SURVEY OF INORGANIC ARSENIC IN SEAWEED AND SEAWEED-CONTAINING PRODUCTS AVAILABLE IN AUSTRALIA

Executive summary

Food Standards Australia New Zealand (FSANZ) conducted a small survey investigating levels of inorganic arsenic in dried seaweed and products containing seaweed available in Australia. This survey was conducted as part of the FSANZ surveillance and monitoring program in 2010 with the intention of reviewing our consumer advice released in 2004. In November 2004, FSANZ issued a media release advising Australian consumers to avoid hijiki seaweed as it may contain high levels of naturally occurring inorganic arsenic.

The levels of inorganic arsenic in various seaweed types tested were all below the maximum level (ML) for seaweed of 1 mg/kg in the *Australia New Zealand Food Standards Code* (the Code), with the exception of one composite sample of hijiki seaweed. The details of the hijiki seaweed were referred to the relevant jurisdiction for further investigation and/or any relevant follow-up activity. High inorganic arsenic concentrations in hijiki seaweed are consistent with findings in other countries. The levels of inorganic arsenic in products containing seaweed (e.g. seaweed chips) were comparable with the levels reported for similar foods in other countries.

Inorganic arsenic survey results were combined with results from the 23rd Australian Total Diet Study (ATDS) to estimate total inorganic arsenic dietary exposure. In general, consumption of seaweed and seaweed products in the Australian population is likely to be low and the resulting contribution to total dietary inorganic arsenic exposure is therefore likely to be small for the general population. Population groups or individuals that have a high exposure to arsenic from other sources in the diet, and who also regularly consume hijiiki seaweed, should be aware that they may have a higher potential health risk from arsenic than the general population. FSANZ has therefore reviewed and updated the factsheet for consumers regarding seaweed, which is available on the FSANZ website.

The findings from this survey indicate that the majority of samples tested demonstrated compliance with the requirements in the Code, with the exception of one composite sample of Hijiki. This high level of compliance is consistent with the monitoring conducted by the Department of Agriculture, Fisheries and Forestry (DAFF) at the border.

FSANZ will continue to monitor arsenic levels in food through the ATDS. The next ATDS (the 25th study) will investigate arsenic levels, including inorganic arsenic, in a range of foods commonly consumed in the typical Australian diet.

1 Background

In November 2004, FSANZ issued a media release advising Australian consumers to avoid hijiki seaweed as it may contain high levels of naturally occurring inorganic arsenic. This was based on advice obtained from the United Kingdom (UK) where the Food Safety Authority (FSA) reported high levels of inorganic arsenic in hijiki seaweed (FSA 2004). At the time, FSANZ provided risk assessment advice to the Department of Agriculture, Fisheries and Forestry (DAFF) (formerly Australian Quarantine and Inspection Service) that inorganic arsenic levels above 1 mg/kg were considered a medium to high risk. This advice to DAFF resulted in the testing of all imported hijiki seaweed for inorganic arsenic. This was to ensure that levels did not represent an unacceptable risk to public health and safety.

FSANZ regularly monitors the food supply for levels of substances in food. Given the consumer advice issued in 2004 about high levels of inorganic arsenic in certain seaweeds, a survey on inorganic arsenic in seaweed was included in FSANZ's monitoring and surveillance program for 2010 with the intention of reviewing the consumer advice released in 2004.

1.1 Seaweed

Seaweed is a type of algae commonly harvested from cold, tropical and temperate waters. Seaweed species are diverse and are generally classified into three separate phyla based on colour and other characteristics (FAO 2003; Gupta and Abu-Ghannam 2011). These are:

- brown seaweed from Phaeophyceae, which includes *Laminaria* spp., *Undaria* spp. and *Hizikia* (also known as hijiki) spp. These species are commonly used in salads, soups and stir-fries.
- red seaweed from Rhodophyceae, which includes laver, nori and dulse. Nori is commonly used in sushi and dulse is used as a condiment.
- green seaweed, from Chlorophyceae which includes the *Ulva* spp., (sea lettuce is derived from this species).

Seaweed bioaccumulates available elements from the environment such as sodium, potassium, chloride, magnesium, calcium, phosphorus, iron, manganese, zinc, copper, chromium, selenium and iodine (Almela et al 2002; Gupta and Abu-Ghannam 2011; Dawczynski et al 2007; Smith et al 2010). While seaweed contains a number of elements with nutritional properties, it also accumulates some heavy metal contaminants including inorganic arsenic that may raise health concerns, depending on the level of exposure (Dawczynski et al. 2007; Hwang et al. 2010; Smith et al. 2010; Almela et al. 2002; Almela et al. 2006). Hijiki[1] seaweed, in particular, can accumulate very high levels of arsenic under certain circumstances. The level of individual elements varies in seaweed and is influenced by the species of seaweed, source, season, temperature and method of harvesting (Borak and Hosgood 2007).

1.2 A focus on arsenic

Arsenic is a metalloid that occurs in different inorganic and organic forms, which are found in the environment both from natural occurrence and from anthropogenic (human) activity (WHO 2011a). While individuals are often exposed to both organic and inorganic arsenic through the diet, it is the inorganic species (which include arsenate V [As^{V}] and arsenite III [As^{III}])[2] that are considered to be

[1] The term 'hijiki seaweed' can be used to refer to unprocessed harvested seaweed which is then dried, or processed product which has been boiled with other brown seaweed types, dried and packaged. For the purpose of this report, Hijiki encompasses both forms unless otherwise indicated in published research papers.

[2] Several arsenic species occur in food. Monomethylarsonic acid (MMA), and dimethylarsinic acid (DMA) are organic species of arsenic with toxicological significance. Inorganic arsenic is usually reported as the sum of arsenite and arsenate.

more toxic to humans than organic arsenic. Only inorganic arsenic is known to be carcinogenic in humans. Inorganic arsenic contamination of groundwater is common in certain parts of the world. Dietary exposure to inorganic arsenic occurs predominantly from groundwater derived drinking-water, groundwater used in cooking and commonly consumed foods such as rice and other cereal grains and their flours (EFSA 2009; WHO 2011a).

Seafood is a major contributor to total (inorganic plus organic) arsenic dietary exposure and was, for example, estimated to contribute to approximately 90% of exposure in the United States (US) (Borak and Hosgood 2007). The predominant species of arsenic in seafood is, however, the less toxic organic form, with a minor contribution from the more toxic, inorganic species (Borak and Hosgood 2007). Arsenic is also found in fruits and vegetables at parts per billion concentrations, predominantly in the inorganic forms (Norton et al 2012). Seaweed contains higher inorganic arsenic levels as a proportion of the total arsenic (e.g. 60-73%; Almela et al 2002; Rose et al 2007) than many other foods. Given the diversity in the range of seaweed species available, the levels of inorganic arsenic also vary. Specific types of seaweed such as hijiki, have been found to consistently contain higher levels of inorganic arsenic than other types (Almela et al 2002; Rose et al 2007).

1.3 Risk management measures in Australia, New Zealand and in other countries

The *Australia New Zealand Food Standards Code* (the Code) includes a maximum limit (ML) for inorganic arsenic in seaweed. Standard 1.4.1 – Contaminants and Natural Toxicants contains a ML for inorganic arsenic of 1 mg/kg, calculated with respect to the mass of seaweed at 85% hydration.

In general, MLs are established for contaminants in those foods which are significant contributors to the overall dietary exposure for the particular contaminant. A ML for inorganic arsenic in seaweed was maintained when the Code was reviewed to harmonise the regulation of metal contaminants in food between Australia and New Zealand through Proposal P157 – Contaminants in Foods. The ML for inorganic arsenic in seaweed was expected to be highly protective of consumers (ANZFA 1999). While a ML is set for inorganic arsenic in seaweed, the general principle of keeping levels of contaminants in food As Low As Reasonably Achievable (ALARA) applies, particularly given the carcinogenic nature of inorganic arsenic. The majority of seaweed is imported into Australia and therefore a large proportion of the seaweed sold in Australia will have been monitored at the border by DAFF for compliance with the Code.

Standard 1.4.1 of the Code also includes a formula for determining the appropriate ML to apply to mixed foods that takes into account the proportion of each individual food within the mixed food. The formula can be used to determine the appropriate ML for inorganic arsenic in foods containing seaweed as an ingredient, if the proportion of each ingredient is known.

Food regulatory counterparts in other countries have not established specific maximum limits for inorganic arsenic in seaweed; however limits have been set for total arsenic. For example, in the UK there is a limit of 1 mg/kg of total arsenic in food, although this level specifically excludes seaweed. In 2004, the UK Food Standards Agency (FSA) issued a warning to consumers to avoid consumption of hijiki seaweed based on survey findings of total arsenic and inorganic arsenic in five imported seaweed species (FSA 2004). The FSA repeated this message in 2010, after identifying a brand of hijiki seaweed with high levels of inorganic arsenic (FSA 2010). Similarly, the Canadian Food Inspection Agency (CFIA), has taken an advisory approach, recommending that hijiki seaweed consumption is avoided due to the potential health risks (CFIA 2010).

1.4 Monitoring dietary exposure to arsenic from the food supply

FSANZ has been monitoring the dietary exposure of the Australian population to total arsenic for a number of years through the Australian Total Diet Study (ATDS) with results reported in the 19th, 20th and 23rd ATDS (FSANZ 2001a, FSANZ 2003, ANZFA 2001, see Section 5.2). The majority of foods contained quantifiable concentrations of arsenic in at least one of the samples analysed, however inorganic arsenic was only measured in seafood. The contribution of seaweed to the overall dietary exposure to total arsenic was not captured in these studies as it was not considered to be a food commonly consumed in a typical Australian diet.

2 Objectives

The objectives of this survey were to:

- determine the concentration of inorganic arsenic in a variety of seaweed types and seaweed-containing products available in Australia
- describe any additional health and safety risks associated with increased exposure to inorganic arsenic from seaweed consumption
- review the consumer advice issued in 2004 based on the findings of this study, and revise if appropriate.

3 Methodology

3.1 Sampling

The samples used for inorganic arsenic analysis were selected from the range of seaweed and seaweed products that had already been sampled for the *Survey of iodine in seaweed and seaweed containing products* (FSANZ, 2011b). These samples were collected from a variety of retail outlets in April/May 2010 from all states and territories in Australia.

A total of 38 individual samples of seaweed and seaweed products were investigated in this survey. From these samples, the analyses conducted were:

- Twenty two (22) individual samples.
- Three (3) composites comprising three primary samples (individual purchases) of different brands.
- One (1) composite comprising three primary samples (individual purchases) of the same brand.
- Two (2) composites comprising two primary samples (individual purchases) of the same brand.

Composite samples comprised of the same type of seaweed (e.g. wakame) based on the ingredients list, or the same type of product (e.g. miso paste) with varying use-by dates/batch codes.

3.2 Sample preparation

All seaweed samples were analysed in a dried state, directly from the packaging. Seaweed containing products, including soup and tea, were analysed by the laboratory as purchased.

3.3 Analysis

FSANZ engaged the National Measurement Institute (NMI) to analyse the samples for total inorganic arsenic using a NATA accredited method of acid extraction followed by Hydride Generation Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) (Holak and Specchio 1991). The Limit of Reporting (LOR) was 0.05 mg/kg with a Practical Quantitation Limit (PQL) of 0.03 mg/kg. The PQL is equivalent to the Limit of Quantification (LOQ) and is reported by some laboratories instead of the LOQ. In this survey, the LOR is slightly higher than the PQL, to account for matrix variations in the samples analysed.

Total inorganic arsenic in this report is defined as total arsenite (As^{3+}) and arsenate (As^{5+}). Because of the extraction method used, it is possible that total inorganic arsenic detected may also contain some low levels of monomethylarsenate (MMA) which is an organic form of arsenic with toxicological significance. For the purposes of this report, a conservative approach has been taken and the possible presence of organic MMA has been included in the total inorganic arsenic concentration.

All analytical concentration values for inorganic arsenic presented in this report are from dried seaweed rather than the 85% hydrated form, unless otherwise specified. The inorganic arsenic concentration in the 85% hydrated form was calculated only for the sample where the level in the dried seaweed was above the ML in the Code to enable the analytical concentrations to be compared with the ML on the same basis.

For the purposes of calculating mean and median concentrations of inorganic arsenic in seaweed and food containing seaweed (Table 1 and 2), samples reported as <LOR of 0.05 mg/kg were assumed to be 0.05 mg/kg. This is known as the upper bound estimate and is a conservative approach since it is more likely to overestimate rather than underestimate the true mean arsenic concentration of the samples analysed.

4 Results

A summary of the results is provided in Table 1 and Table 2.

For samples of dried seaweed, inorganic arsenic levels were reported above the LOR of 0.05 mg/kg for all samples except one (seaweed type not specified). Concentrations ranged from <0.05 mg/kg in an unspecified type of seaweed to 7.8 mg/kg in dried hjijki. In general, inorganic arsenic concentrations were higher in wakame, kombu, hijiki and *Sargassum fusiforme* in comparison to levels detected in nori, unspecified types of seaweed and sea vegetables.

For seaweed containing products, inorganic arsenic concentration was reported above the LOR for only two samples (seaweed chips). The concentration of inorganic arsenic in these chip samples was similar to levels detected in some seaweed types (e.g. nori, unspecified types of seaweed). The difference between the inorganic arsenic in dried seaweed and seaweed containing products may simply reflect the proportion of seaweed in the final product.

Table 1 *Inorganic arsenic concentration (mg/kg) in individual and composite samples of dried seaweed*

Seaweed type (as indicated on product packaging)	Inorganic arsenic concentration (mg/kg)[†]	Mean inorganic arsenic concentration (mg/kg)[∞]
Wakame (dried)	**0.19**	**0.18**
	0.20	
	0.16	
	0.16[β]	
Kombu (dried)	**0.33**	**0.22**
	0.19	
	0.18	
	0.16	
Hijiki (dried)	**7.80**[‡]	**n/a**
Sargassum fusiforme (dried)	**0.32**[¥]	**n/a**
Nori (dried)	**0.16**[€]	**0.11**
	0.09	
	0.10	
	0.09	
Seaweed, type not specified (dried)	**0.12**	**0.09**[α]
	<0.05 (0.05 upper bound)	
Sea vegetable (dried)	**0.10**[β]	**n/a**
Overall Mean	0.61	**n/a**
Overall Median	0.16	**n/a**
Minimum	0.05 (upper bound)	**n/a**
Maximum	7.80	**n/a**

[†] Concentration values are for individual samples unless otherwise indicated.
[β] Composite sample comprised 3 primary purchases (individual samples) of different brands.
[‡] Concentration value is from a composite sample comprising 2 primary purchases (individual samples) of the same brand of product.
[¥] Concentration value is from a composite sample comprising 2 primary purchases (individual samples) of different brands.
[€] Concentration value is from a composite sample comprising 3 primary purchases (individual samples) of the same brand of product.
[∞] The mean has been rounded to two decimal places.
n/a: not applicable.
[α] To calculate the mean for this sample the upper bound was used (non-detect results assigned value of 0.05 mg/kg).

Table 2 *Inorganic arsenic concentration (mg/kg) in individual and composite samples of products containing seaweed.*

Products containing seaweed (as purchased)	Total Inorganic arsenic concentration (mg/kg)†	Mean concentration for total inorganic arsenic (mg/kg) ‡
Miso soup (dried)	<0.05β	n/a
Seasoning sauce (as purchased)	<0.05	0.05 (upper bound)
	<0.05	
	<0.05	
Seaweed chips	<0.05	0.10
	0.14	
	0.11	
Desserts containing seaweed (as purchased)	<0.05	0.05 (upper bound)
	<0.05	
	<0.05	
Japanese tea (dried)	<0.05	n/a

† Concentrations are for individual samples unless otherwise indicated.
β samples were analysed as a composites comprising 3 primary purchases (individual samples) of different brands.
‡ For the purpose of calculating the mean, values reported at or below the LOR have been assumed to be the LOR of 0.05 mg/kg (upper bound). The mean has been rounded to two decimal places.
n/a: not applicable.

4.1 Comparing inorganic arsenic levels in dried seaweed with permissions in the Code

The results from this survey indicate that arsenic levels in dried seaweed samples were well below the ML for seaweed of 1 mg/kg (see section 1.3) with the exception of one composite sample of dried hijiki seaweed for which an inorganic arsenic concentration of 7.8 mg/kg (equivalent to 1.4 mg/kg at 85% hydration)[3] was reported.

For mixed foods that contain seaweed as an ingredient, a formula is included in the Code to calculate an appropriate ML to apply for comparative purposes, based on the proportion of each ingredient in the final product (see section 1.3). However, since the samples used in this survey were purchased from retail outlets, some of the information required to calculate the appropriate MLs for these mixed foods was not available. For example, in some cases the proportion of seaweed in the mixed food was not indicated on the label.

4.2 Comparing inorganic arsenic concentrations determined from this survey with levels reported in other countries

The high level of inorganic arsenic in hijiki seaweed in comparison to other seaweeds is consistent with previous studies. For example, a study conducted by Almela et al. (2006) determined the concentration of inorganic arsenic in a variety of seaweed types available in Spain. The study found that inorganic arsenic levels in *Hizikia fusiforme* were at least 27-fold higher in comparison to other brown seaweed types, and 47-fold and 115-fold higher in comparison to red and green seaweed samples, respectively. In the current survey, the inorganic arsenic level in hijiki seaweed was at least 23-fold higher than the other brown seaweed samples tested and approximately 48-fold higher than the red seaweed, nori.

A comparison of inorganic arsenic levels in seaweed species in a number of countries is provided in Table 3. The concentration of inorganic arsenic in wakame, kombu and nori seaweed is similar in the various countries. Evidently, in all countries represented in Table 3, the concentration of

[3] This calculation is based on a moisture content of 14.6% as determined from this survey in a second sample of the same dried hijiki seaweed composite.

inorganic arsenic in hijiki seaweed was the highest, ranging from 7.8 mg/kg in Australia to 117 mg/kg in Spain (Almela et al. 2006).

Table 3 *A comparison of inorganic arsenic concentration in seaweed species in various countries*

Seaweed Type (dried)	Inorganic arsenic concentration (mg/kg)					
	FSANZ 2012 N=38	NSWFA 2010[¥] N=48	Almela et al 2002[Ω] N=18	Almela et al 2006[£] N=112	FSA, 2004; Rose et al 2007[†] N=31	Smith et al 2010[α] N=10
	AUSTRALIA[*]		SPAIN[∞]		UK[€]	NEW ZEALAND
Wakame	0.16 - 0.20	0.06 – 0.51	0.15 - 0.26	<LD -1.12	<0.3	0.1
Kombu	0.16 - 0.33	<0.05 - 0.52	0.254 - 0.297	0.238 -1.44	<0.3	n/a
Hijiki/ Sargassum fusiforme[π]	0.32 - 7.8	n/a	83 - 85	41.6-117	77	n/a
Nori	0.09 - 0.16[€]	0.08 - 0.39	0.19 - 0.57	0.116 - 0.402	<0.3	1.2[‡]
Sea vegetable	0.10	0.13 - 0.23	n/a	n/a	n/a	n/a

[†] Mean values are presented.
[‡] value presented is for Porphyra;
[¥] values presented represent the range of values from various samples tested.
[Ω] fresh hijiki was dried prior to analysis.
[£] seaweed type is listed as Hizikia fusiforme; LD = limit of detection.
[*] The Limit of Reporting (LOR) for both studies is 0.05 mg/kg;
[∞] the LOR for both studies is 0.014 mg/kg;
[€] LOR for both studies is 0.3 mg/kg;
[α] LOR is not reported.
n/a not applicable
[π] Hijiki samples are as purchased from retail outlets. The status of hijiki processing prior to packaging is unknown (see footnote 1)

A comparison of inorganic arsenic levels in products containing seaweed with similar products in other countries is difficult due to the limited number of published studies in this area. Almela et al (2006) determined the concentration of inorganic arsenic in red miso soup and tisane (herbal tea) to be 0.05 mg/kg and 0.610 mg/kg, respectively (dry weight). These levels are comparable to those determined in this study, which reported inorganic arsenic levels at or below the LOR of 0.05 mg/kg for both miso soup and tea.

5 Risk assessment

5.1 Hazard assessment

Inorganic arsenic is a carcinogen in humans (WHO, 2011a). In 2010, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) re-considered the existing health-based guidance value for inorganic arsenic using a benchmark dosing model approach. The inorganic arsenic lower limit on the benchmark dose for a 0.5% increased incidence of lung cancer ($BMDL_{0.5}$) was determined from epidemiological studies to be 3 µg/kg body weight per day (bw/day) (2–7 µg/kg bw/day based on the range of estimated total dietary exposure) using a range of assumptions to estimate total dietary exposure to inorganic arsenic from drinking-water and food (; WHO 2011a). Uncertainties in this $BMDL_{0.5}$ relate to assumptions regarding total exposure and to extrapolation of the $BMDL_{0.5}$ to populations other than those in Asia, where the epidemiological studies were undertaken, due to the uncertainties around the influence of nutritional status, such as low protein intake, and other lifestyle factors on the observed outcomes. JECFA noted that the existing health-based guidance value, namely the provisional tolerable weekly intake (PTWI) of 15 µg/kg bw (equivalent to 2.1 µg/kg bw/day) was in the region of the $BMDL_{0.5}$ and therefore was no longer appropriate and the PTWI was withdrawn.

JECFA recommended that future epidemiological studies of the health impacts of arsenic should incorporate appropriate measures of total exposure to inorganic arsenic, including from food, drinking water and from water used in cooking and processing of food. It was further recommended that epidemiological studies not only focus on relative risks, but also analyse and report the data such that they are suitable for estimating exposure levels associated with additional (lifetime) risks, so as to make their results usable for quantitative risk assessment.

5.2 Estimated dietary exposure to total arsenic and inorganic arsenic

5.2.1 Australian Total Diet Study

In the 19th, 20th and 23rd ATDS, total arsenic (sum of inorganic and organic species) concentrations were determined in all foods commonly consumed in a typical Australian diet. The estimated mean dietary exposure to total arsenic in the 23rd ATDS was 0.4-1.4 µg/kg bw/day, dependent on the population groups being assessed (FSANZ 2011a). Results consistent with this were reported for the previous 19thand 20th ATDS (ANZFA 2001; FSANZ 2003). In the 23rd ATDS, the estimated 90th percentile dietary exposures to total arsenic for each age group were between 1.0 and 2.8 µg/kg bw/day for the lower bound[4], and between 1.2-3.2 µg/kg bw/day for the upper bound[5] estimates. The major contributors to dietary exposure were seafood and cereal and grain based foods, consistent with those reported in other countries (EFSA 2009, WHO 2011 a and b).

Comparison of arsenic exposure between Australia and other countries is difficult because of major differences in consumption patterns, regional geology and the amount of arsenic present in drinking water. Broadly speaking, total arsenic exposure in Australia is at the lower end of the range of exposures reported in comparable countries and regions, such as the US and the European Union (EU). However, it should be noted that even within countries, the exposure to arsenic between localised populations can vary substantially (see section 5.2.3 below).

In the 23rd ATDS, inorganic arsenic concentrations were also determined in a range of seafood samples that are considered to be commonly consumed in Australia (e.g. battered fish fillets, frozen fish portions, tuna canned in brine and cooked prawns). Seaweed and seaweed products were not included in the 23rd ATDS. All samples analysed for inorganic arsenic were reported to be below the LOR of <0.05 mg/kg.

5.2.2 Estimated additional dietary exposure to arsenic from seaweed

This survey has found that some seaweeds are a potential source of arsenic exposure that had not been included in the dietary exposure estimates for total arsenic in the 23rd ATDS.

Using the dietary exposure estimates from the 23rd ATDS as a baseline, FSANZ considered a wide range of possible scenarios to describe potential additional dietary exposure to inorganic arsenic for individual consumers of seaweed based food. Based on FSANZ's understanding of current typical Australian consumption patterns, seaweed is unlikely to be widely or regularly consumed by very young children and across the wider population, with the possible exception of sushi nori. In the absence of consumption data from national nutrition surveys for seaweed and seaweed products at an individual level, FSANZ assumed that all population groups would consume the equivalent of 10 g of dried seaweed per day, an amount that is likely to be an upper level of

[4] Lower bound assumes that where no arsenic was reported it is not present in the food
[5] Upper bound assumes that where no arsenic was reported it was present at the limit of reporting

consumption. Appendix 1 describes the scenarios in detail, shows the related inorganic arsenic exposure estimates and clearly identifies the assumptions and uncertainties of the dietary exposure estimates.

For the 'best case' scenario, potential inorganic arsenic exposure from all food sources ranged from 0.3-0.7 µg/kg bw/day; for the worst case scenario, from 2.2 to 7.6 µg/kg bw/day. For the population group aged 2-5 years, exposure varied from 0.7-7.6 µg/kg bw/day, depending on the scenario. For 6-12 year olds and 13-16 year olds exposure varied from 0.5-4.2 µg/kg bw/day and 0.3-2.7 µg/kg bw/day respectively. For adults, the range was 0.3 - 2.2 µg/kg bw/day.

Overall, dietary exposure estimates show that daily consumption of seaweed has only a minor impact on overall inorganic arsenic exposure when the concentrations of inorganic arsenic is at the median level for seaweed, as determined in this survey. If the highly protective assumption is made that all the seaweed consumed contains inorganic arsenic at the maximum level reported in this survey, this (not unexpectedly), results in substantially increased exposure estimates across all population groups (worst case scenario). However, it is noted that this is unlikely to occur in reality as arsenic concentration in seaweed covers a wide distribution of values and only some population sub groups or individuals will consume seaweed and seaweed products on a daily basis with many consuming less than 10 g dried seaweed a day.

5.2.3 Dietary exposure reported in the literature for countries other than Australia

It is often difficult to compare exposure estimates on total and inorganic arsenic between studies and between countries. It is important to note that drinking water is the major contributor to arsenic exposure in certain regions of some countries, but that this is not always included in dietary exposure estimates. Inorganic arsenic exposure estimates, if reported, are often not based on direct analyses, but derived by applying different factors to total arsenic results for different foods to represent the proportion that is likely to be inorganic arsenic. These factors may vary between studies.

A comprehensive review of dietary exposure estimates for different countries was undertaken by Uneyama *et al.* (2007). They reported the following daily total arsenic exposures which are represented in Table 4.

Table 4 *A comparison of estimated inorganic arsenic intake in various countries*‡

Region	Estimated inorganic arsenic exposure	
	Minimum (µg/day)	Maximum (µg/day)
Europe	0.001 Portugal	458 Spain
Asia	27 Japan	658 India
USA	7	137
Canada	6	38.1
New Zealand	n/a	55
South America	6.9 Brazil	145 Brazil

‡ Information taken from Uneyama et al, 2007.

Watanabe *et al* (2004) reported mean exposure to total arsenic in Bangladesh at 13.48 (men) and 10.30 (women) µg/kg bw/day and Kile *et al* (2007) reported 0.91 µg/kg bw/day. The large differences in exposure were due to the assumptions on the level of arsenic in drinking water made in the first study.

Diaz *et al* (2004) report that the mean total arsenic exposure in Chile ranged from 0.63-1.1 μg/kg bw/day for food only and from 2.18 to 23.3 μg/kg bw/day where water was included in the estimates.

Leblanc et al (2000) and Sirot *et al* (2009) estimated the mean exposure to total arsenic in French populations. Leblanc et al (2000) reported mean exposure for the whole French population at 1.82 μg/kg bw/day from the French Total Diet Study, which did not include drinking water in the estimates. The Sirot et al (2009) study was on a coastal population where fish and seafood consumption was higher than elsewhere; mean exposure to total arsenic was reported to be 11.04-13.53 μg/kg bw/day and the 95th percentile to be 25.14-33.0 μg/kg bw/day. Drinking water was included in their exposure estimate.

Tsuda *et al* (1995) and Ogawa and Kayama (2009, as quoted by WHO 2011b) reported that the mean exposure to total arsenic for Japanese populations was 3.82-4.73 μg/kg bw/day and 19.71-24.10 μg/kg bw/day respectively. Ogawa and Kayama (2009, as quoted by WHO 2011b) focused their estimates on fish and rice growing communities that were high consumers of seaweed, fish and shell fish. They also reported 95th percentile and maximum exposures: 68.86-78.00 μg/kg bw/day and 114.00-159.57 μg/kg bw/day respectively. In contrast, they reported that the mean exposure for the whole Japanese population (based on a Total Diet Study) was estimated at 4.91-4.96 μg/kg bw/day.

The European Food Safety Authority (EFSA) (2009) reported a wide range of exposure estimates in European countries. For example, lower bound exposures for total arsenic reported across 19 European countries ranged from 0.4 to 4.3 μg/kg bw/day at the mean of exposure (0.6-4.5 μg/kg bw/day for the upper bound) and from 1.8 to 11.0 μg/kg bw/day for the 95th percentile (2.0-11.2 μg/kg bw/day at the upper bound). These variations in exposure between countries were a consequence of different consumption patterns, since the same arsenic concentrations were used as inputs in the exposure assessment.

Xue *et al* (2010) reported exposure to total arsenic from food in the US based on a Total Diet Study to be 0.36 μg/kg bw/day at the mean and 1.40 μg/kg bw/day at the 95th percentile. For exposure from water, they reported 0.03 μg/kg bw/day at the mean and 0.11 μg/kg bw/day at the 95th percentile. The mean inorganic arsenic exposure from food was 0.05 μg/kg/day.

More recently, the literature on dietary exposure to arsenic in different countries has been comprehensively reviewed by the World Health Organisation (WHO) (2011a and b). Mean and 95th percentile inorganic arsenic dietary exposure estimates were summarised for Europe, North America, South America and Asia. In Europe, adult exposure was estimated at 0.02-0.61 μg/kg bw/day at the mean, and 0.27-0.99 μg/kg bw/day at the 95th percentile. For children (1-8 years) exposure estimates were higher, ranging from 0.31 to 1.39 μg/kg bw/day at the mean and 0.61-2.66 μg/kg bw/day at the 95th percentile. In North America, mean exposure to inorganic arsenic for the whole Canadian population was estimated at 0.29 μg/kg bw/day. In the US, adult mean exposure was estimated to be 0.08-0.20 and 0.16-0.34 μg/kg bw/day at the 95th percentile. Mean exposure of children (1-6 years old) to inorganic arsenic in the US was estimated at 0.12-0.32 μg/kg bw/day.

According to WHO (2011a), exposure to inorganic arsenic in South America (Chile only) was 2.08-21.48 μg/kg bw/day, noting that contaminated water was a contributor to exposure. In Asia (Bangladesh, China, Taiwan, Japan), mean exposure for adults ranged from 0.24-3.00 μg/kg bw/day, 0.83-1.29 μg/kg bw/day at the 95th percentile (Japan only).

5.3 Risk characterisation

The health risks associated with dietary exposure to inorganic arsenic from the consumption of seaweed is variable and dependent on the:

- concentration of inorganic arsenic in the seaweed consumed
- amount of seaweed consumed and whether this is on a regular basis
- the consumption of other foods in the diet that also contain inorganic arsenic

If seaweed is consumed that has inorganic arsenic levels below the ML of 1 mg/kg, consumption is unlikely to have a substantial impact on inorganic arsenic exposure. Consequently, based on the data currently available, for the overall Australian population the risk of significantly increased exposure to inorganic arsenic from consumption of seaweed and seaweed products is considered low. This scenario is likely given the inorganic arsenic levels in the majority of samples tested in this survey is low and compliant with the requirements in the Code (with the exception of a single composite sample of hijiki seaweed).

However, there might be some population groups or individuals who consume large amounts of hijiki seaweed regularly and therefore are more likely to be exposed to high amounts of arsenic compared with the overall Australian population. These high consuming people may have a higher potential health risk from exposure to inorganic arsenic than the general population but this risk is not easily quantifiable. In particular, small children who consume hijiki seaweed regularly may be at more risk of increased inorganic arsenic exposure from seaweed than other age groups because of their low bodyweight and resultant higher amount of food consumed per kilogram bodyweight.

The JECFA Committee (WHO 2011a) noted in its evaluation that there was considerable uncertainty regarding the magnitude of the calculated $BMDL_{0.5}$ (3 µg/kg bw/day; range - 2–7 µg/kg bw/day) and whether it could readily be extrapolated to populations other than those is Asia, where the epidemiological studies were undertaken, due to uncertainties around the influence of nutritional status, such as low protein intake, and other lifestyle factors on observed outcomes. The additional risk arising from a small increase in exposure through seaweed consumption in Australia is difficult to estimate but given the uncertainties surrounding the $BMDL_{0.5}$ identified by JECFA, it seems unlikely to appreciably alter the risk for consumers.

6 Risk management activities

In response to the findings from this survey, the relevant jurisdiction that supplied the hijiki seaweed sample was notified of the result for further investigation and/or any follow-up activity. DAFF was also notified of the survey findings.

For border testing of imported food, hijiki seaweed is classified as a risk category food, given the possibility of high concentrations of inorganic arsenic. Hijiki seaweed, from a new producer exporting to Australia, is initially referred to DAFF by Customs at a rate of 100% of consignments, and is tested to ensure inorganic arsenic levels do not exceed the ML in the Code of 1 mg/kg (at 85% hydration). Once five consecutive consignments from the producer of the specific food have passed inspection, the inspection rate is reduced to 25%. After a further 20 consecutive passes, the inspection rate is reduced to 5%. Any subsequent consignments that fail result in a return to 100% testing of that product from that producer until a history of compliance is re-established for the food. Consignments of risk food which fail inspection cannot be imported. These foods are re-exported or destroyed.

In recent years, the rate of compliance of inorganic arsenic in imported hijiki seaweed has been high, at 100% (n=10) for the period of July to December 2010 (AQIS 2010). Before this, the last report of non-compliance was in the period of July 2006-June 2007, where two consignments failed

(AQIS 2007). This recent high compliance of imported hijiki seaweed with the ML for inorganic arsenic is reassuring for Australian consumers of imported hijiki seaweed.

In 2011, additional measures were implemented at the Australian border for hijiki seaweed. This has involved updating the description of hijiki seaweed in the DAFF risk food category to also encompass scientific names and synonyms, recognising the variation in labelling used for this type of seaweed. According to this description, hijiki seaweed is also known as *Hizikia fusiforme, Sargassum fusiforme, Hizikia fusiformis,* Hiziki*,* Mehijiki*,* Hoshi hiziki*,* Deer tail grass*,* Sheep nest grass *and* Horsetail tangle. Interestingly, products labelled as both hijiki and *Sargassum fusiforme* were analysed in this study; however the concentrations of inorganic arsenic varied by at least 20-fold (Tables 1 and 3). This difference in concentration is consistent with the concentration ranges demonstrated for hijiki seaweed in Table 3. Hijiki seaweed is harvested from the lower end of the eulittoral and upper sublittoral zone where arsenic levels are variable and are influenced by seasonal changes and geochemical composition. Therefore, it is possible that the two seaweed samples are of the same species but were harvested from different regions and/or at different times of the year (FAO 2003; Gupta and Abu-Ghannam 2011; Borak and Hosgood 2007).

There are also difficulties associated with identifying seaweed species, particularly for seaweed that is imported in the original packaging and re-labelled in English for sale in Australia (NSWFA 2010). A considerable amount of seaweed is imported into Australia (e.g. approximately 5,500 tonnes in 2011), mainly from China, Japan, Korea and Ireland (RIRDC 2010; ABS 2011). It is possible that some of these products may have been incorrectly labelled. Given the number of synonyms for a single seaweed species, any conclusions comparing these samples should take this into consideration. For further information on alternative names for brown seaweed, please refer to the FSANZ website at:
http://www.foodstandards.gov.au/scienceandeducation/factsheets/factsheets/adviceonbrownseaweedforpregnantwomenbreastfeedingwomenandchildren27june2011/brownseaweedstable.cfm

FSANZ considers that existing risk management measures, i.e. the ML in the Code and testing at the border, for hijiki seaweed are suitably protective of the health and safety of the Australian population. However, the dietary exposure of the Australian population to organic and inorganic arsenic in food will continue to be investigated by FSANZ and included in the upcoming 25th ATDS. The suitability of risk management measures will be further reviewed following completion of the 25th ATDS.

Further studies may be necessary to better understand the variability of arsenic concentrations in specific foods due to a number of factors, such as the geology of the region in which foods are grown and different varieties. Information about seaweed consumption data for different population groups in Australia would also be useful for the purposes of the dietary exposure assessment. Contemporary food consumption data will become available in the future through the 2011-13 Australian Health Survey, which is currently being conducted by the Australian Bureau of Statistics.

7 Risk communication

FSANZ has reviewed and updated the factsheet for consumers regarding arsenic in food, which is available on the FSANZ website at:
http://www.foodstandards.gov.au/consumerinformation/arsenic.cfm

The factsheet contains information on seaweed, iodine, arsenic, a summary of the current survey findings and risk management measures.

FSANZ will update its advice to consumers through the factsheet following completion of the 25th ATDS and other possible studies, or as additional information becomes available.

8 Conclusion

Overall, this report suggests that levels of inorganic arsenic in most seaweed available in Australia are below the regulatory limit, with the notable exception of one composite hijiki seaweed sample. This composite is comprised of individual samples of the same brand, so conclusions cannot be drawn as to whether this finding is representative of all hijiki seaweed available in Australia. DAFF continues to monitor inorganic arsenic levels in hijiki seaweed imported into Australia for compliance with the Code.

In general, the consumption of seaweed and seaweed products in the Australian population is likely to be low and the resulting contribution to total dietary exposure to inorganic arsenic is therefore likely to be small for the general population. Population groups and individuals who have a high exposure to arsenic from other sources in the diet, and also regularly consume hijiiki seaweed, should be aware that they may have a higher potential health risk from exposure to arsenic than the general population.

9 Acknowledgements

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Appendix 1: Dietary Exposure Assessment

1. Background

In this survey, FSANZ found that seaweeds are a potential source of arsenic exposure that had not been included in the dietary exposure estimates for total arsenic in the 23rd ATDS. Using the dietary exposure estimates for total arsenic from the 23rd ATDS as a baseline, FSANZ considered a range of possible scenarios to describe potential additional dietary exposure to inorganic arsenic for individual consumers of seaweed based food.

2. Assumptions

The 23rd ATDS reported average exposure (mean) and high consumers[6] exposure (90th percentile) to total arsenic, which were considered the populations of interest for this assessment. Exposures reported were the same for the whole population and consumers because all respondents consumed foods that were potential sources of arsenic exposure. Upper bound and lower bound dietary exposures reported in the 23rd ATDS were very similar for total arsenic. Therefore, the upper bound mean and 90th percentile of exposure only were selected as the baselines (Table A1, expressed as mg/day) to which potential exposure from seaweed (including all seaweed products) was added. Using these baselines ensures that the assessment is sufficiently protective of high consumers.

The same age groups used in the ATDS were used in this assessment with the exception of 9-month-olds who were not included because it was considered highly unlikely that this age group would consume seaweed or seaweed products.

FSANZ has no suitable data on seaweed consumption. Based on FSANZ's understanding of current typical Australian consumption patterns, seaweed is unlikely to be widely or regularly consumed by very young children and across the wider population, with the possible exception of sushi nori. In the absence of such consumption data at an individual level, FSANZ has assumed that all population groups would consume the equivalent of 10 g of dried seaweed per day, an amount that is likely to be an upper level of consumption. This approach is consistent with the assumptions made by EFSA when estimating the potential contribution to inorganic arsenic exposure from seaweed (EFSA 2009). The data for inorganic arsenic content of seaweed used in this assessment has been restricted to that reported in Table 1 (see above), using the overall median and maximum inorganic arsenic concentrations for dried seaweed of 0.16 and 7.80 mg/kg respectively to construct exposure scenarios.

Considering the lack of representative speciation data for seaweed and other foods, it was not possible to use inorganic arsenic concentration data as an input for dietary exposure estimates. No typical ratios for organic versus inorganic arsenic content of seaweeds or the wider food supply were readily available. Consequently, the proportion of inorganic to total arsenic was assumed to vary from 50-100% in different scenarios, with 70% considered to be an estimate of the overall average. A similar approach was followed by EFSA in their review of arsenic in 2009 (EFSA 2009).

Mean bodyweights of the population groups were calculated based on the values reported in the 1995 National Nutrition Survey (NNS) for adults (unweighted) and 2007 Australian National Children's Nutrition and Physical Activity Survey (ANCNPAS) (weighted) which formed the basis for the exposure estimates reported for the 23rd ATDS (Table A2).

[6] Consumers are defined as the consumers of foods containing the chemical of interest

APPENDIX 1

Table A1 *Mean and 90th Percentile exposures to total arsenic reported in the 23rd ATDS*

Population	distinct count (number)†	weighted count (number)‡	Dietary Exposure (mg/d)		
			Ratio consumers/ respondents¥	Mean	90th percentile
2007 Australian National Children's Nutrition and Physical Activity Survey (ANCNPAS)					
2-5 years	1,566	1,178	100	0.025	0.058
6-12 years	1,606	2,090	100	0.032	0.073
13-16 years	1,315	1,219	100	0.037	0.086
1995 National Nutrition Survey (NNS)					
17+ years	11,129	Not weighted	100	0.041	0.084

† Distinct count is the number of actual consumers in the survey (sample population), ‡Weighted count is where some consumers contribute more or less than others to make each contribution more representative of the actual population, ¥Ratio consumer to respondent is where the respondent count is divided by the consumer count. In this case, all respondents are consumers.

Table A2 *Mean bodyweights used in dietary exposure estimates for this assessment*

Age group	Survey	mean bw (kg)	Weighted
2-5	2007 ANCNPAS	18	✓
6-12	2007 ANCNPAS	36	✓
13-16	2007 ANCNPAS	61	✓
17+	1996 NNS	74	×

3. Dietary exposure estimates for different scenarios

There are a number of possible scenarios that can be constructed based on assumptions about the possible baseline dietary exposure to arsenic (mean or 90th percentile), the concentration of arsenic in the seaweed, the proportion of inorganic arsenic present in the food and the consumption amounts of seaweed. Assuming all seaweed consumption (including all seaweed products) was 10 g/day (dry weight) and a background exposure at the upper bound for all populations, 12 exposure scenarios were constructed (Table A3). The four scenarios shown in bold were selected for reporting in Table A4 for all population groups. Scenario 3 presents a 'best case', Scenario 10 a 'worst case' and Scenarios 5 and 8 are more 'typical cases', i.e. cases that fall between the best and worst case scenarios. All twelve scenarios were calculated for the most vulnerable population (children aged 2-5 years) and compared to background exposures.

Table A3 *Inorganic arsenic exposure scenarios*

Background	Arsenic concentration in Seaweed	% inorganic in all foods that contribute to exposure		
		100	*70*	*50*
Mean Exposure	median	Scenario 1	Scenario 2	**Scenario 3**
	maximum	Scenario 4	**Scenario 5**	Scenario 6
90th Percentile exposure	median	Scenario 7	**Scenario 8**	Scenario 9
	maximum	**Scenario 10**	Scenario 11	Scenario 12

All respondents consumed foods that were potential sources of arsenic exposure.

APPENDIX 1

Table A4 *Estimated dietary exposure to inorganic arsenic in four selected scenarios*

	Scenario 3: 'best case'	**Scenario 5**	**Scenario 8**	**Scenario 10: 'worst case'**
	50% inorganic arsenic	70% inorganic arsenic	70% inorganic arsenic	100% inorganic arsenic
	Seaweed: median concentration	Seaweed: maximum concentration	Seaweed: median concentration	Seaweed: maximum concentration
	Mean background exposure		90th Percentile background	
Population	**Exposure µg/kg bodyweight/day:**			
2-5	0.7	4.0	2.3	7.6
6-12	0.5	2.1	1.5	4.2
13-16	0.3	1.3	1.0	2.7
17+	0.3	1.1	0.8	2.2

The estimated dietary exposure to inorganic arsenic including that from seaweed for Scenarios 3, 5, 8 and 10 are shown in Table A4. For the population group aged 2-5 years, exposure varied from 0.7-7.6 µg/kg bw/day, depending on the scenario. For 6-12 year olds and 13-16 year olds, exposure varied from 0.5-4.2 µg/kg bw/day and 0.3-2.7 µg/kg bw/day respectively. For adults, the range was 0.3-2.2 µg/kg bw/day.

For the 'best case' scenario, exposure ranged from 0.3-0.7 µg/kg bw/day across different population groups and for the worst case scenario, from 2.2 to 7.6 µg/kg bw/day. Exposure scenarios are most sensitive to the presence of high arsenic concentrations in seaweed rather than the background exposure to arsenic as it was estimated in the 23rd ATDS. For example, from Table A4, assuming 70% of arsenic species are inorganic, estimated exposure is higher in the scenario that assumes a maximum concentration of arsenic species in the seaweed and mean background exposure (Scenarios 5) compared to the scenario that assumes a median concentration and 90th percentile background exposure (Scenario 8).

Figures A1a and A1b show the potential exposure to inorganic arsenic of 2-5 year old children under the 12 possible scenarios set out in Table A3. Figure A1a shows scenarios based on arsenic background exposure at the mean and Figure A1b shows scenarios based on the 90th percentile of background exposure. The bars on the far left of each set of charts show the estimated exposure to inorganic arsenic excluding seaweed, i.e. the background exposure.

In both charts it can be seen that estimated dietary exposure to inorganic arsenic without seaweed (background, bars to the left) is quite similar to exposure when seaweed is included under the assumption that inorganic arsenic is present at the median concentration reported in this survey (bars in the centre). In contrast, if seaweed is assumed to have inorganic arsenic concentrations at the maximum reported in this survey potential dietary exposure is far higher than the background (bars at the right).

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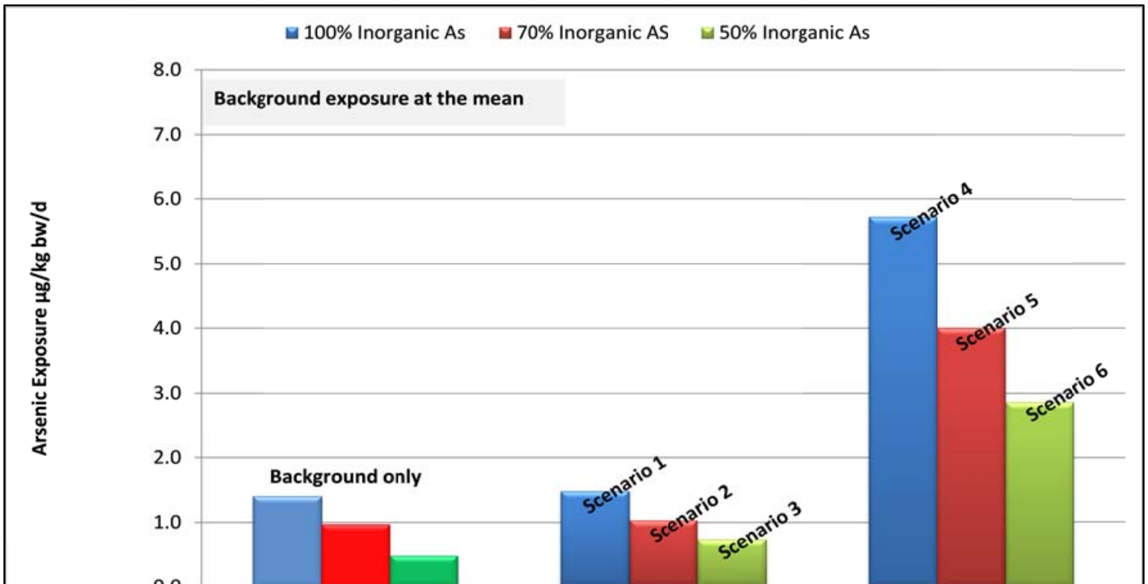
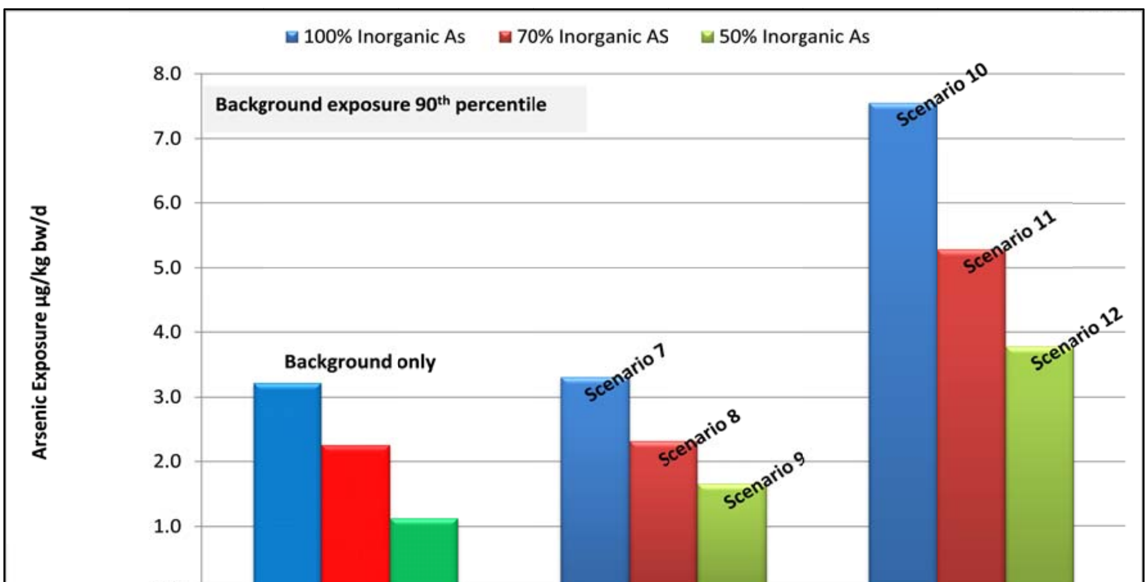
Figure A1 *Estimated dietary exposure of 2-5 year old children to inorganic arsenic assuming 50, 70 and 100% of arsenic species are inorganic and seaweed concentration of arsenic is zero, at the median (0.16 mg/kg) or maximum (7.8 mg/kg)*.

(a) *Background exposure at the mean (average consumers)*



	As in seaweed=0	As in seaweed=median	As in seaweed=maximum
100% Inorganic As	1.4	1.5	5.7
70% Inorganic AS	1.0	1.0	4.0
50% Inorganic As	0.5	0.7	2.9

(b) *Background exposure at the 90th percentile (high consumers)*



	As in seaweed=0	As in seaweed=median	As in seaweed=maximum
100% Inorganic As	3.2	3.3	7.6
70% Inorganic AS	2.3	2.3	5.3
50% Inorganic As	1.1	1.7	3.8

APPENDIX 1

4.0 Uncertainty analysis

4.1 Assessment objectives

FSANZ has surveyed inorganic arsenic in seaweed and seaweed-containing products available in Australia to assess the public health risks associated with the presence of inorganic arsenic in seaweed and seaweed products. The objective was to provide risk managers with the assessment of the risks to public health and safety including an exposure assessment using data currently available.

4.2 Exposure scenarios and input parameters

4.2.1 Uncertainty associated with concentration data

There are several areas of potential uncertainty in dietary exposure estimates. For example, it is uncertain whether the available concentration data is representative of the inorganic arsenic concentration in seaweeds. There is not enough data on the presence of organic and inorganic arsenic species in foods that are major contributors to arsenic exposure, such as rice. There is almost no available data on seaweed consumption (amounts and types) in Australia or the dietary consumption patterns of population groups that are high consumers of seaweed.

The quality of the occurrence data is expected to be good and the uncertainty in the values is considered to be low. The analyses were performed by an accredited laboratory using a validated method of analysis. Based on this method, it is possible that low levels of MMA (an organic form of arsenic with toxicological significance) may also be present. However, for the purposes of this report, a conservative approach has been taken and the possible presence of organic MMA has been included in the total inorganic arsenic concentration. This may result in an overestimate of the total inorganic arsenic levels in seaweed due to the uncertainty of the contribution of the MMA.

For the dietary exposure estimates, maximum and median concentrations were used as inputs. Upper bound and lower bound exposures for baseline exposure were very similar; therefore, the upper bound mean and 90th percentile of exposure only were selected as the baselines indicating the decision on how to treat non detect results for seaweed samples below the LOR was not a critical factor in contributing to uncertainty of results.

4.2.2 Uncertainty associated with food consumption data

The food consumption amounts used as inputs for the exposure baseline were based on 24 hour recall data. In some cases, this type of data is expected to underestimate the number of consumers of a given food on a long term basis, but this is not relevant for this assessment as all respondents were consumers of foods containing arsenic. In the absence of other information, the consumption of seaweed was assigned a value based on an understanding of consumption of foods containing seaweed, such as soups, chips and salads. The value was consistent with approaches taken by other risk assessors such as EFSA. It is uncertain if this value represents an over or underestimate of long term usual consumption of seaweed for some population groups. However, it is most likely that it represents an overestimate of usual consumption for the general Australian population.

The overall uncertainty in the dietary exposure estimations is considered to be medium to high. It most likely represents an overestimate of exposure for the general population but it is not possible to decide if it results in an over or underestimate of exposure for population groups that are high consumers of foods with high levels of inorganic arsenic.