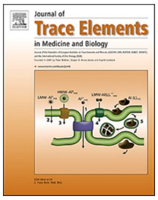
Journal of Trace Elements in Medicine and Biology 78 (2023) 127187

Contents lists available at ScienceDirect

Journal of Trace Elements in Medicine and Biology

journal homepage: www.elsevier.com/locate/jtemb



Dietary exposure and risk assessment to trace elements and iodine in seaweeds

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ARTICLE INFO

Keywords:
Seaweeds
Food
Human
Exposure and risk assessment

ABSTRACT

Introduction: Seaweeds are a rich source of elements such as iodine, and are also able to accumulate contaminants such as trace elements.

Methods: The aim of this study was to assess the dietary exposure as well as the risk from iodine and trace elements in edible seaweeds for the French population using current consumption data. The contribution of seaweeds to overall dietary exposure to trace elements and iodine was evaluated, and for those substances with minimal contribution to overall dietary exposure, simulations were performed to propose increased maximal limits in seaweeds.

Results: Cadmium, inorganic arsenic and mercury in seaweeds were very low contributors to total dietary exposure to these contaminants (0.7 % 1.1 % and 0.1 % on average, respectively). Dietary exposure to lead via seaweed may contribute up to 3.1 % of total dietary exposure. Dietary consumption of iodine via seaweed may contribute up to 33 % of total exposure to iodine, which makes seaweeds the strongest contributor to iodine in diet.

Discussion: New maximal values in seaweeds are proposed for the very low contributors to total dietary exposure: 1 mg/kg dw for cadmium, 10 mg/kg dw for inorganic arsenic and 0.3 mg/kg dw for mercury.

1. Introduction

Marine macroalgae, or seaweeds, are plant-like organisms that live attached to rock or other hard substrata in coastal areas. Seaweeds are found growing throughout the world's oceans, in the form of thousands of different species [21]. Of these, 221 species are of commercial value [16]. Seaweeds are part of the traditional diet in Asia [7,24,29]. Consumption is relatively recent in most parts of Europe but is increasing due to growing consumer interest in healthier lifestyles and vegetarian or vegan diets [23]. Most seaweed consumption in Europe is inspired by Asian food, such as the varieties used in sushi, but other algae-containing products are also available on the market as condiments or snacks [6,17,26]. Seaweeds are a rich source of essential elements such as iodine, calcium, sodium, magnesium, phosphorus and potassium [26]. However, they are also able to accumulate contaminants such as trace elements, ammonium, dioxins and pesticides [18,22,25].

Human exposure and risk assessments for trace metals (such as cadmium, lead, and mercury) as well as iodine found in seaweeds have been performed on the European and French populations [5,8,23]. In these studies, seaweed consumption data were scarce or even absent. In the European study, the seaweed consumption data used in exposure calculations were estimated due to the absence of real data. For example, for the European Food Risk Assessment Fellowship Programme (EU-FORA) 2018/2019, a single serving size of 5 g of seaweeds, once a week, was used to perform this risk assessment on the European population. The authors mentioned in their conclusions that a priority for refining this evaluation would be to collect species-specific consumption data [23]. In the French study, consumption data were obtained from the Individual and National Surveys on Food Consumption (INCA3) survey conducted among 5855 adults and children. Seaweeds were consumed by very few people: 33 adults and 16 children when seaweeds were consumed as a food ingredient and 10 adults and 4 children when seaweeds, including glasswort, were consumed as a food. No frequency

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https://doi.org/10.1016/j.jtemb.2023.127187
Received 21 October 2022; Received in revised form 12 January 2023; Accepted 26 April 2023

Table 1
Number of analyses for trace elements and iodine in seaweeds.

Species	Number of sampling	Number of analyses					
		Total arsenic	Inorganic arsenic	Cadmium	Lead	Total mercury	Iodine
Fucus sp	77	40	0	50	27	25	48
Himanthalia elongata	34	4	23	29	18	14	23
Palmaria palmata	82	23	44	70	33	38	62
Porphyra sp	24	4	10	18	5	12	9
Saccharina latissima	39	3	39	39	18	18	39
Ulva sp	186	11	38	61	40	32	50
Undaria pinnatifida	26	4	18	26	14	13	25
Total	468	89	172	293	155	152	256

For example: 186 samplings of Ulva sp. were harvested. Of these, 11 analyses were conducted for total arsenic, 38 analyses were conducted for inorganic arsenic, etc.

Table 2
Analytic methods used for trace elements and iodine quantification in algae by LABOCEA laboratory.

Substance	Method	Standard
Total arsenic	Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES)	ISO NF EN 15111
Inorganic arsenic	Atomic Fluorescence Spectrometry (AFS)	ISO NF EN 15517
Cadmium	ICP-OES	ISO NF EN ISO 11885
Lead	ICP-OES	ISO NF EN ISO 11885
Total mercury	AFS	ANA-19. MOA.0
Iodine	Inductively Coupled Plasma Mass Spectrometry (ICP-MS)	ISO NF EN 15111

Table 3
Amount per meal (g) data.

	Amount per meal (g)			
	Sushi with nori	Fish rillette	Salt	Chips
Number of data	17	60	2443	638
Distribution	Lognormal	Lognormal	Lognormal	Loglogistic
Mean	131.0	39.7	1.3	31.5
SD	139.2	48.6	0.8	44.4
P50	89.8	25.1	1.1	23.1
P95	375.1	121.3	2.7	79.7

Raw data were obtained from the Individual and National Surveys on Food Consumption (INCA3) survey conducted in 2014–2015 by The French Agency for Food, Environmental and Occupational Health & Safety (Anses). These raw data were fitted to lognormal or loglogistic distributions.

data were available and the quantity of seaweeds eaten was estimated. The authors highlighted the need to set up consumption studies specific to seaweeds in order to refine exposure and risk results [5,8].

In this context, the current consumption of seaweed foodstuffs was assessed in the French population among 780 French adults aged 18 years and over. The types of foodstuffs consumed, the percentage of consumers and the frequency of consumption were evaluated. The seaweed species present in marketed products and their percentage were referenced. One hundred and seventy-two seaweed product types found at different points of purchase were taken into account [17].

The aim of this study is to assess the dietary exposure and the risk from iodine and trace elements in seaweeds for the French population using current consumption data generated by [17]. The contribution of seaweeds to total dietary exposure to trace elements and iodine was evaluated and, for those substances that contribute very little to overall exposure, simulations were performed to propose maximum levels in seaweeds.

2. Material and methods

2.1. Samples and analytical method

Seaweed species have been selected based on previous consumption studies, i.e. species marketed in finished foodstuffs found in the French market: *Fucus sp.* (fucus), *Himanthalia elongata* (sea spaghetti), *Palmaria palmata* (dulse), *Porphyra sp.* (nori), *Saccharina latissima* (royal kombu), *Ulva sp.* (sea lettuce), and *Undaria pinnatifida* (wakamé) [17].

Analytical data were provided by the Chambre Syndicale des Algues et Végétaux Marins (CSAVM) and by the algae technology and innovation centre (**Centre d′étude et de valorisation des algues,** or CEVA in French) for 449 seaweeds harvested in France between 1984 and 2019. Analyses were also carried out as part of this project by the LABOCEA laboratory on 19 samples of seaweeds harvested in Brittany (northwest France) in 2020–2021. A total of 468 samples of seaweeds have been taken into account, including 77 samples of *Fucus sp.,* 34 samples of *Himanthalia elongata*, 82 samples *Palmaria palmata*, 24 samples of *Porphyra sp.,* 39 samples of *Saccharina latissima,* 186 samples of *Ulva sp.* and 26 samples of *Undaria pinnatifida*. All seaweeds are from France. One or more substances were measured per seaweed sample. The substances of interest were total arsenic, inorganic arsenic, cadmium, lead, total mercury and iodine (Table 1). The seaweed samples were collected and analysed by different laboratories according to the standards in force for trace elements and for iodine. For example, the methods used by the LABOCEA laboratory are summarised in Table 2.

2.2. Consumption data

Consumption data from two different French studies were used for exposure assessment.

2.2.1. Data from INCA3 study

- Amount of foodstuffs consumed per meal

No specific data was available in the literature on the amount of seaweed foodstuffs consumed per meal. Consequently, the amount of foodstuffs consumed per meal was researched regardless of the presence of seaweeds.

Food consumption data were obtained from the Individual and National Surveys on Food Consumption (INCA3) survey conducted in 2014–2015 among 5855 individuals (adults and children) as representatives of all individuals living in ordinary households in metropolitan France. The respondents were asked to describe their food consumption by identifying all the foods and beverages consumed during the day or night. The amount of foodstuffs consumed were quantified with the help of a book of photographs of food servings and household measures. This survey was carried out by the French Agency for Food, Environmental and Occupational Health & Safety (Anses) [3]. The raw data from the INCA3 study are available in OpenData on the Anses website.

Amount per meal data (g/meal) obtained for sushi with nori (n = 17), fish rillettes (n = 60), table salt (n = 2443) and chips (n = 638) were adjusted to lognormal (sushi, rillettes and table salt) or loglogistic (chips) distributions (Table 3).

2.2.2. Data from [17]

Consumption data were published in a preceding publication; please see [17] for methodological details or presentation of results.

- Seaweed foodstuffs, percentage of consumers and frequency of consumption

  A web questionnaire survey was conducted between November 2020 and February 2021. This survey was distributed via professional and personal networks such as the mailing list of Brest university staff and Brest Hospital staff, LinkedIn and Facebook. This enquiry enabled the listing of seaweed foodstuffs currently consumed by 780 French adults, as well as the percentage of consumers and thus the corresponding frequency of consumption for the different foodstuffs. Seaweed food products studied include seaweeds consumed "as a vegetable" in accompaniment to a dish, as nori seaweed with sushi (maki, california rolls), or as an ingredient in miso soup, salads, bread, pasta, chips, tartar, fish rillettes, mustard, table salt, cheese and drinks.
- Species of seaweeds found in foodstuffs and percentage of seaweeds in finished products

  Surveys were carried out at different points of purchase, such as supermarkets and hypermarkets, organic food stores, delicatessens and stores specialising in Asian food. Enquiries were conducted between November 2020 and February 2021 in the city of Brest, in the region of Brittany in France. The websites of all brands found in stores were then consulted. This research obtained, for 172 seaweed product types found in the market, the species of seaweeds present and their percentages in the finished products.
- Amount of seaweed found in miso soup

  Miso soup varieties found in the market were dehydrated preparations in powder form. For their preparation, hot water is added to reconstitute the soup before consumption. The soup is typically presented in an individual sachet, with one sachet corresponding to one serving of soup. As the percentage of seaweed present in the product as well as the weight of an individual serving is indicated on the label, the amount of seaweed present in a sachet and therefore consumed per serving of soup can be assessed. The amount of seaweed consumed is between 0.13 g and 4.58 g. As the raw data ($n = 8$) could not be fitted to a distribution, the mean value (1.81 g) was used in exposure calculations.
- Percentage of seaweed found in sushi

The percentage of nori seaweed in maki or in California rolls was not indicated on the packaging of these fresh products. Experimental data were obtained to assess this parameter. (1) One piece of maki or California roll was weighed as consumed on a precision balance; (2) nori seaweed contained in the maki or the California roll was weighed alone after 1 day of drying at ambient temperature. The percentage of algae in each product was thus obtained. The nori was weighed dry to be under similar conditions to those for making makis and California rolls in which the nori used is dehydrated. Experiments were performed on 36 makis and on 30 California rolls sold at three points of sale.

2.3. Exposure assessment

2.3.1. Foodstuffs of interest

Exposure was assessed for the different foodstuffs for which consumption data were available for all parameters of the exposure equation. Exposure was then assessed for sushi with nori, miso soup, fish rillettes, tartars, table salt and chips. Very little information on the amount per meal was available for seaweed tartars in INCA3 study ($n = 4$; obtained from 2 individuals). As tartar can be easily consumed as a spread on bread, rusks, blinis, etc., it was decided to attribute the data on fish rillettes, also consumed "in spreads", to this category. Exposure was not assessed for the other consumed products, i.e. seaweeds consumed "as a vegetable" in accompaniment to a dish, as well as seaweeds present in salad, cheese, bread, mustard and pasta, because of the lack of consumption data.

2.3.2. Equations for probabilistic exposure assessment

2.3.2.1. Exposure per foodstuff in the consumer population. Dietary exposure to trace elements and iodine was firstly assessed for consumers only and for each seaweed foodstuff (sushi with nori, fish rillettes, tartars, table salt and chips) using the following equation:

$$Exposure\quad per\quad foodstuff(Ef)(\mathrm{mg/kg\ bw/day}) = \left(\frac{\mathrm{C}}{1000}\times \mathrm{P}\times \mathrm{A}\times \mathrm{F}\right)\Big/\mathrm{BW}$$

C: Concentration of the substance in the seaweed species (mg/kg dry weight (dw)). The concentration was divided by 1000 in order to be expressed in mg/g dw.

P: Proportion of seaweeds in the foodstuff (without unit) [17].

A: Amount of the foodstuff eaten per meal (g) (INCA3 data).

F: Frequency of consumption of the seaweed foodstuff (day^{-1}) [17].

BW: Body weight (kg of bw). A mass of 70 kg was used, according to the Efsa recommendations [13].

The concentration values (C), the proportion of seaweeds in the finished product values (P) and the amount of the foodstuff eaten per meal (A) were adjusted when possible to theoretical distributions with the chi-squared goodness of fit test (lognormal, loglogistic or exponential) (@Risk 7.6 software, Palisade Corp.). When the data did not fit to a theoretical distribution, the mean value was used. The frequency values (F) were adjusted to discrete distributions. The probabilistic exposure assessment was performed using Monte Carlo random simulations (@Risk 7.6 software). The exposure distributions were assessed by 10,000 iterations according to recommendations of the US EPA [28].

As was found in the consumption study, several species of algae can be found alone or in a mixture in a finished product [17]. Consequently, exposure was assessed taking into account the different combinations of seaweeds (species and their respective proportion) found in the French market.

For example, 43 references of tartars mentioned on their label the species of seaweeds present in the product and the proportion. Exposure to trace metals or iodine in tartars was assessed for each of the 43 references, taking into account the different species found and their proportion per product; then an average of the 43 results was calculated.

When two seaweeds (for example *Himanthalia elongata* and *Palmaria palmata*) were found in a same tartar, exposure to trace metals or iodine was assessed by summing the exposure via *Himanthalia elongata* (using the concentration of trace metals or iodine in this seaweed and the proportion of *Himanthalia elongata* mentioned on the label of the product) and the exposure via *Palmaria palmata (*using the concentration of trace metals or iodine in this seaweed and the proportion of *Palmaria palmata* mentioned on the label of the product). Then an average of the 43 exposure results (obtained from the 43 tartars) was calculated.

Many substance concentrations were left-censored. According to the harmonised total diet study approach guidance document, analytical values for non-quantified samples were replaced by the value of zero (limit of detection values were not available) in a lower bound (LB) scenario, and were replaced by a limit of quantification (LOQ) value in an upper bound (UB) scenario [12].

Case of miso soup

$$Exposure\quad per\quad foodstuff(Ef)(\mathrm{mg/kg\ bw/day}) = \left(\frac{\mathrm{C}}{1000}\times \mathrm{A}\times \mathrm{F}\right)\Big/\mathrm{BW}$$

C: Concentration of the substance in the seaweed (mg/kg dw). The concentration was divided by 1000 in order to be expressed in mg/g dw.

A: Amount of seaweeds eaten per soup (g). A mean value equal to

Table 4
Concentration of trace metals and iodine in *Fucus sp.* (mg/kg of dry weight).

Fucus sp.	Concentration (mg/kg dw)											
	Total arsenic		Inorganic arsenic		Cadmium		Lead		Total mercury		Iodine	
	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB
Minimum	49,00	49,00			0,44	0,44	0,00	0,01	0,00	0,01	259,00	259,00
Maximum	81,00	81,00			0,82	0,82	1,40	1,40	0,01	0,10	635,00	635,00
Mean	66,56	66,56			0,60	0,60	0,60	0,95	0,00	0,03	426,98	426,98
Standard deviation	8,30	8,30			0,08	0,08	0,60	1,01	0,00	0,04	96,98	96,98
Median	66,05	66,05			0,59	0,59	0,42	0,65	0,00	0,01	416,37	416,37
P95	81,02	81,02			0,74	0,74	1,8	2,72			602,14	602,14
Number of data (N)	40	40	0	0	50	50	27	27	25	25	48	48
Theorical distribution	Yes, lognormal	Yes, lognormal			Yes, lognormal	Yes, lognormal	Yes, exponential	Yes, lognormal	No	No	Yes, lognormal	Yes, lognormal
Data < LOQ (N)	0	0			0	0	8	8	16	16	0	0
Data < LOQ (%)	0	0			0	0	30	30	64	64	0	0
Data > recommendations of HCSP (N)	/	/			44	44	0	0	0	0	0	0
Data > recommendations of HCSP (%)	/	/			88	88	0	0	0	0	0	0

LB: lower bound; UB: upper bound; LOQ: limit of quantification; N: number of data
Minimum and maximum values were raw data. When the raw data could be fitted to a mathematical distribution, the presented values (mean, standard deviation, median and P95) were taken from the distribution.

Table 5
Concentration of trace metals and iodine in *Himanthalia elongata* (mg/kg of dry weight).

Himanthalia elongata	Concentration (mg/kg dw)											
	Total arsenic		Inorganic arsenic		Cadmium		Lead		Total mercury		Iodine	
	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB
Minimum	18,88	18,88	0,00	0,05	0,00	0,13	0,00	0,14	0,00	0,01	0,00	0,50
Maximum	55,27	55,27	0,39	0,39	1,30	1,30	3,60	3,60	0,03	0,03	112,00	112,00
Mean	34,54	34,54	0,10	0,21	0,45	0,45	0,76	1,30	0,00	0,01	50,82	50,84
Standard deviation	15,16	15,16	0,10	0,15	0,31	0,31	0,76	1,55	0,01	0,01	32,38	32,35
Median	32,00	32,00	0,07	0,18	0,33	0,37	0,53	0,99	0,00	0,02	52,60	52,60
P95			0,29	0,46		1,04	2,29	3,2				
Number of data (N)	4	4	23	23	29	29	18	18	14	14	23	23
Theorical distribution	No	No	Yes, exponential	Yes, loglogistic	No	Yes, lognormal	Yes, exponential	Yes, loglogistic	No	No	No	No
Data < LOQ (N)	0	0	14	14	1	1	9	9	10	10	1	1
Data < LOQ (%)	0	0	61	61	3	3	50	50	71	71	4	4
Data > recommendations of HCSP (N)	/	/	0	0	9	9	0	0	0	0	0	0
Data > recommendations of HCSP (%)	/	/	0	0	31	31	0	0	0	0	0	0

LB: lower bound; UB: upper bound; LOQ: limit of quantification; N: number of data
Minimum and maximum values were raw data. When the raw data could be fitted to a mathematical distribution, the presented values (mean, standard deviation, median and P95) were taken from the distribution.

1.81 g was used for calculations.

F: Frequency of consumption of the seaweed foodstuff (day^{-1}) [17].

BW: Body weight (kg of bw). A mass of 70 kg was used, according to the Efsa recommendations [13].

2.3.2.2. Exposure for the whole foodstuffs in the general population. Dietary exposure to trace elements and iodine was assessed secondly for the general population (consumers and non-consumers) and for the whole seaweed foodstuffs (sushi with nori, miso soup, fish rillettes, tartars, table salt and chips). A binomial distribution was used to take into account the different profiles of consumers using every possible combination:

$$Exposure(mg/kgpc/jour) = \sum((Ef) \times Bin.i)$$

Ef: Exposure per foodstuff (mg/kg bw/day) obtained in the consumer population.

Bin. i: Binomial I = (1; percentage of consumers of the foodstuff in the general population) [17]. The percentage of consumers was equal to 71 % for sushi with nori, 48 % for miso soup, 42 % for fish rillettes, 42 % for tartars, 31 % for table salt and 24 % for chips.

3. Results and discussion

3.1. Concentrations of trace elements and iodine in seaweeds

Analytical results are presented for each seaweed species and for each substance in Tables 4 to 10. Minimum, maximum, mean, standard deviation, median and P95 values are reported. The quantity and the percentage of left-censored data (data < limit of quantification (LOQ)) is mentioned. The French High Council for Public Health (Haut Conseil de la Santé Publique, or HCSP) has issued recommendations related to the maximum limit of trace elements and iodine in edible seaweeds from France ([19]). These values are equal to 3 mg/kg dw for inorganic

Table 6
Concentration of trace metals and iodine in *Palmaria palmata* (mg/kg of dry weight).

Palmaria palmata	Concentration (mg/kg dw)											
	Total arsenic		Inorganic arsenic		Cadmium		Lead		Total mercury		Iodine	
	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB
Minimum	1,00	1,00	0,00	0,05	0,00	0,03	0,00	0,50	0,00	0,01	5,90	5,90
Maximum	22,00	22,00	1,30	1,30	59,00	59,00	3,20	3,20	0,13	0,13	802,00	802,00
Mean	12,09	12,09	0,24	0,27	1,00	1,01	0,31	1,06	0,01	0,07	88,39	88,39
Standard deviation	6,34	6,34	0,24	0,30	7,03	7,03	0,31	0,35	0,01	0,04	89,59	89,59
Median	10,88	10,88	0,17	0,19	0,14	0,15	0,21	1,01	0,01	0,10	62,08	62,08
P95	22,74	22,74	0,72	0,79			0,94	1,68	0,04		247,4	247,4
Number of data (N)	23	23	44	44	70	70	33	33	38	38	62	62
Theorical distribution	Yes, loglogistic	Yes, loglogistic	Yes, exponential	Yes, lognormal	No	No	Yes, exponential	Yes, loglogistic	Yes, exponential	No	Yes, lognormal	Yes, lognormal
Data < LOQ (N)	0	0	15	15	6	6	26	26	30	30	0	0
Data < LOQ (%)	0	0	34	34	9	9	79	79	79	79	0	0
Data > recommendations of HCSP (N)	/	/	0	0	1	1	0	0	1	1	0	0
Data > recommendations of HCSP (%)	/	/	0	0	1	1	0	0	3	3	0	0

LB: lower bound; UB: upper bound; LOQ: limit of quantification; N: number of data
Minimum and maximum values were raw data. When the raw data could be fitted to a mathematical distribution, the presented values (mean, standard deviation, median and P95) were taken from the distribution.

arsenic, 0.5 mg/kg dw for cadmium, 0.1 mg/kg dw for total mercury, 5 mg/kg dw for lead and 2000 mg/kg dw for iodine. The values and the percentages of data above these different thresholds are mentioned.

Concentrations of trace elements and iodine varied depending of the species of seaweed. For example, the concentration of iodine in *Himanthalia elongata* was on average equal to 50 mg/kg dw. The concentration of iodine in *Saccharina latissima* was much greater, with a mean value equal to 4299 mg/kg dw. The concentration of total arsenic was on average equal to 6 mg/kg dw in *Ulva sp.,* and on average equal to 676 mg/kg dw in *Fucus sp*.

For cadmium, values exceeding the maximal limit were observed in all the algal species studied. The cadmium concentration was above the threshold in 88 % of *Fucus sp.* samples, 31 % of *Himanthalia elongata* samples, 10 % of *Saccharina latissima* samples, 8% of *Undaria pinnatifida* samples, 6 % of *Porphyra sp*. samples, 2 % of *Ulva sp.* samples and 1 % of *Palmaria palmata* samples. In 69 % of *Saccharina latissima* samples, iodine concentrations exceeded the threshold with values up to 8052 mg/kg dw. No values in excess of the iodine maximal value were observed for the other species of algae. Lead concentration was above the threshold in 10% of *Ulva sp.* samples; inorganic arsenic concentration was above the threshold in 10 % of *Saccharina latissima* samples. In a few cases, mercury concentrations exceeded the maximal limit (in 6 % of *Ulva sp.* samples and in 3 % of *Palmaria palmata* samples).

3.2. Exposure assessment to trace metals and iodine in seaweeds

Dietary exposure to trace elements and iodine was assessed for the different foodstuffs for consumers only and for the general population. As exposure values obtained with a lower bound (LB) scenario and upper bound (UB) scenario were in the same order of magnitude, only those results obtained in the UB scenario were presented in Tables 11 and 12.

For example, in the consumer population, exposure to iodine was highly variable depending on the foodstuff consumed. Iodine exposure was highest from the consumption of chips (mean and P95 values respectively equal to 1.24 μg/kg bw/day and 5.22 μg/kg bw/day), and the lowest via the consumption of table salt (mean and P95 values respectively equal to 6.44 ng/kg bw/day and 17.8 ng/kg bw/day). Exposure to iodine in the general population was highest via the consumption of tartars with mean and P95 values respectively equal to 0.40 and 1.55 μg/kg bw/day. Exposure to iodine in chips was equal to 0.30 μg/kg bw/day (mean) and 1.26 μg/kg bw/day (P95); exposure to iodine in table salt was equal to 2.03 ng/kg bw/day (mean) and 10.8 ng/kg bw/day (P95). Total exposure to iodine in the general population (i.e. via the whole seaweed foodstuffs) was equal to 1.03 μg/kg bw/day (mean) and 3.28 μg/kg bw/day (P95).

As for iodine, the exposure to trace metals was highly variable depending on the foodstuff consumed. Cadmium exposure in the consumer population was highest via the consumption of tartars (mean and P95 values respectively equal to 2.93 ng/kg bw/day and 607 ng/kg bw/day), and lowest from the consumption of table salt (mean and P95 values respectively equal to 0.02 ng/kg bw/day and 0.06 ng/kg bw/day). In the general population, exposure to cadmium in tartars was equal to 1.24 ng/kg bw/day (mean) and 4.68 ng/kg bw/day (P95); exposure to cadmium in table salt was equal to 0.007 ng/kg bw/day (mean) and 0.04 ng/kg bw/day (P95). Total exposure to cadmium in the general population was equal to 1.80 ng/kg bw/day (mean) and 5.68 ng/kg bw/day (P95).

In the consumer population, exposure to inorganic arsenic was highest via the consumption of tartars (mean and P95 values respectively equal to 2.43 ng/kg bw/day and 5.39 ng/kg bw/day), and lowest from the consumption of miso soup (mean and P95 values respectively equal to 0.20 ng/kg bw/day and 0.67 ng/kg bw/day). Total exposure to inorganic arsenic in the general population was equal to 2.19 ng/kg bw/day (mean) and 7.08 ng/kg bw/day (P95). Total exposure to total arsenic in the general population was equal to 138.00 ng/kg bw/day (mean) and 387.00 ng/kg bw/day (P95).

Table 7
Concentration of trace metals and iodine in *Porphyra sp.* (mg/kg of dry weight).

Porphyra sp.	Concentration (mg/kg dw)											
	Total arsenic		Inorganic arsenic		Cadmium		Lead		Total mercury		Iodine	
	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB
Minimum	25,00	25,00	0,22	0,22	0,04	0,04	0,00	0,50	0,00	0,01	27,00	27,00
Maximum	55,00	55,00	1,81	1,81	0,60	0,60	1,14	1,14	0,05	0,10	205,10	205,10
Mean	38,00	38,00	0,62	0,62	0,25	0,25	0,38	0,88	0,02	0,04	59,23	59,23
Standard deviation	12,49	12,49	0,48	0,48	0,19	0,19	0,54	0,25	0,02	0,03	55,89	55,89
Median	36,01	36,01	0,52	0,52	0,21	0,21	0,00	1,00	0,02	0,03	38,00	38,00
P95			1,35	1,35	0,55	0,55			0,07	0,11		
Number of data (N)	4	4	10	10	18	18	5	5	12	12	9	9
Theorical distribution	No	No	Yes, loglogistic	Yes, loglogistic	Yes, loglogistic	Yes, loglogistic	No	No	Yes, exponential	Yes, lognormal	No	No
Data < LOQ (N)	0	0	0	0	0	0	3	3	4	4	0	0
Data < LOQ (%)	0	0	0	0	0	0	60	60	33	33	0	0
Data > recommendations of HCSP (N)	/	/	0	0	1	1	0	0	0	0	0	0
Data > recommendations of HCSP (%)	/	/	0	0	6	6	0	0	0	0	0	0

LB: lower bound; UB: upper bound; LOQ: limit of quantification; N: number of data
Minimum and maximum values were raw data. When the raw data could be fitted to a mathematical distribution, the presented values (mean, standard deviation, median and P95) were taken from the distribution.

Table 8
Concentration of trace metals and iodine in *Saccharina latissima* (mg/kg of dry weight).

Saccharina latissima	Concentration (mg/kg dw)											
	Total arsenic		Inorganic arsenic		Cadmium		Lead		Total mercury		Iodine	
	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB
Minimum	25,65	25,65	0,00	0,05	0,00	0,10	0,00	0,45	0,00	0,02	113,50	113,50
Maximum	74,74	74,74	49,50	49,50	0,70	0,70	2,00	2,00	0,17	0,17	8051,50	8051,50
Mean	44,70	44,70	2,00	2,08	0,26	0,27	0,44	0,99	0,04	0,04	4298,60	4298,60
Standard deviation	26,32	26,32	7,96	7,94	0,15	0,13	0,44	0,36	0,04	0,04	7423,70	7423,70
Median	33,72	33,72	0,00	0,20	0,23	0,24	0,31	1,10	0,03	0,03	2154,01	2154,01
P95						0,51	1,33		0,11	0,11	14,893,71	14,893,71
Number of data (N)	3	3	39	39	39	39	18	18	18	18	39	39
Theorical distribution	No	No	No	No	No	Yes, lognormal	Yes, exponential	No	Yes, exponential	Yes, lognormal	Yes, lognormal	Yes, lognormal
Data < LOQ (N)	0	0	20	20	3	3	9	9	8	8	0	0
Data < LOQ (%)	0	0	51	51	8	8	50	50	44	44	0	0
Data > recommendations of HCSP (N)	/	/	4	4	4	4	0	0	1	1	27	27
Data > recommendations of HCSP (%)	/	/	10	10	10	10	0	0	6	6	69	69

LB: lower bound; UB: upper bound; LOQ: limit of quantification; N: number of data
Minimum and maximum values were raw data. When the raw data could be fitted to a mathematical distribution, the presented values (mean, standard deviation, median and P95) were taken from the distribution.

Exposure to lead in consumers only was highest via the consumption of tartars (mean and P95 values respectively equal to 9.04 ng/kg bw/day and 19.10 ng/kg bw/day), and lowest via the consumption of table salt (mean and P95 values respectively equal to 0.06 ng/kg bw/day and 0.18 ng/kg bw/day). Total exposure to lead in the general population was equal to 6.52 ng/kg bw/day (mean) and 19.20 ng/kg bw/day (P95).

Total exposure to total mercury in the general population was equal to 0.20 ng/kg bw/day (mean) and 0.62 ng/kg bw/day (P95).

3.3. Risk assessment to trace metals and iodine in seaweeds

Exposure values were compared with threshold limits determined by public health agencies (Table 13).

Inorganic arsenic: A range of benchmark dose lower confidence limit ($BMDL_{01}$) values between 0.3 and 8 µg/kg bw/day was identified for cancers of the lung, skin and bladder, as well as skin lesions without specifying margins of exposure (MoE) beyond which the risk can be excluded [10]. Exposure to inorganic arsenic via the consumption of seaweeds was equal to 0.007 µg/kg bw/day (P95 value, obtained with UB scenario). This value was much lower than the $BMDL_{01}$ values proposed by Efsa, and corresponded to 2.4 % of the benchmark of 0.3 µg/kg bw/day and 0.1 % of the benchmark of 8 µg/kg bw/day. The margin of exposure was equal to 42 when $BMDL_{01}$ value was equal to 0.3; it was equal to 1127 when the $BMDL_{01}$ value was equal to 8. No threshold limits were available for total arsenic.

Cadmium: A tolerable daily intake equal to 0.35 µg/kg bw/day was established based on bone effects [4]. Exposure to cadmium via the consumption of seaweeds was equal to 0.0057 µg/kg bw/day (P95 value, obtained with UB scenario), which means 1.6% of the TDI set to this element.

Lead: A $BMDL_{10}$ equal to 0.63 µg/kg bw/day was derived for nephrotoxicity in adults. The Efsa Panel concluded that a margin of exposure of 10 or greater would be sufficient to ensure that there was no appreciable risk of a clinically significant change in the prevalence of chronic kidney disease [11]. Exposure to lead via the consumption of seaweeds was equal to 0.019 µg/kg bw/day (P95 value, obtained with UB scenario). This exposure value was much lower than the $BMDL_{10}$ value

Table 9
Concentration of trace metals and iodine in *Ulva sp.* (mg/kg of dry weight).

Ulva sp.	Concentration (mg/kg dw)											
	Total arsenic		Inorganic arsenic		Cadmium		Lead		Total mercury		Iodine	
	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB
Minimum	1,45	1,45	0,00	0,02	0,00	0,03	0,00	0,20	0,00	0,01	13,10	13,10
Maximum	8,80	8,80	2,30	2,30	0,70	0,70	13,40	13,40	1,00	1,00	300,00	300,00
Mean	5,92	5,92	0,53	0,61	0,16	0,17	2,38	2,49	0,06	0,07	81,81	81,81
Standard deviation	2,00	2,00	0,53	0,95	0,16	0,12	2,83	2,40	0,17	0,17	63,89	63,89
Median	6,28	6,28	0,37	0,33	0,11	0,14	1,65	1,79	0,04	0,04	64,48	64,48
P95			1,58	2,05	0,48	0,40	7,12	6,8			200,61	200,61
Number of data (N)	11	11	38	38	61	61	40	40	32	32	50	50
Theorical distribution	No	No	Yes, exponential	Yes, lognormal	Yes, exponential	Yes, lognormal	Yes, exponential	Yes, lognormal	No	No	Yes, lognormal	Yes, lognormal
Data < LOQ (N)	0	0	11	11	5	5	5	5	11	11	0	0
Data < LOQ (%)	0	0	29	29	8	8	13	13	34	34	0	0
Data > recommendations of HCSP (N)	/	/	0	0	1	1	4	4	2	2	0	0
Data > recommendations of HCSP (%)	/	/	0	0	2	2	10	10	6	6	0	0

LB: lower bound; UB: upper bound; LOQ: limit of quantification; N: number of data
Minimum and maximum values were raw data. When the raw data could be fitted to a mathematical distribution, the presented values (mean, standard deviation, median and P95) were taken from the distribution.

Table 10
Concentration of trace metals and iodine in *Undaria pinnatifida* (mg/kg of dry weight).

Undaria pinnatifida	Concentration (mg/kg dw)											
	Total arsenic		Inorganic arsenic		Cadmium		Lead		Total mercury		Iodine	
	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB
Minimum	23,08	23,08	0,00	0,05	0,00	0,12	0,00	0,29	0,00	0,01	7,90	7,90
Maximum	85,22	85,22	0,60	0,60	0,71	0,71	2,00	2,00	0,02	0,02	586,90	586,90
Mean	53,16	53,16	0,08	0,19	0,26	0,29	0,52	0,98	0,01	0,01	231,18	231,18
Standard deviation	27,98	27,98	0,08	0,13	0,16	0,13	0,52	0,50	0,01	0,00	483,88	483,88
Median	52,16	52,16	0,06	0,16	0,27	0,26	0,36	1,08	0,00	0,02	158,93	158,93
P95			0,24	0,43		0,53	1,56				614,38	614,38
Number of data (N)	4	4	18	18	26	26	14	14	13	13	25	25
Theorical distribution	No	No	Yes, exponential	Yes, lognormal	No	Yes, lognormal	Yes, exponential	No	No	No	Yes, loglogistic	Yes, loglogistic
Data < LOQ (N)	0	0	13	13	4	4	7	7	8	8	0	0
Data < LOQ (%)	0	0	72	72	15	15	50	50	62	62	0	0
Data > recommendations of HCSP (N)	/	/	0	0	2	2	0	0	0	0	0	0
Data > recommendations of HCSP (%)	/	/	0	0	8	8	0	0	0	0	0	0

LB: lower bound; UB: upper bound; LOQ: limit of quantification; N: number of data
Minimum and maximum values were raw data. When the raw data could be fitted to a mathematical distribution, the presented values (mean, standard deviation, median and P95) wer taken from the distribution.

established by Efsa (3.0% of the $BMDL_{10}$). The margin of exposure was equal to 33.

Mercury: Most of the mercury was found in its methyl form in fish and seafood [1,20,27]. Scarce data is available on the speciation of this element for seaweeds. Therefore, all of the mercury present in the algae was considered to be methylmercury. Methylmercury has a defined tolerable weekly intake of 1.3 µg/kg bw/week based on neurodevelopmental effects in children [14]. Exposure to methylmercury via the consumption of seaweeds was equal to 0.000615 µg/kg bw/day (P95 value, obtained with UB scenario), i.e. 0.0043 µg/kg bw/week, and which means 0.3% of the TWI set to this element.

Iodine: a tolerable upper intake level equal to 600 µg iodine/day for adults has been derived based on thyroid effects [9]. Exposure to iodine via seaweeds is equal to 3.28 µg/kg bw/day (P95 value, obtained with UB scenario), i.e. 229.6 µg/day for an adult of 70 kg bw, which is equivalent to 38% of the UL.

3.4. Contribution to total dietary exposure

3.4.1. Inorganic arsenic, cadmium and lead

The dietary exposure to 445 substances including trace metals was estimated for the French population in the Second French Total Diet Study (TDS 2) [2]. As a total diet study involves collecting samples of foodstuffs regularly consumed by the population, seaweed foodstuffs were not included in the food sampling for the TDS 2.

Exposure to inorganic arsenic in TDS 2 was estimated at 0.28 µg/kg bw/day (mean) and 0.51 µg/kg bw/day in French adults. Water was the main contributor to inorganic arsenic exposure (27 %), followed by coffee (16 %) [2]. Dietary exposure to inorganic arsenic via seaweed in adults (0.002 µg/kg bw/day on average) would contribute up to 0.7% of dietary exposure to inorganic arsenic, which makes seaweeds a very low contributor to dietary exposure for this contaminant.

Exposure to cadmium in the French adult population was equal to 0.16 µg/kg bw/day (mean) and 0.27 µg/kg bw/day (P95) in TDS 2. The

Table 11
Exposure (ng/kg bw/day) to trace metals and iodine for the different seaweed foodstuffs in the consumer population.

Consumers only	Exposure (ng/kg bw/day)					
	Total arsenic	Inorganic arsenic	Cadmium	Lead	Total mercury	Iodine
Sushi with nori						
Mean	31,80	0,52	0,22	1,00	0,03	48,20
SD	70,40	1,24	0,59	2,41	0,09	103,00
Median	10,60	0,14	0,06	0,32	0,01	15,70
P95	128,00	2,14	0,91	3,97	0,14	191,00
Miso soup						
Mean	45,60	0,20	0,25	0,88	0,02	194,00
SD	60,20	0,29	0,37	1,09	0,02	467,00
Median	40,00	0,12	0,13	0,74	0,01	64,50
P95	173,00	0,67	0,90	3,23	0,05	725,00
Fish rillettes						
Mean	24,10	0,34	0,23	0,89	0,02	356,00
SD	136,00	3,26	0,98	9,77	0,14	6350,00
Median	4,56	0,03	0,05	0,16	0,00	41,60
P95	83,20	1,11	0,75	2,59	0,06	973,00
Tartars						
Mean	139,00	2,43	2,93	9,04	0,29	923,00
SD	82,30	1,96	1,76	6,60	0,18	1070,00
Median	119,00	1,97	2,51	7,54	0,25	656,00
P95	284,00	5,39	607,00	19,10	0,60	2280,00
Salt						
Mean	1,21		0,02	0,06	0,00	6,44
SD	1,04		0,02	0,07	0,00	6,99
Median	0,92		0,02	0,05	0,00	4,52
P95	3,21		0,06	0,18	0,01	17,80
Chips						
Mean	95,20	3,12	0,77	4,36	0,14	1240,00
SD	170,00	4,72	1,36	10,60	0,32	2840,00
Median	47,80	0,88	0,39	1,96	0,05	425,00
P95	326,00	7,17	2,55	14,80	0,51	5220,00

Calculations were performed using the upper bound scenario (analytical values for non-quantified samples were replaced by LOQ value).

main contributors to cadmium exposure were bread and dried bread products (22 %), followed by potatoes and potato products (12 %) [2]. Exposure to cadmium via seaweed consumption in adults (0.0018 µg/kg bw/day on average) would contribute up to 1.1 % of dietary exposure to cadmium, which makes seaweeds a very low contributor to dietary exposure for this contaminant.

Dietary exposure to lead was estimated as equal to 0.20 µg/kg bw/day (mean) and 0.35 µg/kg bw/day in French adults via TDS 2. The main contributors were alcoholic beverages (14%), bread and dried bread products (13 %) and water (11%) [2]. Dietary exposure to lead via seaweed in adults (0.0065 µg/kg bw/day on average) would contribute up to 3.1 % of dietary exposure to lead, which makes seaweeds a low contributor to dietary exposure for this contaminant.

3.4.2. Mercury

Exposure to methylmercury via the consumption of seafood (fish, molluscs, crustaceans and seafood-based dishes) was assessed in French adults in the Calipso study. Exposure was on average equal to 1.51 µg/kg bw/week, with a P95 value equal to 3.52 µg/kg bw/week. The seafood products contributing most to methylmercury intake were tuna (19.2 %) and cod (7.18 %) [27]. Fish accounts for more than 75 % of the methylmercury intake. Seaweed foodstuffs were not included in the food sampling of the Calipso study. On the assumption that 100 % of the mercury was presented in its methylated form in seaweeds, the dietary exposure in adults (0.0002 µg/kg bw/day on average, i.e., 0.0014 µg/kg bw/week) contributes up to 0.09% of dietary exposure to methylmercury in seafood, which makes seaweeds a very low contributor to dietary exposure for this contaminant.

3.4.3. Iodine

Intake of iodine in the diet was assessed in the French population via the third individual and national survey on food consumption (INCA3 survey). On average, iodine intake was equal to 148 µg/day in adults. The main contributors were the group of meat, fish and eggs (22 %), milk products (20 %) and fruits and vegetables (12 %) [3]. Dietary exposure to iodine via seaweed in adults (72.1 µg/day on average) would contribute up to 33 % of dietary exposure to iodine, which makes seaweeds the strongest contributor to dietary exposure for iodine. Exposure to iodine, including contribution from seaweeds, would be equivalent to 37 % of the UL.

3.5. Influence of increasing the maximum level on dietary exposure to trace elements from seaweeds

As mentioned in the commission recommendation ([15]/464 on the monitoring of metals and iodine in seaweed, halophytes and products based on seaweed, no maximum levels have been established in Europe for arsenic, cadmium and lead in seaweeds except in food supplements. A maximum residue level (MRL) for mercury in algae and prokaryotic organisms has been established at the default level of 0.01 mg/kg [15]. The HCSP has issued recommendations related to the maximum value of trace elements and iodine in edible seaweeds from France ([19]). These values were equal to 3 mg/kg dw for inorganic arsenic, 0.5 mg/kg dw for cadmium, 0.1 mg/kg dw for total mercury, 5 mg/kg dw for lead and 2000 mg/kg dw for iodine, respectively. These current maximum levels (MLs) were defined without knowledge of the real risks linked to the consumption of seaweed according to an ALARA type method (As Low As Reasonably Achievable).

This present study provided exposure data to trace elements in seaweeds; and showed the low impact of these products on total oral exposure to trace elements. In this context, new ML values slightly higher than the current MLs have been proposed. These new MLs only lead to a negligible increase in total dietary exposure given the exposure linked to main contributors.

As seaweeds are likely to be a very low contributor to oral cadmium (1.1 %), inorganic arsenic (0.7 %) and mercury (0.1 %) exposure, the impact of increasing the maximum levels (ML) proposed by the HCSP on chronic dietary exposure to these substances was assessed by presenting

Table 12
Exposure (ng/kg bw/day) to trace metals and iodine for the different seaweed foodstuffs and for all seaweed foodstuffs (total) in the general population (consumers and non-consumers).

General population (consumers and non-consumers)	Exposure (ng/kg bw/day)					
	Total arsenic	Inorganic arsenic	Cadmium	Lead	Total mercury	Iodine
Sushi with nori						
Mean	23,10	0,40	0,14	0,70	0,03	36,40
SD	57,90	1,45	0,44	1,95	0,08	104,00
Median	3,39	0,05	0,02	0,11	0,00	5,19
P95	103,00	1,70	0,65	3,13	0,11	160,00
Miso soup						
Mean	21,70	0,10	0,12	0,45	0,01	94,20
SD	46,30	0,23	0,28	0,95	0,02	310,00
Median	0,00	0,00	0,00	0,00	0,00	0,00
P95	84,70	0,43	0,58	1,69	0,03	431,00
Fish rillettes						
Mean	13,60	0,12	0,10	0,30	0,01	130,00
SD	378,00	0,82	1,93	1,79	0,07	1540,00
Median	0,00	0,00	0,00	0,00	0,00	0,00
P95	32,70	0,42	0,30	1,10	0,03	346,00
Tartars						
Mean	59,00	1,05	1,24	3,88	0,12	404,00
SD	89,20	1,69	1,88	6,34	0,19	851,00
Median	0,00	0,00	0,00	0,00	0,00	0,00
P95	222,00	4,13	4,68	14,40	0,47	1550,00
Salt						
Mean	0,37		0,01	0,02	0,00	2,03
SD	0,81		0,02	0,05	0,00	5,16
Median	0,00		0,00	0,00	0,00	0,00
P95	1,99		0,04	0,11	0,00	10,80
Chips						
Mean	22,00	0,50	0,19	1,13	0,03	304,00
SD	93,80	2,21	0,86	18,60	0,14	1520,00
Median	0,00	0,00	0,00	0,00	0,00	0,00
P95	118,00	2,70	0,96	4,76	0,16	1260,00
Total						
Mean	138,00	2,19	1,80	6,52	0,20	1030,00
SD	319,00	3,33	2,34	10,10	0,28	4550,00
Median	99,50	1,37	0,97	4,04	0,12	487,00
P95	387,00	7,08	5,68	19,20	0,62	3280,00

Calculations were performed using the upper bound scenario (analytical values for non-quantified samples were replaced by the LOQ value).

Table 13
Exposure (µg/kg bw/day) of the general population to trace metals and iodine via seaweed consumption, and comparison with threshold limits.

Substance	Exposure (µg/kg bw/day)		Threshold limits	MoE value	Reference
	Mean	P95			
Inorganic arsenic	0.0022	0.0071	$BMDL_{01}$: 0.3–8 µg/kg bw/day No minimum MoE value was specified by Efsa	42–1127	[10]
Cadmium	0.0018	0.0057	TDI: 0.35 µg/kg bw/day		[4]
Lead	0.0065	0.0192	$BMDL_{10}$: 0.63 µg/kg bw/day Minimum MoE specified by Efsa: 10	33	Efsa, 2013
Total mercury	0.0002	0.0006	TWI for MeHg: 1.3 µg/kg bw/week		Efsa, 2012
Iodine	1.0300	3.2800	UL: 600 µg/day (adult)		[9]

BMDL: benchmark dose lower confidence limit; MeHg: methylmercury; TDI: tolerable daily intake; TWI: tolerable weekly intake; UL: tolerable upper intake level

different exposure scenarios:

- The "current" scenario: all available contamination data were fitted to a theoretical distribution for exposure assessment. These raw data can be superior to the ML proposed by the HCSP.
- The "current ML" scenario: the theoretical distribution of contamination obtained in the current scenario was right-truncated, with a maximum equal to the ML value proposed by the HCSP (i.e., 3 mg/kg dw for inorganic arsenic, 0.5 mg/kg dw for cadmium and 0.1 mg/kg dw for total mercury).
- The "increased ML" scenario: the theoretical distribution of contamination obtained in the current scenario was right-truncated, with a maximum equal to a proposed new ML. This suggested ML value should have a no impact on exposure results (i.e. values similar to those obtained in the current scenario) and on the contribution to total dietary exposure.

Cadmium: The exposure values obtained when the ML of contamination was equal to 1 mg/kg dw ("increased ML scenario") were very close to the exposure values obtained in the current scenario, where the contamination distribution was derived from all the contamination data. As cadmium in seaweeds only represents 1.1 % of cadmium exposure in total food, it may be relevant to propose a maximum cadmium limit authorised in France equal to 1 mg/kg dw instead of the current 0.5 mg/kg dw (Table 14).

Inorganic arsenic: The exposure values obtained in the "increased ML" scenario, equal to 10 mg/kg dw, are very close to the exposure values obtained in the current scenario, where the contamination distribution is derived from all the contamination data. As inorganic arsenic in

Table 14
Influence of increasing the maximum level (ML) of dietary exposure to trace elements from seaweeds.

	Current scenario	Current ML scenario (value proposed by the HCSP)	Increased ML scenario
Cadmium in seaweeds			
ML value		0.5 mg/kg dw	1 mg/kg dw
Exposure (ng/kg bw/day)			
Mean	1.80	1.25	1.72
Median	0.97	0.82	0.94
P95	5.68	3.79	5.34
Contribution to total dietary exposure (%)	1.1	0.8	1.1
Inorganic arsenic in seaweeds			
ML value		3 mg/kg dw	10 mg/kg bw
Exposure (ng/kg bw/day)			
Mean	2.19	2.07	2.21
Median	1.37	1.29	1.31
P95	7.08	6.45	6.69
Contribution to total dietary exposure (%)	0.7	0.7	0.7
Mercury in seaweeds			
ML value		0.1 mg/kg dw	0.3 mg/kg dw
Exposure (ng/kg bw/day)			
Mean	0.20	0.19	0.20
Median	0.12	0.11	1.20
P95	0.62	0.61	0.62
Contribution to total dietary exposure (%)	0.09	0.09	0.09

Exposure was assessed for the general population
The percentage of contribution to total dietary exposure was assessed using mean values

seaweeds only represents 0.7 % of its exposure in total food, it may be relevant to propose a maximum limit authorised in France equal to 10 mg/kg dw instead of the current 3 mg/kg dw (Table 14).

Mercury: The exposure values obtained when the ML of contamination was equal to 0.3 mg/kg dw are very close to the exposure values obtained in the current scenario, where the contamination distribution is derived from all the contamination data. As mercury in seaweeds only represents 0.1 % of its exposure in total food, it may be relevant to propose a maximum limit authorised in France equal to 0.3 mg/kg dw instead of the current 0.1 mg/kg dw (Table 14).

4. Conclusion

This study focuses on seaweed foodstuffs, which are a specific food item with relatively low consumption in France. The exposure and risk assessment of metals and iodine in seaweeds using current consumption data, the analysis of the contribution for each substance to total dietary exposure, and the proposed increases in the maximum level of certain trace metals, may be useful for safety assessors of public agencies and risk managers.

CRediT authorship contribution statement

All authors approved the publication.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Anne-Sophie Ficheux reports financial support was provided by Chambre Syndicale des Algues et des Végétaux Marins (CSAVM).

Acknowledgements

This investigation was supported by the European Maritime and Fisheries Fund (EMFF), by the Region Bretagne and by the Chambre Syndicale des Algues et des Végétaux Marins (CSAVM).

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