is unclear whether this possibility also exists for alien species, as alien species are not explicitly mentioned in this part of the Regulation.

In addition to alien and 'locally absent' species, some cultivars and hybrids also fall within the scope of the Regulation. This is the case if their number of chromosomes has artificially been doubled, or when artificial techniques have been used to obtain hybrids of different seaweed species and these hybrids are fertile. It is irrelevant whether native or alien species are used in the development of these cultivars and hybrids. As it is not known how certain provisions in the Regulation are interpreted, for other cultivars or hybrids it is unclear whether they fall within its scope. For example, it is unclear whether artificially obtained hybrids that can only reproduce vegetatively (by growth of fragments into new plants) are considered 'fertile' and are therefore regulated. It is also unclear whether hybrids of seaweed species that do not occur naturally in the same area are considered to be 'artificially hybridised' and therefore regulated.

In addition, cultivars and hybrids may also be developed that do not fall within the scope of this Regulation but present a risk to nature when grown in an open aquaculture facility. When breeding seaweed, attempts are made to develop cultivars and hybrids with properties that are beneficial for seaweed cultivation, for example because they increase production or allow the seaweed to be grown in more places. However, some properties that are beneficial for seaweed cultivation, such as faster growth, the ability to grow in other places or to withstand conditions at sea, increase the risk to nature.

There are also a number of activities that are unlikely to fall within the scope of the Regulation, but which could pose a risk, such as research on alien seaweed species in open aquaculture facilities, for example for the cultivation of seaweed.

It is currently unclear who is responsible for granting permits to grow alien seaweed under the Alien Species in Aquaculture Regulation. According to the Ministry of LVVN, this is RVO, but RVO indicates that they do not grant these permits. In addition, at present, the NVWA does not monitor compliance with this Regulation.

It follows from the provisions on Natura 2000 sites in the Environment and Planning Act that seaweed may only be grown if it does not have significant adverse effects on Natura 2000 sites and special national nature conservation areas (taking into account the conservation objectives). Because all areas where seaweed can be grown are Natura 2000 sites themselves or could affect Natura 2000 sites, this applies in practice to all areas where seaweed can be grown.

In permits, sometimes the Latin names for the species concerned are not mentioned, but only common names are used. As a result, it is possible that alien species may be grown inadvertently within permits. For example, a permit for the cultivation of 'zeesla' would allow cultivation of several native species: 'Stijve zeesla' (*Ulva rigida*), 'Getande zeesla' (*Ulva rigida var. fimbriata*), 'Gekromde zeesla' (*Ulva pseudocurvata*) and 'zeesla' (*Ulva lactuca*). But it would also allow cultivation of the alien species 'Geperforeerde zeesla' (*Ulva australis*). In a similar way, it is possible that alien species may be grown inadvertently when only the Latin name of the genus is used in a permit. For example, with a permit for the cultivation of *Ulva,* in addition to sixteen native *Ulva* species, hundreds of alien species can be grown, because there are 388 species within this genus (Gittenberger et al., 2020a) most of which are alien to the Netherlands.

5.5 Risk assessment

Alien seaweed species that are eligible for cultivation are usually species that grow rapidly. Many of these species are therefore likely to have a negative impact on nature (Gittenberger, 2025). This does not necessarily have to be the case for other alien seaweed species.

When alien seaweed species establish in an area, they can radically change the ecosystem. Seaweed species that form large plants, such as kelp, can slow down sea currents and alter their direction. As a result, the amount and size of sediment particles deposited in the area changes. This can alter the hydromorphological characteristics of an area. This also has an impact on the composition of the sediment and therefore on the species that live in the area. Some seaweed species contain substances that are very harmful to fish that eat it. There are also seaweed species that degrade so rapidly that especially in closed inland waters acidification can occur and the oxygen content of the water may drop sharply (Gittenberger, 2025). This causes water quality to deteriorate and has a negative impact on achieving the WFD objectives. The changes, in turn, also affect the species that occur in an area (Gittenberger, 2025). Among the species affected by this are also characteristic species for habitat types in the Southwest Delta and the Wadden Sea. These characteristic species serve as a quality indicator for these Natura 2000 sites.

Alien seaweed species compete with native seaweed species that occur in the same area for light, space and nutrients and therefore have a negative effect on the native seaweed species present. Alien seaweed species with large plants or species that form a dense layer at the surface of the water block light so that smaller (native) seaweed species can no longer grow properly and are outcompeted. Other seaweed species overgrow the seabed or cover dikes, displacing the native species that occur there. As a result, alien seaweed species have a negative impact on the native seaweed species that occur in the same area (Gittenberger, 2025).

Other groups of organisms, including characteristic species for habitat types in Natura 2000 sites, may also be negatively impacted by alien seaweed species. If, due to the faster degradation of certain alien seaweed species, the oxygen content in the water drops too much (most likely to occur in closed inland waters), this leads to mortality in all kinds of species. This is especially the case with benthic species on and in the seabed that filter the water, such as bivalves, and with species that extract nutrients from the sediment, such as worms. When alien seaweed species change the sedimentation in an area, the species composition in the seabed shifts, because depending on the composition of the sediment other species of worms and bivalves live in the sediment. Alien seaweed species that overgrow the seabed cause a decline in benthic species that occur on and in soft sediments. In addition, there are alien seaweed species that produce substances that are harmful to herbivorous fish. Other alien seaweed species inhibit the growth of sea urchins by being less nutritious than native seaweed species (Gittenberger, 2025).

On the other hand, alien seaweed species can also have a positive effect on species that occur in the same area. Alien seaweed species with large plants or with many plants growing close to each other offer shelter to fish and shrimp, for example. There are also alien seaweed species that other species can settle on. These alien seaweed species therefore have a positive effect on biodiversity in the area (Gittenberger, 2025).

In summary, alien seaweed species can alter the area where they occur and have a negative impact on the native seaweed species that occur in the same area. On other species, including characteristic species for habitat types in Natura 2000 sites, they can have both a negative and a positive impact. Their impact also depends on the initial situation of the area. Alien seaweed species that provide shelter will have a positive effect on species that live on or above the seabed, such as crabs and fish. However, if the area consists of soft sediments and there are mainly animal species that burrow into these sediments, such as bivalves and worms, then the shelter provided by the seaweed will not have a positive effect on the animal species present. In this case, the seaweed will have a negative effect on the animal species present, because it reduces the availability of soft sediments (Gittenberger, 2025).

5.5.1 Species identification

In 2019, species were inventoried at ten Dutch seaweed farms in the Eastern Scheldt, Wadden Sea and North Sea (including wild harvest), plus one grower of starting material (field research). Seaweed species that were cultivated, but also other species that were present (both seaweed and other species) were included in the inventory. Organisms at seaweed farms and during wild harvest were collected and, if possible, identified directly during sampling. The sampling continued until less than one new species was expected to be found with a twice as long search effort. Microscopic or DNA analysis were carried out if required to identify the species. (Gittenberger et al., 2020b). A total of 125 species were found: 64 species of seaweed, 15 of which are alien, and 61 species of seaweed, 20 of which are alien (Gittenberger et al., 2020b) (Figure 8).

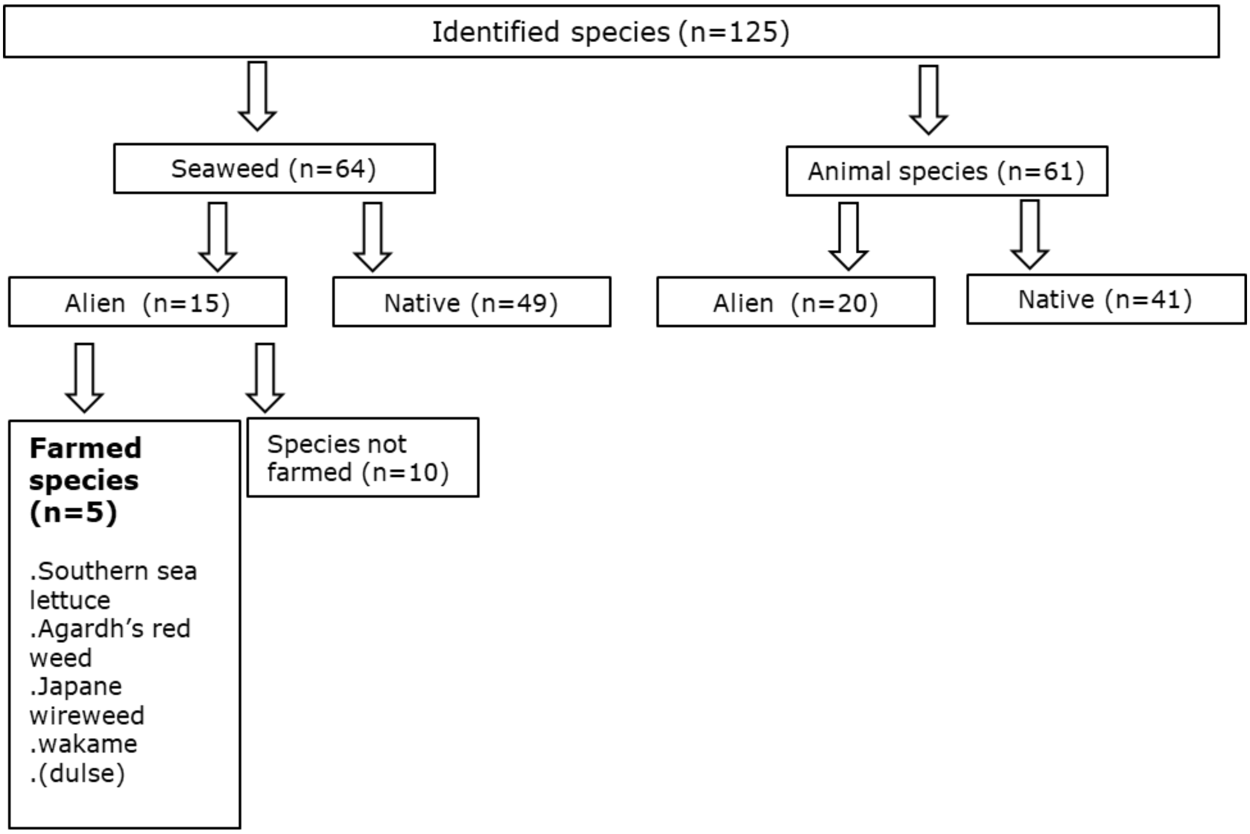

Figure 8 Number of species identified at seaweed farms and wild harvest through field surveys (dulse was only found in a quarantine basin at a grower of starting material).

The alien species were, with a few exceptions, not only alien to the Netherlands, but also to Europe. The exceptions were one species of seaweed which is native in North-West Europe, but not found in the Netherlands, (dulse), and one bryozoan species whose area of origin is unknown.

In addition, Stichting North Sea Farmers provided a list of 19 species and two genera that might be candidates for growth within wind farms in the North Sea (Gittenberger et al., 2020a). The genera:

*Ulv*a with 388 species worldwide, and *Gracilaria* with 285 species, have not been taken into account. Both genera contain native ánd alien species. For both genera, their flawed taxonomy is a point of attention. Due to the cultivation methods used, the leaves have unusual shapes so that they can no longer be identified morphologically (based on external characteristics). Without DNA determination, it is often unclear which *Ulva* or *Gracilaria* species is grown (Gittenberger et al., 2020a; Gittenberger et al., 2020b). Some other species have also been excluded because they are not or not in the short term suitable for the cultivation systems used, or cannot withstand the exposed conditions (strong currents and waves) in wind farms at the North Sea (Gittenberger et al., 2020a). Eight species that might be grown in wind farms within five years remained of the initial list. Of these eight species, four were alien (Figure 9).

5.5.1.1 Alien seaweed species

The 2019 survey of Dutch seaweed farms (including wild harvest) yielded 15 alien seaweed species, five of which were cultivated. The other ten alien seaweed species were not cultivated but were nevertheless present in the cultivation system (Gittenberger et al., 2020b) (Figure 8). The five cultivated alien seaweed species are:

- southern sea lettuce (*Ulva australis*)
- dulse (*Palmaria palmata*) (found only in a quarantine basin at a grower of starting material)
- Agardh's red weed (*Agardhiella subulata*)
- Japanese wireweed (*Sargassum muticum*)
- wakame (*Undaria pinnatifida*)

DNA analyses showed that in 2019 mainly the native *Ulva rigida* was grown, but also the alien *Ulva australis* (southern sea lettuce). With regard to dulse, it should be noted that this species is alien to the Netherlands, but native to Northwest Europe (Gittenberger et al., 2020b).

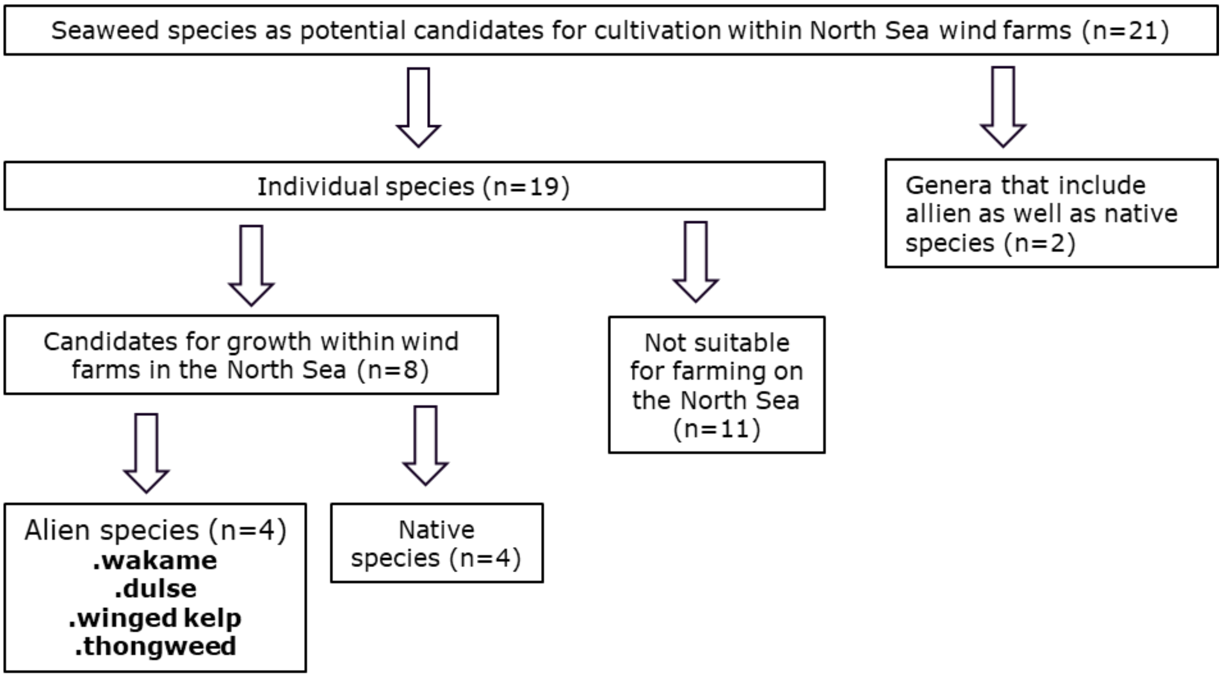

Figure 9 Number of seaweed species that are potential candidates for cultivation in North Sea wind farms.

The ten alien seaweed species that were not cultivated but have been found in seaweed farms (including wild harvest) are: *Bonnemaisonia hamifera, Caulacanthus okamurae, Ceramium sungminbooi, Colpomenia peregrina, Dasysiphonia japonica, Gelidium vagum, Gracilaria vermiculophylla, Grateloupia turuturu, Melanothamnus harvey* and *Polysiphonia senticulosa.* Three species *(Bonnemaisonia hamifera, Gelidium vagum* and *Grateloupia turuturu*) were only found in seaweed taken from the Eastern Scheldt (wild harvest, see 3.2.2).

Four alien seaweed species might be suitable for cultivation in wind farms in the North Sea in the near future:

- wakame (*Undaria pinnatifida*)
- dulse (*Palmaria palmata*)
- winged kelp (*Alaria esculenta)*
- thongweed (*Himantalia elongata*)

Wakame and dulse are already grown elsewhere in the Netherlands. The cultivation of dulse concerns a specific situation. Dulse was grown in a quarantine basin to obtain inoculum for seaweed farms in the same country where the starting material of dulse was initially collected (Ireland). Dulse, but also winged kelp and thongweed, are alien to the Netherlands but native to other parts of Northwest Europe (Gittenberger et al., 2020a).

The risk assessment elaborates on the seven alien seaweed species that are already cultivated and/or are potentially suitable for cultivation in North Sea wind farms within five years (in bold in Figure 8 and Figure 9; Table 30) .

5.5.1.2 Alien animal species

In addition to seaweed, 61 animal species have been found among the seaweed. Of these, 20 were alien to the Netherlands (Figure 8). These were worms (n=2) and flatworms (n=1), ascidians (n=5), bryozoans (n=2), crustaceans (n=5), molluscs (n=3), sponges (n=1) and sea spiders (n=1). These species are also alien to Europe (Gittenberger et al., 2020b).

5.5.2 Impact on nature

For all alien seaweed species (cultivated and non-cultivated;n=15) plus the other alien species found in cultivation (n=20) (Figure 8), it has been estimated whether they have an impact on Dutch nature. These alien species have been categorized using two scoring systems (ISEIA and Harmonia+ see Gittenberger et al. (2020b)). The results indicate that several alien species that have been found at the seaweed farms and in wild harvested material have an impact on Dutch nature. This is the case, inter alia, for several alien species found between the seaweed, such as a number of ascidians, crustaceans and molluscs, but also for several seaweed species that were not cultivated themselves, such as *Gracilaria vermiculophylla* and *Grateloupia turuturu*. Seaweed species that were grown, such as *Agardhiella subulata* (Agardh's red weed), *Sargassum muticum* (Japanese wireweed), *Undaria pinnatifida* (wakame) and to a lesser extent *Palmaria palmata* (dulse) and *Ulva australis* (southern sea lettuce) also have an impact on Dutch nature (Gittenberger et al., 2020b).

5.5.2.1 Alien seaweed species

For the farmed alien seaweed species (including wild harvest) and the seaweed species potentially suitable for cultivation in wind farms, the impact on Dutch nature has also been analysed in more detail (Gittenberger, 2025).

Wakame can dominate the ecosystem in an area and is considered one of the most harmful alien species worldwide. It changes the ecosystem in which it occurs in different ways. In a short period of time (a few months) wakame forms large plants that grow up to two meters long and have broad leaves. These plants change the flow and sedimentation in the area where they grow, but also in the surrounding area. This alters the hydromorphological characteristics of these areas and affects the species that live there. Depending on the composition of the sediment, other species of worms and bivalves live in the sediment. The large plants of wakame also block light, so that smaller (native) seaweed species no longer grow well and are outcompeted. The large plants, however, also provide shelter to different animal species and are a place where species can settle. This increases biodiversity. There is, however, a decline in benthic species that occur on and in soft sediments, because wakame reduces the availability of soft sediments. All effects of wakame combined significantly change the species composition and biodiversity in the area (Gittenberger, 2025) and also affect characteristic species for habitat types in the Southwest Delta and Wadden Sea, which serve as a quality indicator for these Natura 2000 areas.

Japanese wireweed can dominate an ecosystem in an area. It forms plants that grow close to each other, become meters long and have many branches. As a result, Japanese wireweed, like wakame, changes the flow and sedimentation in an area. Japanese wireweed forms many small gas filled bladders (resembling berries) which are attached to its branches and allow it to float. As a result, Japanese wireweed forms a dense layer at the water surface. Virtually no sunlight passes through it. As a result, other seaweed species can no longer grow and disappear (Gittenberger, 2025). The overall effects of Japanese wireweed are similar to those of wakame.

Agardh's red weed can also dominate an ecosystem. Although its plants are smaller than those of wakame and Japanese wireweed, they are still larger than native species. As a result, native species on the seabed get less sunlight and nutrients. Agardh's red weed hardly allows other vegetation and overgrows the seabed almost completely. Also, other species find it difficult to settle on Agardh's red weed its fleshy texture. In addition, its plants die at the end of the growing season and degrade faster than native seaweeds. Especially in closed inland waters, acidification can occur and the oxygen content in the water may drop sharply. As a result, the water quality deteriorates. This has a negative impact on the achievement of the WFD objectives. When oxygen levels become too low, this leads to mortality of native bivalves in particular. Because several alien species are more tolerant to low oxygen levels than native species, Agardh's red weed indirectly promotes the establishment of alien species (Gittenberger, 2025). The changes caused by Agardh's red weed can also have an effect on characteristic species for habitat types in the Southwest Delta and Wadden Sea, which serve as a quality indicator for these Natura 2000 sites.

Southern sea lettuce can only be distinguished from native sea lettuce species using DNA analyses, making the impact of this species less visible. However, southern sea lettuce is locally dominant on dikes and seems to compete strongly with native sea lettuce species (Gittenberger, 2025).

Unlike the above species, winged kelp and thongweed have not established themselves in the Netherlands (Gittenberger et al., 2020a). As a result, less information is available about the potential impact of these species on nature in the Netherlands. However, based on their properties, their impact can be estimated. Winged kelp is likely to have similar effects on the ecosystem as wakame It forms large plants with leaves up to four meters long and is sometimes referred to as Atlantic wakame (Gittenberger et al., 2020a; Gittenberger, 2025). Thongweed forms plants that grow up to a meter long. It grows in a similar way as Japanese wireweed with many individuals right next to each other. As a result, the plants of thongweed, like Japanese wireweed and wakame, can change the flow and sedimentation in an area (Gittenberger, 2025). Thongweed is therefore likely to have similar effects on the ecosystem as Japanese wireweed and wakame.

5.5.3 Introduction, establishment and spread

Spores, fragments of seaweed and detached plants mainly disperse through currents. For successful dispersal, the seaweed must be able to survive for some time without being attached to substrate. For sea lettuce this is known to be possible ('detached existence') (Gittenberger et al., 2020a). The ability to float is also important. Species like knotted wrack (which has air bladders) float easily in contrast to species like winged kelp and wakame which sink almost immediately after detachment (Gittenberger et al., 2020a). Seaweeds disperse naturally through currents, but can also be spread through human activities. This can be done deliberately, for example when starting material for seaweed cultivation is taken from another area. But they can also be spread unknowingly, for example by hitchhiking with starting material that is taken from another area or by vessels that travel between different areas (through biofouling). This also applies to vessels involved in the cultivation or harvesting of seaweed.

Seaweed can only establish if there is a suitable habitat. These include factors such as the presence of hard substrate (e.g. a rocky coast), an appropriate water temperature and sufficient sunlight (low turbidity of water) (Gittenberger et al., 2020a).

Most seaweed species that occur in Northwest Europe can reach Dutch waters by natural dispersion (through currents) and may establish when a suitable habitat is present.

In the Netherlands, the Southwest Delta and the Wadden Sea in particular offer opportunities for establishment of alien seaweed species. There is hard substrate where the seaweed can settle and there is sufficient sunlight. The Dutch coast is less suitable for establishment, because the water is relatively turbid and there is little hard substrate available. Further from the coast, the water is so deep that sunlight does not penetrate sufficiently far for most seaweed species to grow (Gittenberger, 2025).

Table 30 shows the alien seaweed species identified and potential candidates for cultivation in wind farms. Agardh's red weed, Japanese wireweed, southern sea lettuce and wakame are already common in some Dutch waters. Japanese wireweed has been observed along the Dutch coast since 1977, Agardh's red weed is widespread in the Eastern Scheldt, and southern sea lettuce is present along the entire Dutch coast (Gittenberger et al., 2020b). Wakame has been observed in sheltered areas such as the Eastern Scheldt (since 1999) and marinas of the Western Scheldt and the Wadden Sea (more specifically: Terschelling since 2008) (Gittenberger et al., 2020a). Dulse reaches the Dutch coast in a natural way and regularly washes ashore, but has not established itself in the Netherlands. (Gittenberger et al., 2020b). Winged kelp and thongweed also wash ashore regularly, but established, attached plants have not been found in the Netherlands (Gittenberger et al., 2020a).

Table 30 Alien seaweed species grown in the Netherlands (plus wild harvest) and/or potentially suitable for cultivation within wind farms (Gittenberger et al., 2020a).

Dutch name	Latin name	Native / alien		Introduced in the Netherlands	Spread in the Netherlands	Established in the Netherlands
		Netherlands	North West Europe[$]			
Alien seaweed species farmed in the Netherlands						
Agardh's red weed	*Agardhiella subulata*	alien	alien	yes	yes	yes
Japanese wireweed	*Sargassum muticum*	alien	alien	yes	yes	yes
Southern sea lettuce	*Ulva australis*	alien	alien	yes	yes	yes
Wakame*	*Undaria pinnatifida*	alien	alien	yes	yes	yes
Dulse*#	*Palmaria palmata*	alien	native	washes ashore	no	no
Seaweed species that might be candidates for growth within wind farms in the North Sea						
Winged kelp	*Alaria esculenta*	alien	native	washes ashore	no	no
Thongweed	*Himanthalia elongata*	alien	native	washes ashore	no	no

#dulse has only been found in a quarantine basin at a grower of starting material.
*dulse and wakame could also potentially be suitable for cultivation in wind farms.
$ The sea around Great Britain and Ireland plus the North Sea from the northern coast of Brittany (France) to the northern tip of Denmark (Gittenberger et al., 2020a).

5.5.4 Risk assessment seaweed cultivation

All seven alien seaweed species already cultivated or potentially suitable for cultivation in North Sea wind farms have an impact on Dutch nature or could have an impact if they would establish here (see paragraph 5.5.2). In order to determine whether seaweed cultivation activities increase the impact of an alien seaweed species and therefore pose an additional risk, it is estimated to what extent these activities increase the chance of introduction, establishment and spread of alien seaweed species (Gittenberger et al., 2020a; Gittenberger et al., 2020b).

5.5.4.1 Factors influencing introduction, establishment and spread

A number of factors influence the possible introduction, establishment and spread of alien species: the location of cultivation, the starting material used, the cultivation system and what is done with the harvested seaweed.

The chance of spreading alien species is increased if seaweed is collected in one place and then grown in another. The use of starting material from abroad also increases the chances of introduction, establishment and spread of alien species. The research carried out in 2019 shows that in the Netherlands the starting material for seaweed cultivation is mainly collected locally, from the immediate vicinity of the cultivation. In this situation, the chance of spreading alien species is small.

In addition to the seaweed species grown, the type of cultivation system also influences the chance of introduction, establishment and spread of alien species. In the Netherlands, two types of cultivation systems are used: hanging cultures in open water and salt water basins on land (see section 3.2.2). In basins on land there is a better control of growing conditions than in nature. It is important what happens to the water from the basins after harvest. In one place in the Netherlands, an alien species that is not yet present in the Netherlands is grown in closed (quarantaine) basins. Here the water from the basins is used by the local municipality for the production of road salt (Gittenberger et al., 2020b). In the case of hanging cultures in open water, there is a distinction between locations at sea and sheltered locations that are connected to the sea (Gittenberger et al., 2020a). On hanging cultures in the North Sea, few alien species were found. Also in the basins on land, almost no alien species have been found. Most alien species have been found in hanging cultures in sheltered open water and in wild harvested material.

Furthermore, the chance of alien species establishing is smaller if the cultivation system is removed from the water in the summer months. These are the months in which most marine species settle (Gittenberger et al., 2020b). This is possible for seaweed species that grow in winter and are harvested in spring/early summer, such as sugar kelp (a native species), wakame and Agardh's red weed (Table 1 in Section 3.1.3). It is not known whether this is common practice.

Another important factor in determining the chance of introduction, establishment and spread is what is done with the harvested seaweed. If it is not used as starting material, but is sold for consumption or a non-food application, the chance of establishment and distribution via this route is virtually nil. The seaweed from the Dutch seaweed farms was either intended for consumption or used for research purposes. It was not used or for cultivation in other waters or to produce inoculum (Gittenberger et al., 2020b).

5.5.4.2 Assessment of additional risk

Non-cultivated alien seaweed species

The alien species found (section 5.5.1.2) are all established species in the area where the seaweed was grown. This also applies to the ten alien seaweed species that were not cultivated but found at seaweed farms and in wild harvested material (Gittenberger et al., 2020b). As these alien species had already established in the area, considering these alien species the seaweed cultivation activities did not pose an additional risk to nature.

Cultivated alien seaweed species

For the seven alien species that are already cultivated or are candidates for growth within wind farms in the North Sea the extent to which current seaweed cultivation activities and potential future cultivation in wind farms increase their presence in the Netherlands and their impact on nature has been assessed. Furthermore, considering these alien seaweed species, it has been assessed whether current seaweed cultivation activities and potential future cultivation in wind farms in the North Sea pose an additional risk to nature.

Dulse, winged kelp and thongweed are native to other parts of northwestern Europe and regularly wash ashore on the North Sea coast, but plants attached to substrate have not been found. Possibly this is because the Dutch coast does not have a rocky coast with strong currents. Because these species are not able to establish here, there is little chance that these species have an impact on nature when they are grown in wind farms in the North Sea (Gittenberger et al., 2020a). In addition, these species could also establish naturally in wind farms. Cultivation of these species in wind farms therefore does not pose an additional risk to nature provided that local or upstream collected starting material is used.

Japanese wireweed and southern sea lettuce are already common along the entire Dutch coast and in the Southwest Delta (Gittenberger et al., 2020a; Van der Loos, 2025). Agardh's red weed is widespread in the Eastern Scheldt, the Grevelingen and the Veerse Meer (Gittenberger et al., 2020a; Gittenberger, 2025). Since these species have already established themselves in the areas where they are grown and are common there, the impact of these species on nature is unlikely to increase due to current seaweed farming activities. The cultivation of these species in these areas therefore poses no additional risk to nature as long as locally collected starting material is used.

Wakame is found in a few places in the Netherlands, but only grows in relatively sheltered places. Wakame has been present in the Eastern Scheldt since 1999 and is nowadays very common in the Eastern Scheldt. The cultivation of wakame in the Eastern Scheldt will therefore in all likelihood not increase the impact of this species on nature as long as starting material from the immediate vicinity of the facility is used (Gittenberger et al., 2020b). If wakame were to be grown in wind farms in the North Sea, the species is not expected to disperse over long distances, as wakame is usually harvested before spores are formed, and the spores and leaves of wakame sink quite quickly. Although some individuals could reach the Wadden Sea, this will in all likelihood not increase its impact on nature. There already is a wakame population near the marina of Terschelling and wakame also occurs further north in the Wadden Sea (at the German and Danish borders) (Gittenberger et al., 2020a). The cultivation of wakame in the Eastern Scheldt or in wind farms in the North Sea therefore poses no additional risk to nature provided that the starting material for cultivation comes from the immediate vicinity of the facility and therefore only grows in relatively sheltered places.

5.5.4.3 Risks of changes in seaweed cultivation

Cultivation of seaweed may pose a greater risk to nature if, compared to the current situation, changes occur in the locations, the origin of starting material, in used seaweed species or in cultivation methods.

When seaweed is grown on a larger scale, the number of spores, seaweed fragments and detached plants increases. This may allow (alien) seaweed to disperse over larger distances and settle in larger quantities, increasing the chance of establishment and spread, and the risk to nature.

Starting material

Changes in the cultivated alien seaweed species and in the locations where seaweed is cultivated may increase the risk to nature. When using alien seaweed species that are not yet present in the Netherlands, new alien seaweed species are introduced in the Netherlands. When alien seaweed species are cultivated that already occur in the Netherlands, but are not yet found in the vicinity of the cultivation site, the spread of these species increases. The cultivation of alien seaweed species that are not common in the vicinity of the cultivation site increases the presence of these species. Alien seaweed species that are eligible for cultivation are usually species that grow rapidly. They are therefore likely to have a negative impact on nature. Such changes would therefore increase the risk to nature.

When cultivars or hybrids are used as starting material, this may also increase the risk to nature. Cultivars and hybrids are being developed with properties that are beneficial for seaweed cultivation, for example because they increase production or allow the seaweed to be grown in more places. These properties can, however, increase the risk to nature. This is the case, for example, when the cultivar or hybrid grows faster causing it to outcompete native species, when it can grow in other places or when it is better adapted to survive exposed conditions at sea. With regard to the alien seaweed species currently cultivated or potentially suitable for cultivation in wind farms, this situation could occur, for example, in wakame, but also in dulse, winged kelp or thongweed. The wakame that occurs in the Netherlands only grows in relatively sheltered places. However, there are also populations, cultivars and a hybrid between winged kelp and wakame, which can establish in places with strong currents and waves (exposed conditions) (Gittenberger et al., 2020a). If these wakame populations, cultivars or hybrids were used as the starting material for cultivation, the impact of wakame on nature would greatly increase, because it would be able to grow in more places than is currently the case. Cultivating such wakame would therefore greatly increase the risk to nature. The same is the case if starting material from populations or cultivars that can establish themselves in Dutch waters would be used to cultivate dulse, winged kelp and thongweed. In that case too, cultivation will greatly increase the risk to nature (Gittenberger et al., 2020a).

When starting material is no longer collected locally, but is taken from a different place, other species can hitchhike with the seaweed and thus be spread. As a result, new alien species can be introduced in the Netherlands and establish here. In addition, alien species that are already present in the Netherlands can be spread to other locations. In both cases, this poses a risk to nature, as alien species can be introduced into an area that have a negative impact on the species present there. Therefore, starting material that comes from elsewhere poses a risk to nature.

In 2019, Dutch seaweed farms used starting material that was collected locally. But in the meantime, there are several indications that starting material nowadays also comes from other places. For example, winged kelp (*Alaria esculenta*) which was grown in the Eastern Scheldt, was offered for sale on the internet (Gittenberger, 2025). Winged kelp washes ashore on the Dutch coast (Van der Loos et al., 2021), but did not occur in the Eastern Scheldt before (Gittenberger, 2025). In addition, various seaweed species are offered for sale on the internet that are harvested from the Eastern Scheldt (wild harvest) (Rungis, 2025), but previously did not occur there. This applies, for example, to oarweed (*Laminaria digitata*): a native species which was previously only present close to Texel (Van der Loos, 2025). But also to the alien species dulse (*Palmaria palmata*) and thongweed (*Himanthalia elongata*). Previously, these two alien species were only found washed ashore on the Dutch coast (Van der Loos et al., 2021). In addition, scientific research was carried out with material from foreign populations of sugar kelp (*Saccharina latissima*) that had been grown in the Netherlands. Alien seaweed species, such as dulse and winged kelp, are cultivated for research purposes as well (Gittenberger, 2025).

Increase in alien seaweed species

The number of new alien seaweed species found in Dutch waters has increased sharply in recent years (Figure 10). This is also an indication that starting material from abroad is used. In the past four years, 15 new alien seaweed species have been found. This is much more than usual. Normally, two or three new alien seaweed species are found in the Netherlands over a period of five years. Only from 1991 to 1995 six new species were found. This high number was likely caused by Pacific oyster transports. These transports have stopped since the 1990s due to, among other things, their role in the introduction, establishment and spread of alien species (Gittenberger, 2025). These transports can therefore not explain the recent increase.

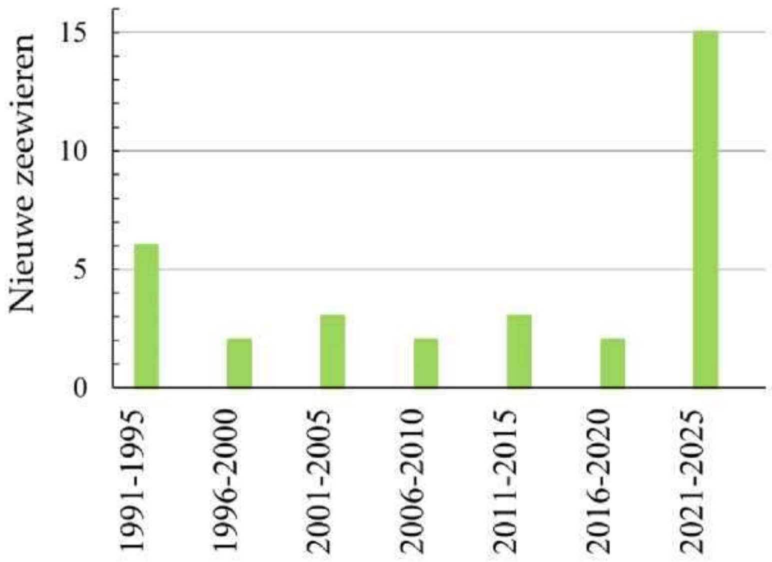

Figure 10 The number of new alien seaweed species discovered in the Netherlands from 1991 to 2025. Figure reprinted from (Gittenberger, 2025).

It is not known to what extent the cultivation of seaweed is responsible for the recent increase in the number of new alien seaweed species in Dutch waters. The effort to detect new alien species has been increasing since 2009, but increased monitoring does not provide a good explanation for the higher number of new alien seaweed species. This number has only recently increased sharply and it has increased much more than for other groups of organisms. Increased shipping also does not provide a good explanation for the sudden increase, because other groups of organisms that, like seaweed, can be transported by biofouling on vessels have not increased to the same extent. In addition, it is striking that nine of the new seaweed species found in the last four years belong to groups known to be cultivated: sea lettuce (*Ulva* spp.) and nori (*Porphyra* spp., *Neopyropia* spp. and *Pyropia* spp.). Because these alien species have now been found in the Netherlands, any cultivation of these species will no longer require a permit under the Alien Species in Aquaculture Regulation. *Ulva* species are cultivated in the Netherlands and the possibilities to cultivate species that can be used as nori are being investigated. In both groups there are native and alien species that are difficult to tell apart based on their appearance. In groups whose species are morphologically difficult to distinguish, such as *Ulva* spp., *Porphyra* spp./*Neopyropia* spp./*Pyropia* spp. and *Gracilaria* spp., without DNA analysis it is often not clear which species is cultivated. Unintentional cultivation of an (invasive) alien species can therefore not be excluded (Gittenberger, 2025).

5.5.5 Conclusion on risks of alien species

Alien seaweed species pose a risk to nature. They can change the ecosystem and the area in which they establish. Alien seaweed species have a negative impact on native seaweed species. On other species, they can have a negative or a positive impact. Alien seaweed species that are eligible for cultivation are usually species that grow rapidly. They are therefore likely to have a negative impact on nature. This need not necessarily be the case for other alien seaweed species.

In several genera with both native and alien species, such as *Ulva, Porphyra/Neopyropia/Pyropia* and *Gracilaria,* the species are difficult to distinguish morphologically. Therefore, instead of a native species, an (invasive) alien species can be grown unintentionally. This can be prevented by verifying the identity of the starting material using DNA analyses.

Several alien species, both (non-cultivated) seaweed species and animal species, that pose a risk to Dutch nature have been found at seaweed farms and in wild harvested material. Most species have been found in hanging cultures in sheltered open water and in wild harvested material. The alien species found are all established species in the area where the seaweed was cultivated, so there is no additional risk to nature.

Alien seaweed species grown in the Netherlands (plus wild harvest) and/or potentially suitable for cultivation in wind farms are: Agardh's red weed (*Agardhiella subulata*), Japanese wireweed (*Sargassum muticum*), southern sea lettuce (*Ulva australis*), wakame (*Undaria pinnatifida*), dulse (*Palmaria palmata*), winged kelp (*Alaria esculenta*) and thongweed (*Himanthalia elongata*). All these seven alien seaweed species have an impact on Dutch nature or could have an impact if they could establish here.

However, the current seaweed cultivation activities with Agardh's red weed, Japanese wireweed, southern sea lettuce and wakame do not pose an additional risk to nature when using locally collected starting material, as these alien species are already common in the areas where they are currently grown. Therefore, in these areas cultivation does not increase the impact of these alien species on Dutch nature.

Cultivation in wind farms also poses no additional risk to nature for the assessed alien seaweed species when the starting material comes from the immediate vicinity of the wind farm. Dulse, winged kelp and thongweed cannot establish in the Netherlands, and Japanese wireweed and southern sea lettuce are already common along the entire Dutch coast. Wakame only occurs in a few relatively sheltered places in the Netherlands. As long as locally collected starting material is used for cultivation, any propagules of wakame that could reach the Wadden Sea from a wind farm will in all likelihood not increase its impact on nature. These propagules will only grow in relatively sheltered places. In addition, there already is a wakame population near the marina in Terschelling and wakame also occurs further north in the Wadden Sea.

The cultivation of alien seaweed species with an impact on Dutch nature thus does not always pose an additional risk. Also, the impact of alien seaweed species may differ between areas. This also means that the impact of an alien seaweed species in a nearby country may differ from its impact in the Netherlands. Whether an alien seaweed species has already established itself in the area where it will be grown and its abundance in the area determines to a large extent whether the cultivation poses an additional risk to nature. If an alien species of seaweed does not yet occur in an area or is not a common species, growing this species poses a risk to nature. But, if an alien species of seaweed is already widespread and common throughout the area, cultivation will generally not increase its impact on nature. However, it remains important that the starting material is collected locally. The sharp increase in the number of new alien seaweed species in the Netherlands is an indication that this is not always the case. If the starting material does not originate from the area itself, cultivation poses an additional risk to nature. The seaweed grown may have different properties than the alien seaweed that is already present in the area and may have a greater impact on nature. For the same reason, the use of cultivars or hybrids also poses an additional risk to nature. There is a deliberate search for seaweed populations with properties beneficial to seaweed cultivation, and cultivars and hybrids with these properties are being developed. However, some of these properties increase the risk to nature.

The use of non-locally collected starting material also poses a risk to nature, because alien species with a negative impact on Dutch nature can hitchhike with the starting material. As a result, they can be introduced in the Netherlands or spread further within the Netherlands.

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7 List of terms and abbreviations

7.1 Abbreviations

Institutes or organisations	
AESAN	Spanish Agency for Food Safety and Nutrition (Agencia Española de Seguridad Alimentaria y Nutrición)
ANSES	French Agency for Food, Environmental and Occupational Health & Safety. (Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail)
ASC	Aquaculture Stewardship Council
ATSDR	U.S. Agency for Toxic Substances and Disease Registry
BfR	German Federal Institute for Risk Assessment (Bundesinstitut für Risikobewertung)
BuRO	Office for Risk Assessment & Research (BuRO) of the Netherlands Food and Consumer Product Safety Authority
Ctgb	Dutch Board for the Authorisation of Plant Protection Products and Biocides
CSHPF	French High Council for Public Health
EC	European Community (precursor of EU)
EFSA	European Food Safety Authority
EU	European Union
FAO	Food and Agricultural Organization of the United Nations
FDA (US)	Food and Drug Administration, U.S. Department of Health and Human Services
FSAI	Food Safety Authority of Ireland
JRC	Joint Research Centre
LNV	Ministry of Agriculture, Nature and Food Quality (Ministerie van Landbouw, Natuur en Voedselkwaliteit)(since 2 July 2024 LVVN)
LVVN	Ministry of Agriculture, Fisheries, Food Security and Nature (Ministerie van Landbouw, Visserij, Voedselzekerheid en Natuur)
MSc	Marine Stewardship Council
NVWA	Netherlands Food and Consumer Product Safety Authority (Nederlandse Voedsel- en Warenautoriteit)
RIVM	National Institute for Public Health and the Environment (Rijksinstituut voor Volksgezondheid en Milieu)
RVO	Netherlands Enterprise Agency (Rijksdienst voor Ondernemend Nederland)
WFBR	Wageningen Food & Biobased Research
WFSR	Wageningen Food Safety Research
WMR	Wageningen Marine Research
WHO	World Health Organization
Legislation	1
GFL	General Food Law
MSFD	Marine Framework Directive
Wbbl	Commodities Act Decree on the Preparation and Treatment of Foodstuffs (Warenwetbesluit Bereiding en behandeling van levensmiddelen)
Chemicals	1
MOSH	Mineral Oil Saturated Hydrocarbons
MOAH	Mineral Oil Aromatic Hydrocarbons
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
DL-PCBs	Dioxin-like PCBs
NDL-PCBs	Non dioxin-like PCBs
PCDD	Polychlorinated dibenzo-p-dioxins
PCDF	Polychlorinated dibenzofurans

PFAS	Poly- and perfluoroalkyl compounds (for individual PFAS abbreviations see Annex V)
(total) dioxins	All polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans together
Microorganisms	
HAV	Hepatitis A virus
HEV	Hepatitis E virus
NoV	Norovirus
spp.	Species, both microorganisms and seaweed
STEC	Shigatoxin-producing *Escherichia coli*
Technical terms	
ARfD	Acute Reference Dose; estimation of the amount of a substance in food or drinking water that a person can take within 24 hours without significant health effects (RIVM, 2024)
Aw	Water activity: measure of the amount of free water in a product
BMDLx	Benchmark Dose Lower Confidence Limit is the 95% lowest confidence interval of the estimated dose presenting an x% additional risk
CFU	Colony Forming Unit
DALY	Disability Adjusted Life Years; is a measure of lost life years plus years lived with health problems (see also burden of disease)
ID50	Dose in which 50% of those exposed will become ill
LB	Lower Bound; in LB calculations, reported contents <LOQ are replaced by the value 0
LOAEL	Lowest Observed Adverse Effect Level is the lowest experimental dose of a substance in which an undesirable effect is observed.
LOQ	Quantification limit (limit of quantification); lowest value that can be quantitatively demonstrated
ML	Maximum Limit; the maximum permitted concentrations of a substance in a food
MoE	Margin of Exposure; the ratio between a reference point (BMDL05) and the exposure
MPN	Most Probable Number; semi-quantitative method by which the *most likely number of* cultureable (living) bacterial cells in a product is determined
MRL	Maximum Residue Limit; the maximum permitted concentration of a substance in a food
PEQ	(Toxic) PFOA (Perfluorooctanoic acid) equivalents; an individual PFAS content converted to a PFOA equivalent using RPF
pH	Acidity
PTWI	Provisional (provisional) TWI
RASFF	Rapid Alert System for Food and Feed
RPF	Relative Potential Factor (for PFAS); the toxic potency of an individual PFAS relative to PFOA (Perfluorooctanoic acid)
TDI	Permissible Daily Intake; estimation of the amount of a substance that can be ingested daily during life, with no noticeable effect on health (RIVM, 2024)
TEF	Toxic Equivalence Factor (for dioxins, dibenzofurans and DL-PCBs); the toxic potency of an individual dioxin, dibenzofuran or DL-PCB relative to TCDD (2,3,7,8=tetrachlorodibenzo-p-dioxin)
TEQ	Toxic Equivalents (for dioxins, dibenzofurans and DL-PCBs); an individual content of a dioxin, dibenzofuran or DL-PCB converted to a TCDD equivalent using TEF
TWI	Tolerable Weekly Intake (7x the TDI)
UB	Upper Bound: <LOQ levels reported in UB calculations are replaced by the corresponding LOQs
VBNC	Viable but non-culturable; state in which a bacterial cell is viable but not cultureable. The cell is in very low metabolic activity and does not divide, but is alive and has the ability to become cultureable once it is revived
VCP	Food consumption survey (Voedselconsumptiepeiling)

7.2 List of terms

General	
Biostimulant	Biostimulant stimulates the natural nutritional processes of plants (Ctgb, 2025)
Export	Movement of products to other countries
Import	Introduction of products into from other countries
Processing	Treatment of the product. This includes washing, packaging, cutting, heating, smoking, salting, maturing, drying, marinating, extracting or extruding, or a combination of such treatments.
Seaweed	
Alien species	Species not naturally occurring in a geographical area (Gittenberger et al., 2020a)
Breeding	Growing up of starting material after which it can be farmed
Cultivar	A seaweed or group of seaweeds that has been selected for desirable properties and can be propagated and cultivated while retaining properties
Established species	Established means that a species survives and reproduces independently (for a number of years)
Fresh seaweed	Seaweed that has not been processed or only rinsed, washed and/or sliced
Growing	Growing a crop (seaweed)
Halophytes	Plants (not seaweed) that grow on a soil with high salinity
Hybrid	A descendant of a cross between two species
Hydromorphological characteristics	Hydromorphological characteristics are characteristics that include both the shape and structure of the watercourse (morphology) and the flow of the water (hydrology).
Inoculum	Cultivated seaweed (from starting material) grafted into cultivation system for further growth
Invasive aliens	Species that can (or has) entered an area only through human activity and whose introduction or spread adversely affects or threatens native biodiversity and related ecosystem services
Kelp	Large-leaved brown seaweeds; an order of brown seaweeds (*Laminariales*) comprising several dozen species of seaweeds, such as wakame (*Undaria pinnatifida*), kombu (*Saccharina japonica*), sugar kelp (*Saccharina latissima*) and giant kelp (*Macrocystis pyrifera*)
Local absent species	Species not present in this part of their natural range because the conditions are not suitable for this species
Native species	Species naturally occurring in a geographical area (Gittenberger et al., 2020a)
Polyploid organism	An organism that contains more than the usual (double) set of chromosomes
Raw seaweed	Seaweed which has not been heated or has undergone any other equivalent treatment.
Seaweed product	A food that consists of (almost) 100% seaweed or has seaweed as an ingredient
Spores	Spores of seaweed play a role in the reproduction of seaweed
Starting material	Seaweed or seaweed material intended for cultivation as inoculum
Non- indigenoius species	See alien species
Wild harvest	Collection of seaweed in the wild; loose seaweed on the coast, or partially cut off
Food safety	
Acute	Short-term, one-off
Burden of disease	The amount of health loss (expressed in years; unit is DALY) in a population caused by diseases

Chronic	Long-term, lifelong
Colony Forming Unit (CFU)	Size for the number of culturable (living) bacterial cells. Expressed in CFU per ml or per g of product. Because there is a possibility that 1 colony has been formed from more cells, this unit is used and not the number of cells per ml or gram
Environmental contaminant	Contaminants (pollutants) in the environment
Food Infection	Infectious disease arises from eating food and is caused by the (presence of) disease-causing microorganisms in that food. The disease itself arises after the ingress of the microorganisms into the body
Genotoxic	Damage to DNA can cause hereditary changes
Health based guidance value	Maximum amount of a substance that a human can ingest without health risks (mg or µg substance per kg body weight) (RIVM, 2024)
Hepatotoxicity	Toxic to the liver
Mutagenic	Genotoxic
Neurotoxic	Toxic to the nervous system
Opportunistic pathogens	Microorganisms that are not normally pathogenic, but can be under certain circumstances. Opportunistic infections are more common and more severe in people with weakened immune systems than in people with healthy immune systems.
Pathogenic microorganisms or pathogen	Disease-causing microorganism
Product standard	Maximum content of a substance in food, established per substance-food combination
Spore	A bacterial spore is a survival form intended to be able to survive for a long time under conditions that are unfavorable to the bacterium itself (vegetative form).
Toxicological reference value	A value that indicates the level of a particular substance to which humans can be safely exposed for a certain period of time; for example the Acceptable Daily Intake (ADI)
Virulence genes	Genes involved in the disease-causing potential of a microorganism
Water activity	A measure of the amount of free water present in a product, expressed in values between 0 and 1. By definition, pure water has an Aw value equal to 1

8 Annexes

Annex I. Approach of research

8.1 Public health

For this chain risk assessment, a series of research projects commissioned by NVWA-BuRO were carried out by a number of knowledge institutes from 2018 to 2022.

A literature review on chemical hazards in seaweed with regard to food safety was carried out by Wageningen Food Safety Research (WFSR) (Banach et al., 2020b) and on microbiological hazards by Wageningen Food & Biobased Research (WFBR) (Rodríguez Illera & Van Bokhorst-Van de Veen, 2019).

The chemical contamination and iodine levels of seaweed from Dutch seaweed farms have been investigated by WFSR on behalf of BuRO. In the same period, similar research was carried out by WFSR on behalf of the then Ministry of Agriculture, Nature and Food Quality, with a focus on representative sampling (variation in sampling spot in the seaweed bed, depth in sampling bed and the moment of sampling in the growing season). The studies for BuRO and LNV are complementary and the results have been compiled by WFSR in one report (Faassen et al., 2022).

During these investigations, WFSR approached the seaweed famers via North Sea Farmers (formerly called Noordzeeboerderij) for cooperation in the investigation. Seven seaweed farmers, including North Sea Farmers themselves, have cooperated. BuRO has had no direct contact with the seaweed farmers about this.

All seaweed sampling at the different seaweed farms was carried out by WFSR. Two meetings were organized where WFSR reported interim results to LNV, BuRO and North Sea Farmers together. The results of the chemical analyses were shared by WFSR individually with the seaweed farmers during the studies and in its entirety with North Sea Farmers. In this final report of WFSR, the results were anonymised. Due to business-sensitive information, the individual results report remains confidential (Faassen et al., 2022). WFSR included the aggregated, anonymised results in its public reporting (Banach et al., 2020b).

In addition, WFSR has been commissioned by LVVN to investigate the influence of processing and preparation of fresh seaweed on the levels of a number of contaminants (Van Tuinen et al., 2023; Gsell et al., 2025).

In addition, in 2018, 2019 and 2020, the NVWA sampled seaweed products including sushi in stores and wholesalers. The chemical analyses were carried out by WFSR. On behalf of BuRO, the chemical analyses of the samples from 2018 and 2019 were expanded with additional substances and dust groups. The results for 2018 and 2019 are presented together in one report (Faassen, 2020).

8.2 Nature

In order to identify the risks of seaweed cultivation in the area of alien species, BuRO commissioned research agency GiMaRIS to carry out three studies. The first study involved an inventory of alien species in 2019 (field research) and an estimate of the chance of their introduction, establishment and spread (Gittenberger et al., 2020b). The second study examined the risks of seaweed cultivation of the species proposed by the North Sea Farmers Foundation as species that could be cultivated in the North Sea (desk research in collaboration with Wageningen Marine Research (WMR)) (Gittenberger et al., 2020a). The third study assessed the impact of a number of alien seaweed species with commercial value on nature in the Netherlands (desk research and expert judgement) (Gittenberger, 2025).

Annex II. Additional literature review

8.3 Supplementary literature review on food safety – chemistry

Following the methodology used by the WFSR researchers (Banach et al., 2020b), additional literature research has been carried out. The search is limited: Limited to publication years 2019-2022 (20 July 2022).

In Scopus is searched with the following search terms:

1: seaweed

TITLE(seaweed* OR "edible algae" OR "Rhodymenia palmata" OR "Palmata palmata" OR "palmaria palmata" OR dulse OR "Porphyra tenera" OR nori OR "Ascophyllum nodosum" OR "Chlorella luteoviridis" OR "Heterochlorella luteoviridis" OR "Chlorella pyrenoidosa" OR "Chlorella vulgaris" OR "Eisenia bicyclis" OR "Fucus vesiculosus" OR "Hizikia fusiforme" OR "Sargassum fusiforme" OR "Hizikia fusiformis" OR hiziki OR "Laminaria digitata" OR "Finger kelp" OR "Laminaria japonica" OR "Laminariaic longruris" OR "Lamniaria saccharina" OR "Saccharina" OR hyperborea OR 'sugar kelp' OR 'Undaria pinnatifida' OR wakame OR 'Sphaerotrichia divaricate' OR 'Ulva lactuca' OR 'sea lettuce' OR 'Himanthalia elongate' OR 'Anthrospira Platensis' OR spirulina OR nanachloropsis OR porphyra OR undaria OR arame OR hizikia OR kelp OR laminaria OR saccharina OR palmaria OR ulva OR 'Alaria esculenta' OR 'Fucus serratus' OR 'Fucus serratus' OR 'Laminaria hyperborea' OR 'Saccharina japonica' OR 'Saccharina latissimia' OR 'Pelvetia canaliculate' OR 'Chondrus crispus' OR 'Gracilaria verrucose' OR 'Phymatolithon calum' OR OR 'palmata' OR 'Vertebrata lanosa' OR Caulerpa OR 'Cladophora rupestris' OR 'Enteromorpha' OR 'Mekong weed' OR rockweed OR dulse OR kombu OR tangle OR oarweed OR rockweed OR badderlocks)

2: chemical hazards

TITLE-ABS-KEY("Food contamination" OR "Chemical pollutant*" OR "chemical hazard*" OR contamina* OR toxin* OR "toxic substance*" OR "toxic compound*" OR pollutant* OR "agricultural chemical*" OR "chemical compound*" OR "chemical substance*" OR residue* OR toxicant* OR toxic* OR "heavy metal*" OR pesticide* OR iodine OR lectin* OR arsenic OR microplastic* OR dioxin OR pcb* OR "polychlorinated biphenyl*")

3: public health

TITLE-ABS-KEY("Public health" OR "HACCP" OR "Consumer protection" OR consumer* OR "Food safety" OR "risk assessment*" OR "risk analysis*" OR "hazard analysis*" OR "Human health*" OR "Health impact" OR "health risk*" OR human)

#1 AND #2 AND #3)

The above search yielded 316 publications in Scopus.

The same search terms have been used in Web of Science. Instead of TITLE-ABS-KEY, TS (topic) was used. The search yielded 256 publications.

8.4 Supplementary literature review on food safety – microbiology

The literature study was carried out by WFBR on behalf of BuRO (Rodríguez Illera & Van Bokhorst-Van de Veen, 2019). This literature study covers all literature up to and including 04-02-2019. This study looked for scientific literature in Scopus and Web of Science (WoS) and for grey literature (including reports: outbreaks, risk assessments) on the internet. This resulted in 31 relevant articles from Scopus and WoS and 8 documents from the grey literature (of which three RIVM reports 'State of Zoonoses').

Scientific and grey literature

BuRO has supplemented the literature study of WFBR with literature up to and including 03-10-2023.
For this, the same searches were used as by WFBR. However, a search carried over incorrectly by BuRO turned out to yield a wide selection of hits – mostly not relevant – in WoS (1,449 hits), even after the application of additional exclusion criteria (984 hits). Of these, the top 150 hits (sorted by relevance) were screened by title (and possibly abstract), resulting in a number of relevant publications. In total, this additional search resulted in 26

Table 31 Summary of the results of the additional literature searches.

Literature search system	Additional period		
	Hits	Relevant	Unique
	3-10-2023		
Scopus	324	2	2
WoS	11	1	0
WoS[*]	1.449	8	6
Google		14	14
Reports		3	3
Pathogens	86	6	1
Total			26
	14-2-2025		
Scopus processing	125	10	8

[*] Incorrectly copied search used, first 150 hits screened

relevant publications, which have been further read (and possibly used) for this risk assessment (Table 31, Table 32).

Finally, BuRO carried out an additional literature study on 14-02-2025 specifically for the effect of different processing methods on the microbiological safety of seaweed. The reason for this was a recent publication by WFBR in this area (Banach et al., 2024). The WFBR search was used and literature from the years 2022-2024 was searched.

The search terms used for processing methods are:

TITLE-ABS-KEY (processing OR drying OR salting OR ferment* OR freezing OR blanching OR heat* OR cook*) AND PUBYEAR >2021 AND PUBYEAR <2025

It was only searched in Scopus, because in the previous additional search it yielded the most (relevant) hits (with the right search). This did not yield the aforementioned article of Banach et al. (2024) with the exclusion criteria, therefore it was sought without the exclusion criteria. This resulted in 125 articles that were screened by title. In addition to the article by Banach et al. (2024), this resulted in 7 new relevant publications, which were further read (and possibly used) for this risk assessment (Table 31).

Outbreaks

Food-related outbreaks are registered in the Netherlands with the NVWA, GGD and RIVM. This is reported annually by RIVM in collaboration with the NVWA and WFSR. At EU level, annual reporting is done by EFSA in cooperation with ECDC in the One Health Zoonoses Reports. The reports covering the period 2017-2023 were consulted by BuRO (Netherlands: (Friesema et al., 2019; Friesema et al., 2020; Friesema et al., 2021;2022;2023;2024); EU: (EFSA & ECDC, 2018;2019;2021a;2021b;2022;2023;2024).

The Centres for Disease Control and Prevention (CDC) National Outbreak Public Data Tool (NORS; (CDC, 2018)) with data on food-related outbreaks in the United States (USA) was consulted by WFBR for the period 1998-2016, BuRO additionally looked for outbreaks in the period 2017-2021.

For Australia, WFBR looked for data on food-related outbreaks in the reports of the Australian state of New South Wales (2009-2018). In addition, the 2019 and 2020 reports were searched by BuRO (Communicable Diseases Branch, 2019;2022). In addition, annual reports were searched in OzFoodNet. These are available until 2017 and searched from 2013 onwards (Bell et al., 2021; OzFoodNet Working Group, 2021;2022). Also, the State of Queensland reports were searched, only a 2020 report was available (State of Queensland (Queensland Health), 2021).

For New Zealand, WFBR has searched the reports of New Zealand Food Safety from the period 2006-2016. In addition, BuRO searched the reports from the period 2017-2022 (Pattis et al., 2019a; Pattis et al., 2019b; Pattis et al., 2020; Horn et al., 2021; Pattis et al., 2022; Horn et al., 2023).

Finally, BuRO searched for information about food-related outbreaks in Hong Kong and Taiwan. These are countries in Asia, of which the consumption of seaweed is suspected to be higher than in Europe and these countries have an English-language website. Searches have been made for Hong Kong on the website of the Centre for Health Protection (www.chp.gov.hk) and the Centre for Food

Safety (www.fcs.gov.hk). For Taiwan, a search was made on the website of the Ministry of Health and Welfare (www.mohw.gov.tw).

Table 32 Summary of the results of the additional literature search on the 15 food-related pathogens.

Pathogen	Hits	Relevant hits
*Bacillus cereus**	13	1
Campylobacter	3	0
Clostridium botulinum en *Clostridium perfringens*#	5	0
Listeria monocytogenes	5	4
Salmonella	17	4
Staphylococcus aureus$	21	1
STEC%	4	2
Norovirus	4	0
Rotavirus	2	0
HAV, HEV&	9	0
Cryptosporidium	1	0
Giardia	1	0
Toxoplasma gondii	1	0
Total	86	12 (6 unique)

Used search strings:
* "Bacillus cereus" OR "B. cereus"
# "Clostridium botulinum" OR "C. botulinum" OR "Clostridium perfringens" OR "C. perfringens"
$ "Staphylococcus aureus" OR "S. aureus"
% (verotox* OR vtec OR (enterohemorr* AND *coli) OR ehec OR shigatox* OR shiga*tox* OR stec OR (enterotox* AND *coli) OR etec OR (enteropath* AND *coli) OR epec OR (enteroinvas* AND *coli) OR (entero*invas* AND *coli) OR eiec OR (enteroaggr* AND *coli) OR eaec OR eaggec OR "adherent-invasive e. coli" OR aiec OR "pathogenic *coli" OR O157)

8.5 Supplementary literature review on food safety – physical

With the help of the search engines PubMed and Scopus, the search terms seaweed, algae, physical, foreign objects, foreign bodies, foreign material, extraneous material, injury (injuries) and hazard(s) were used in different combinations (AND/OR) to search for scientific literature that addresses the physical hazards in the seaweed chain and associated risks. Specifically for micro- and nanoplastics, the combination of microplastics, nanoplastics, seaweed and/or algae was searched. This literature review covers literature until April 2024.

In addition, relevant notifications were searched for in RASFF, the European Union's system for Food and Feed Safety Alerts. The U.S. Food and Drug Administration's (FDA) Recalls, Market Withdrawals, & Safety Alerts. Finally, Google searched for additional information using the various search terms.

Annex III. Sampling protocol

Sampling of seaweed at seaweed farms is not subject to a sampling protocol, as is the case for many other foodstuffs. During the initial sampling of cultivated seaweed, a sampling protocol for the sampling of seaweed has been established. This was done on the basis of existing sampling protocols at the NVWA for crustaceans and molluscs and the experience gained during the first sampling of fresh seaweed. This protocol describes the sampling for sea lettuce and sugar kelp (in saltwater basins on land, in estuaries and at sea), the quantities and method of sampling, measures to prevent contamination and instructions for transport and storage of the samples. Sampling instructions take into account both chemical and microbiological analysis. It is a first step in standardizing sampling of fresh seaweed. It was drawn up by WFSR, North Sea Farmers and the then Ministry of Agriculture, Nature and Food Quality as a tool for the seaweed sector. It is explicitly not an official sampling protocol of the NVWA (North Sea Farm, 2020).

The information from this project has been fed into the development of European standards for micro- and macroalgae for, among other things, an algae sampling method at the request of the European Commission. From the Netherlands, the Netherlands Standards Institute (NEN) is involved (Te Ronde, 2018). The Standards Committee is working on a CEN standard concerning the analytical method for the determination of contaminants (Boos, 2021).Annex IV.

Annex IV. Individually analysed dioxins, DL-PCBs and NDL-PCBs

Table 33 Overview of individually analysed dioxins, DL-PCBs and NDL-PCBs.

Dioxins (PCDD/Fs)	
2,3,7,8-TCDF	2,3,7,8-TCDD
1,2,3,7,8-PeCDF	1,2,3,7,8-PeCDD
2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDD
1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDD
1,2,3,6,7,8-HxCDF	1,2,3,7,8,9-HxCDD
2,3,4,6,7,8-HxCDF	1,2,3,4,6,7,8-HpCDD
1,2,3,7,8,9-HxCDF	OCDD
1,2,3,4,6,7,8-HpCDF	
1,2,3,4,7,8,9-HpCDF	
OCDF	
DL-**PCB's (non-ortho PCB's** and mono-**ortho PCB's)**	
PCB 81	PCB 114
PCB 77	PCB 105
PCB 126	PCB 167
PCB 169	PCB 156
PCB 123	PCB 157
PCB 118	PCB 189
NDL-**PCB's**	
PCB 028	PCB 153
PCB 052	PCB 138
PCB 101	PCB 180

Annex V. List of abbreviations of individual PFAS

Table 34 Full name of individual PFAS plus CAS numbers.

PFAS abbreviation	PFAS	CAS number
PFBA	perfluorobutanoic acid	375-22-4
PFPeA	perfluoropentanoic acid	2706-90-3
PFHxA	perfluorohexanoic acid	307-24-4
PFHpA	perfluoroheptanoic acid	375-85-9
PFOA	perfluorooctanoic acid	335-67-1
PFNA	perfluoronanoic acid	375-95-1
PFDA	perfluorodecanoic acid	335-76-2
PFUnDA	perfluorundecanoic acid	2058-94-8
PFDoDA	perfluorododecanoic acid	307-06-7
PFTrDA	perfluorotridecanoic acid	72629-94-8
PFTeDA	perfluorotetradecanoic acid	376-06-7
PFBS	perfluorobutanesulfonic acid	375-73-5
PFHxS	perfluorohexane sulfonic acid	355-46-4
PFHpS	perfluoroheptanesulfonic acid	375-92-8
PFOS	perfluorooctane sulfonic acid	1763-23-1
PFDS	perfluorodecane sulfonic acid	335-77-3
GenX (HPFO-DA)	2,3,3,3-tetrafluoro-2(heptafluoropropoxy)propionic acid	13252-13-6
NaDONA	sodium salt of ammonium 4,8-dioxa-3h-perfluorononanoate (ADONA)	958445-44-8*
9Cl-PF3ONS	9-chlorohexadecafluoro-3-oxanonane-1-sulfonate	73606-19-6
11Cl-PF3OUdS	11-chloroeicosafluoro-3-oxaundecane-1-sulfonate	83329-89-9
PFHxDA	perfluorohexadecanoic acid	67905-19-5
PFODA	perfluorooctadecanoic acid	16517-11-6
PFOSA	perfluorooctane sulfonamide	754-91-6

*Applies to ADONA reference value

Annex VI. Details of Quantification Limits (LOQ)

Table 35 gives an overview of the quantification limit (LOQ) of the analysis of iodine, heavy metals and other contaminants found in the seaweeds sea lettuce and sugar kelp. Because the LOQ differs per sample, it is shown in a range. For those substances where none of the analytical results were below the LOQ, no value is shown.

Table 35 An overview of the quantification limit (LOQ) of the analysis of iodine, heavy metals and other contaminants found in the seaweeds sea lettuce and sugar kelp.

Substance	Unit	Sea lettuce		Kelp weed	
		Wet	Dry	Wet	Dry
Iodine	mg/kg	-	-	-	-
Cadmium		0.066	0.3	0.02-0.066	0.12-0.47
Mercury		0.004-0.01	0.012-0.050	0.004-0.015	0.020-0.12
Lead		0.06	0.26-0.32	0.06	0.37-0.45
Nickel		-	-	0.1	0.65-0.73
Total arsenic		0.02-0.12	0.06-0.54	-	-
Inorganic arsenic		0.03-0.11	0.14-0.68	0.11	0.44-0.87
Total dioxins	ng WHO(2005)-PCDD/F-TEQ/kg	-	-	-	-
Total DL-PCBs		-	-	-	-
Total NDL-PCBs	µgkg	0.08	0.45	0.08	0.58
Benzo(a)anthracene		0.1	0.02-0.03	0.1	0.01-0.02
Chrysene		0.1	0.02-0.03	0.1	0.02
Benzo(b)fluoranthene		0.1	0.02-0.03	0.1	0.02
Benzo(a)pyrene		0.1	0.02-0.03	0.1	0.02

Table 36 provides an overview of the quantification limit (LOQ) of the analysis of the individual PFAS compounds found in the seaweeds sea lettuce and sugar kelp. The LOQ is based on wet product analysis.

Table 36 An overview of the quantification limit (LOQ) of the analysis of the individual PFAS compounds found in the seaweeds sea lettuce and kelp weed.

PFAS	**LOQ (µg/kg product)**
PFHxA	0.1
PFHpA	0.005
PFOA	0.1
PFNA	0.1
PFDA	0.1
PFUnDA	0.1
PFDoDA	0.005
PFTrDA	0.005
PFTeDA	0.005
PFBS	0.1
PFHxS	0.005
PFHpS	0.01
PFOS	0.1
PFDS	0.1
GenX	0.1
NaDONA	0.005
9Cl-PF3ONS	0.005

Annex VII. Relative potency factors PFAS

Table 37 Overview of measured PFAS and associated relative potency factors based on (Bil et al., 2021). If a range has been reported for the RPF, BuRO has chosen the highest value as RPF, in line with the most recent calculations by RIVM (Schepens et al., 2023).

PFAS*	RPF	Note:
11Cl-PF3OUdS	(-)	no RPF available, not included in calculation
9Cl-PF3ONS	(-)	no RPF available, not included in calculation
GenX	0.06	in article referred to as HFPO-DA
NaDONA	0.03	in article referred to as ADONA
PFBA	0.05	
PFBuS	0.001	in article referred to as PFBS
PFDA	10	in article range 4 to 10
PFDoDA	3	
PFDS	2	
PFHpA	1	in article range 0.01 to 1
PFHpS	2	in article range 0.6 to 2
PFHxA	0.01	
PFHxS	0.6	
PFNA	10	
PFOA	1	
PFOS	2	
PFPeA	0.05	in article range 0.01 to 0.05
PFTeDA	0.3	
PFTrDA	3	in article range 0.3 to 3
PFUnDA	4	

*For explanation of the abbreviations of the individual PFAS, see Annex V

Annex VIII. Concentrations of contaminants in sea lettuce and sugar kelp

Table 38 The mean, minimum, maximum, P50 and P95 content (mg/kg) of iodine, cadmium, mercury, lead, nickel, total arsenic and inorganic arsenic found in the studied seaweeds sea lettuce and sugar kelp. All levels are shown for both wet and dried seaweed*. For LB, the values <LOQ have been replaced by the value 0 and for UB, the values <LOQ have been replaced by the corresponding LOQs.

	Iodine		Cadmium		Mercury		Lead		Nickel		Total arsenic		In organic arsenic	
	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB
	Wet seaweed – sea lettuce (mg/kg)													
Mean	12	12	0.0087	0.022	0.0040	0.0072	0.45	0.47	0.79	0.79	0.78	0.79	0.12	0.15
Minimum	0.76	0.76	0	0.0045	0	0.0035	0	0.0098	0.097	0.097	0	0.015	0	0.028
Maximum	62	62	0.028	0.066	0.031	0.031	2.8	2.8	3.9	3.9	4.3	4.3	0.57	0.57
P50	6.2	6.2	0.0075	0.011	0	0.0047	0.26	0.3	0.59	0.59	0.73	0.73	0.11	0.11
P95	31	31	0.022	0.066	0.016	0.016	1.7	1.7	1.5	1.5	2.3	2.3	0.28	0.28
	Dry seaweed – sea lettuce (mg/kg)													
Mean	57	57	0.038	0.097	0.016	0.0302	2.04	2.1	3.02	3.02	3.4	3.4	0.55	0.70
Minimum	3.7	3.7	0	0.015	0	0.012	0	0.047	0.47	0.47	0	0.065	0	0.29
Maximum	194	194	0.101	0.33	0.072	0.072	7.2	7.2	6.3	6.3	9.7	9.7	1.4	1.4
P50	27	27	0.038	0.049	0	0.028	1.3	1.3	2.7	2.7	3.4	3.4	0.46	0.60
P95	161	161	0.089	0.31	0.041	0.048	6.4	6.4	6.02	6.02	7.7	7.7	1.3	1.3
	Wet seaweed – kelp weed (mg/kg)													
Mean	609	609	0.018	0.029	0.0053	0.014	0.45	0.46	0.72	0.73	7.1	7.1	0.12	0.17
Minimum	27	27	0	0.015	0	0.0035	0	0.053	0	0.10	2.5	2.5	0	0.11
Maximum	3600	3600	0.075	0.075	0.02	0.020	1.9	1.9	3.7	3.7	14	14	0.50	0.50
P50	560	560	0.019	0.021	0	0.015	0.29	0.29	0.48	0.48	7.3	7.3	0.12	0.12
P95	1150	1150	0.049	0.066	0.018	0.018	1.3	1.3	1.8	1.8	11	11	0.39	0.39
	Dry seaweed – kelp weed (mg/kg)													
Mean	3559	3559	0.097	0.17	0.030	0.082	2.6	2.6	4.4	4.5	41	41	0.71	1.02
Minimum	170	170	0	0.082	0	0.020	0	0.35	0	0.65	19	19	0	0.44
Maximum	14400	14400	0.39	0.46	0.12	0.12	11	10.7	26	26	63	63	2.6	2.6
P50	3483	3483	0.12	0.14	0	0.091	1.8	1.8	3.2	3.2	42	42	0.78	0.83
P95	6925	6925	0.24	0.39	0.11	0.12	6.9	6.9	12	12	55	55	2.1	2.1

* In its report, WFSR expressed all analysis results in dry weight. Where analyses have been carried out on wet samples, the dry weight concentrations have been calculated by correcting for the moisture content of the sample (Faassen et al., 2022).

Table 39 The mean, minimum, maximum, P50 and P95 levels of total dioxins, total DL-PCBs, total dioxins + total DL-PCBs (ng WHO(2005)-PCB- TEQ/kg), total NDL-PCBs, benzo(a)anthracenes, chrysene, benzo(b)fluoranthene, benzo(a)pyrene and the sum of PAH4 (µg/kg) found in the studied seaweeds sea lettuce and sugar kelp. All levels are shown for both wet and dried seaweed*. For the LB, the values <LOQ have been replaced by the value 0 and for UB, the values <LOQ have been replaced by the corresponding LOQs.

	Total dioxins		Total DL-PCBs		Total dioxins + total DL-PCBs		Total NDL-PCBs		Benzo(a)-anthracene		Chrysene		Benzo(b)-fluoranthene		Benzo(a)-pyrene		Sum PAH4	
	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB
	(ng WHO(2005)-PCB-TEQ/kg)						(µg/kg)											
	Wet seaweed – sea lettuce																	
Mean	0.039	0.081	0.012	0.013	0.051	0.094	0.094	0.16	0.26	0.29	0.34	0.37	0.50	0.52	0.28	0.31	1.4	1.5
Min.	0.0013	0.027	0.000022	0.0025	0.0013	0.033	0	0.037	0	0.10	0	0.10	0	0.10	0	0.10	0	0.40
Max.	0.15	0.19	0.044	0.044	0.19	0.24	0.41	0.47	0.92	0.92	1.3	1.3	1.6	1.6	1.1	1.1	5.0	5.00
P50	0.036	0.0605	0.0097	0.011	0.046	0.073	0.054	0.14	0.15	0.15	0.21	0.21	0.32	0.32	0.15	0.15	0.82	0.82
P95	0.097	0.18	0.028	0.029	0.13	0.204	0.28	0.32	0.71	0.71	0.88	0.88	1.4	1.4	0.83	0.83	3.8	3.8
	Dry seaweed – sea lettuce																	
Mean	0.17	0.35	0.053	0.057	0.22	0.402	0.39	0.71	1.1	1.1	1.4	1.4	2.0	2.0	1.1	1.1	5.5	5.6
Min.	0.0071	0.066	0.00012	0.014	0.0072	0.079	0	0.15	0	0.016	0	0.016	0	0.016	0	0.016	0	0.065
Max.	0.70	0.89	0.201	0.204	0.90	1.1	1.9	2.2	3.2	3.2	3.7	3.7	6.7	6.7	3.6	3.6	17	17
P50	0.11	0.28	0.034	0.041	0.16	0.32	0.21	0.69	0.74	0.74	1.0	1.0	1.5	1.5	0.71	0.71	4.0	4.0
P95	0.47	0.85	0.14	0.14	0.61	0.99	1.3	1.5	3.0	3.0	3.5	3.5	6.0	6.0	3.2	3.2	15.7	15.7
	Wet seaweed – kelp weed																	
Mean	0.042	0.081	0.011	0.012	0.053	0.093	0.099	0.15	0.45	0.48	0.54	0.57	0.83	0.86	0.56	0.59	2.4	2.5
Min.	0.000025	0.026	0.000026	0.0023	0.0000501	0.028	0	0.027	0	0.10	0	0.10	0	0.10	0	0.10	0	0.40
Max.	0.24	0.24	0.053	0.053	0.29	0.29	0.47	0.47	1.8	1.8	2.2	2.2	3.7	3.7	2.2	2.2	9.9	9.9
P50	0.016	0.064	0.0034	0.0045	0.021	0.0705	0.018	0.10	0.19	0.19	0.24	0.24	0.39	0.39	0.208	0.208	1.03	1.03
P95	0.14	0.18	0.037	0.037	0.18	0.21	0.46	0.46	1.5	1.5	1.7	1.7	2.7	2.7	2.0	2.0	7.9	7.9
	Dry seaweed – kelp weed																	
Mean	0.23	0.47	0.059	0.067	0.29	0.54	0.49	0.79	2.5	2.5	3.003	3.01	4.6	4.6	3.1	3.1	13	13
Min.	0.00016	0.17	0.00017	0.015	0.00033	0.19	0	0.17	0	0.013	0	0.015	0	0.015	0	0.015	0	0.061
Max.	1.2	1.2	0.26	0.27	1.5	1.5	2.3	2.3	9.05	9.05	11	11	19	19	11	11	50	50
P50	0.12	0.37	0.026	0.032	0.14	0.41	0.13	0.67	0.83	0.83	1.2	1.2	1.8	1.8	0.98	0.98	4.7	4.7
P95	0.79	1.0	0.17	0.18	0.96	1.2	2.03	2.03	8.4	8.4	9.6	9.6	15	15	11	11	44	44

Min.: minimum, Max.: maximum

* In its report, WFSR expressed all analysis results in dry weight. Where analyses have been carried out on wet samples, the dry weight concentrations have been calculated by correcting for the moisture content of the sample (Faassen et al., 2022).

Table 40 The total PFAS levels (ng PFAS/kg or ng PEQ/kg for the calculations with RPFs) calculated by BuRO in the studied seaweeds sea lettuce and sugar kelp. The mean, minimum, maximum, P50 and P95 levels are calculated with a lower bound. Four different methods have been used to add up the PFAS; sum of EFSA-4 based on equipotency, sum of EFSA-4 based on RPFs, sum of all measured PFAS based on equipotency and sum of all measured PFAS based on RPFs. All levels are shown for both wet and dried seaweed.

	Sum EFSA-4 (ng PFAS/kg)	Sum EFSA-4 (ng PEQ/kg)	Sum all measured PFAS (ng PFAS/kg)	Sum all measured PFAS (ng PEQ/kg)
Wet seaweed – sea lettuce				
Mean	94	258	121	450
Minimum	0	0	0	0
Maximum	460	1160	523	1682
P50	81	193	103	413
P95	307	829	362	1227
Dry seaweed – sea lettuce				
Mean	446	1231	584	2124
Minimum	0	0	0	0
Maximum	2880	7280	3270	10520
P50	152	441	331	1236
P95	1671	4446	1952	6542
Wet seaweed - kelp weed				
Mean	37	102	50	174
Minimum	7	14	7	14
Maximum	198	573	256	910
P50	18	40	20	40
P95	135	390	173	691
Dry seaweed - kelp weed				
Mean	260	608	368	1184
Minimum	48	96	48	96
Maximum	996	2916	1196	4556
P50	115	260	130	260
P95	872	1989	1000	3667

Annex IX. Maximum safe consumption of seaweed contaminated with PFAS

Table 41 The maximum daily safe consumption of the studied seaweeds sea lettuce and sugar kelp before the health based guidance value of PFAS is exceeded by 1- to 3-year-olds (12 kg) and 18- to 80-year-olds (60 kg). Four different methods have been used to add up the PFAS; sum of EFSA-4 based on equipotency, sum of EFSA-4 based on RPFs, sum of all measured PFAS based on equipotency and sum of all measured PFAS based on RPFs. In bold: the calculated maximum daily safe consumption is lower than the upper limit of high consumption (95% confidence interval of P95 consumption; i.e. <161.4 grams per day and <23.1 grams per day, respectively for wet and dry seaweed). Exposure from other sources has not been taken into account.

Seaweed		Substance	Health based guidance value (ng/kg body weight per day)	P95 concentration	Maximum daily safe consumption (g/day)	
					1- to 3-year-olds	18- to 80-year-olds
Sea lettuce	Wet	Sum EFSA-4 (ng PFAS/kg)	0.63	619	12	61
		Sum EFSA-4 (ng PEQ/kg)		1,667	5	23
		Sum all measured PFAS (ng PFAS/kg)		734	10	51
		Sum all measured PFAS (ng PEQ/kg)		2,480	3	15
	Dry	Sum EFSA-4 (ng PFAS/kg)		3,804	2	10
		Sum EFSA-4 (ng PEQ/kg)		9,430	1	4
		Sum all measured PFAS (ng PFAS/kg)		7,300	1	5
		Sum all measured PFAS (ng PEQ/kg)		14,489	1	3
Kelp weed	Wet	Sum EFSA-4 (ng PFAS/kg)		270	28	140
		Sum EFSA-4 (ng PEQ/kg)		781	10	48
		Sum all measured PFAS (ng PFAS/kg)		353	21	107
		Sum all measured PFAS (ng PEQ/kg)		1,400	5	27
	Dry	Sum EFSA-4 (ng PFAS/kg)		2,280	3	17
		Sum EFSA-4 (ng PEQ/kg)		4,228	2	9
		Sum all measured PFAS (ng PFAS/kg)		6,344	1	6
		Sum all measured PFAS (ng PEQ/kg)		9,830	1	4

Annex X. PFAS intake by P50 and P95 consumption of studied seaweed

Table 42 The intake (ng PFAS/kg body weight/day or ng PEQ/kg body weight/day for RPF calculations) of PFAS of 18- to 80-year-olds (60 kg) by P50 and P95 consumption (seaweed users) of the studied wet and dry seaweed (both sea lettuce and sugar kelp). Four different methods have been used to add up the PFAS; sum of EFSA-4 based on equipotency, sum of EFSA-4 based on RPFs, sum of all measured PFAS based on equipotency and sum of all measured PFAS based on RPFs.

Seaweed		Substance	P50 concentration	Intake (ng PFAS/kg body weight/day or ng PEQ/kg body weight/day)		Health based guidance value (µg/kg body weight per day)
				P50 consumption	P95 consumption	
Sea lettuce	Wet	Sum EFSA-4 (ng PFAS/kg)	161	0.0089	0.25	0.63
		Sum EFSA-4 (ng PEQ/kg)	384	0.021	0.598	
		Sum all measured PFAS (ng PFAS/kg)	207	0.011	0.32	
		Sum all measured PFAS (ng PEQ/kg)	825	0.045	1.3	
	Dry	Sum EFSA-4 (ng PFAS/kg)	211	0.0018	0.047	
		Sum EFSA-4 (ng PEQ/kg)	1145	0.0095	0.25	
		Sum all measured PFAS (ng PFAS/kg)	420	0.0035	0.093	
		Sum all measured PFAS (ng PEQ/kg)	3373	0.028	0.75	
Kelp weed	Wet	Sum EFSA-4 (ng PFAS/kg)	35	0.0019	0.055	
		Sum EFSA-4 (ng PEQ/kg)	80	0.0044	0.12	
		Sum all measured PFAS (ng PFAS/kg)	40	0.0022	0.062	
		Sum all measured PFAS (ng PEQ/kg)	80	0.0044	0.12	
	Dry	Sum EFSA-4 (ng PFAS/kg)	1505	0.013	0.33	
		Sum EFSA-4 (ng PEQ/kg)	1863	0.016	0.41	
		Sum all measured PFAS (ng PFAS/kg)	5382	0.045	1.2	
		Sum all measured PFAS (ng PEQ/kg)	4615	0.038	1.02	

Annex XI. Ratio of total daily PFAS intake and maximum safe intake

Table 43 The ratio of daily intake (ng PFAS/kg body weight/day or ng PEQ/kg body weight/day for RPF calculations) of PFAS of 18- to 80-year-olds (60 kg) by P50 and P95 consumption (seaweed users) of the studied wet and dry seaweed (both sea lettuce and sugar kelp). Ratios >1 are shown in bold. The starting point is a P50 content of PFAS.

Seaweed		Substance	Ratio between daily contaminant intake (ng/kg body weight/day) and health based guidance value	
			P50 consumption	P95 consumption
Sea lettuce	Wet	Sum EFSA-4 (ng PFAS/kg)	0.014	0.40
		Sum EFSA-4 (ng PEQ/kg)	0.034	0.95
		Sum all measured PFAS (ng PFAS/kg)	0.018	0.51
		Sum all measured PFAS (ng PEQ/kg)	0.072	2.04
	Dry	Sum EFSA-4 (ng PFAS/kg)	0.0028	0.074
		Sum EFSA-4 (ng PEQ/kg)	0.015	0.404
		Sum all measured PFAS (ng PFAS/kg)	0.0056	0.15
		Sum all measured PFAS (ng PEQ/kg)	0.045	1.2
Kelp weed	Wet	Sum EFSA-4 (ng PFAS/kg)	0.0031	0.087
		Sum EFSA-4 (ng PEQ/kg)	0.0070	0.20
		Sum all measured PFAS (ng PFAS/kg)	0.0035	0.099
		Sum all measured PFAS (ng PEQ/kg)	0.0070	0.20
	Dry	Sum EFSA-4 (ng PFAS/kg)	0.020	0.53
		Sum EFSA-4 (ng PEQ/kg)	0.025	0.66
		Sum all measured PFAS (ng PFAS/kg)	0.071	1.9
		Sum all measured PFAS (ng PEQ/kg)	0.061	1.6

Annex XII. Tables of microbiological food safety risk

Not all pathogens listed in this table have actually been found on seaweed, such as, for example, *C. jejuni*. However, the research published in the literature on several of these pathogens is limited. Failure to find a pathogen is therefore not proof of absence, especially if pathogens associated with the same reservoir (animal, human, environment) have been found on seaweed. For this reason, this table includes pathogens that can cause food-related infections and that are not necessarily unlikely to occur on seaweed.

Table 44 Overview of relevant (growth) factors of pathogenic bacteria that could occur on seaweed and may be important for the food safety of seaweed (source: (US FDA, 2019b; Cressey et al., 2023)).

Microorganism	Reservoir[i]	Min. ID[ii] (cells)	Growth needed[iii]	Min. Temp. (°C)	pH[iv]	Min. Aw	Sick by ingestion	Toxin
B. cereus	environment (land, water)	>10^5 CFU/g >10^6 CFU/g[vii]	yes	4	4,3	0,91	cells/spores [v] toxin[viii]	[vi] heat stable
C. jejuni	human, animal	>500	no	30	4,9	0,987	cells	
C. botulinum proteolytic: A,B,F	human, animal/environment/soil		yes	10	4,6	0,93	toxin	heat labile
Non-proteolytic: B,E,F				2,5	5	0,93-0,97		
C. perfringens	human, animal/environment/soil sediment	>10^6 CFU/g	yes	4-10	5	0,93	cells/spores	[vi]
E. coli (STEC)	human, animal	±10-100	no	±6.5	4	0,95	cells	N/A
L. monocytogenes	human, animal/environment	±10^3-10^4	no/yes	-0,4	4,4	0,92	cells	N/A
Salmonella	human, animal	>1	no	5,2	3,7	0,94	cells	N/A
S. aureus growth	human, animal/(environment)	>10^5 CFU/g[vii]	yes	7	4	0,83	toxin	heat stable
toxin production				10	4	0,85		
Shigella spp.	human	±10-200	no	6,1	4,8	0,96	cells	N/A
V. cholerae non O1/O139	seawater	>10^6	yes	10	5	0,97	cells	N/A
V. parahaemolytic	seawater	>10^5	yes	5	4,8	0,94	cells	N/A
V. vulnificus	seawater	10^3-10^6	yes	8	5	0,96	cells	N/A
Y. enterocolitica	human, animal	10^4-10^8	yes	-1,3	4,2	0,945	cells	N/A
Viruses, parasites	Human pathogenic viruses and parasites cannot grow outside their living host. There is therefore no increase on seaweed							

[i] Human, animal: Introduced by humans or animals into the seawater or process environment; environment, water: occurs naturally in the environment or water

[ii] Min. ID: 'minimum infectious dose'. These are often estimates, where the values depend on, among others, host, matrix andstrain . It is better to indicate the dose at which the probabilityof developing symptoms can be considered relevant

[iii] Growth needed in product to achieve minimal infectious dose

[iv] Minimum/maximum, the optimum is usually between pH 6-7

[v] Diarrhea-type complaints

[vi] Formed in the intestines

[vii] Number of cells (CFU/g) in food related to toxin production

[viii] -type complaints (cereulide)

Table 45 Overview of publications with quantitative data on the occurrence of (potentially)pathogenic microorganisms on seaweed (products). The number of samples per study is shown.

Reference	#Samples
(Mahmud et al., 2006)	96
(Mahmud et al., 2008)	75
(DVFA, 2021)*	65
(Panebianco et al., 2019)	26
(EFSA BIOHAZ Panel, 2013)	24
(Ziino et al., 2010)*	20
(Barberi et al., 2020)	18
(Choi et al., 2014)	18
(Lytou et al., 2021)	16
(Alsulaiman, 2011)	14
(Martelli et al., 2021)	14
(Moore et al., 2002)#	12
(Zulkifly et al., 2012)	12
(Moreira-Leite et al., 2023)	8
(Banach et al., 2024)	5
(Son et al., 2014)*	4
(Blikra et al., 2019)	3
(Sørensen et al., 2023)	3
(FSAI Sci. Com., 2020)	2
Final total	435

* reference from Cressey et al. (2023)

\# reference from FSAI Sci. Com. (2020)