Integrated Risk Index for Seafood Contaminants (IRISC): pilot study in five European countries

Cano-Sancho, German[a,*]; Sioen, Isabelle[b]; Vandermeersch, Griet[c]; Jacobs, Silke[b]; Robbens, Johan[c]; Nadal, Martí[a]; Domingo, José L[a].

[a] Laboratory of Toxicology and Environmental Health, School of Medicine, IISPV, "Rovira i Virgili University, Reus, Spain.

[b] Nutrition and Food Safety Department, Ghent University, Ghent, Belgium.

[c] Institute for Agricultural and Fisheries Research, Animal Sciences Unit – Fisheries, Oostende, Belgium

Address correspondence:

German-Cano Sancho

Laboratory of Toxicology and Environmental Health, School of Medicine, IISPV, Universitat Rovira i Virgili, Sant Llorenç 21, 43201 Reus, Catalonia, Spain

E-mail: german.cano@urv.cat

Abstract:

Consumption of seafood is one of the most relevant pathways of exposure to environmental pollutants present in food. The list of toxic compounds in seafood is very extensive, including toxic elements, polychlorinated dibenzo-p-dioxins and dibenzofurans (PCCD/Fs), polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs). In order to quantify the importance of the problem, tools to combine and simplify large data collections are mandatory for risk managers and decision-makers. In this study, the development of a prioritization setting focusing on chemical hazards taken up through seafood was aimed. For this purpose, the toxicity data of several chemicals was integrated with concentration and seafood consumption data, building an integrated risk index for seafood contaminants (IRISC) able to draw a map of risk for each chemical and family of chemicals. A pilot trial was performed on a sample of 74 pollutants, four seafood species and five European countries (Belgium, Ireland, Italy, Portugal and Spain). The preliminary results revealed that Portugal and Spain presented the highest IRISC, while Belgium was the region with the lowest IRISC. The contribution of each group of contaminants to the IRISC was very similar among countries, with toxic elements being the major contributor, followed by (PCBs), PCDD/Fs and endocrine disrupting compounds. When the contribution of different seafood species to the Risk Indexes (RIs) was compared, the results elucidated the high input from sardines showing the highest rates (54.9-76.1) in the five countries. The IRISC provides a friendly approach to the chemical risk scene in Europe, establishing normalized prioritization criteria considering toxicity and consumption as well as concentration of each chemical.

Keywords

Risk management, risk index, seafood, fish, chemical contaminants.

1. Introduction

The seafood market has experienced a constant growth in the last century, being an important source of nutrients and energy worldwide. Seafood is recognized for the presence of high quality proteins, polyunsaturated fatty acids, vitamins and minerals. However seafood is also a carrier of a wide range of environmental pollutants. Hence, the beneficial effects of seafood consumption are often compromised by the adverse health effects induced by chemical pollutants. Consequently, safe seafood across the food chain has become a priority for most health authorities and scientific panels. Their challenges implied to provide balanced policies considering the seafood trade, the health benefits and risks (Dewailly et al., 2008; Domingo et al., 2007, 2014).

Toxic elements (TE) such as mercury (Hg), cadmium (Cd), lead (Pb) or arsenic (As) are one of the most relevant group of toxic contaminants in seafood. In addition, the persistent organic pollutants (POPs) that include an extensive list of compounds such as dibenzo-p-dioxins and dibenzofurans (PCCD/Fs), polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbon (PAHs), are also relevant, particularly in seafood species with a high fat content (Bocio et al., 2007; Bocio et al., 2004; Llobet et al., 2007; Martorell et al., 2011; Perello et al., 2012).The chemical properties of these compounds, characterized by their high persistence and bioaccumulation potential, lead to the fact that larger commercial fish species are the higher risk commodities. Additionally to the abovementioned chemicals, the Marine Strategy Framework Directive established a list of priority contaminants in seafood due to the lack of knowledge and the potential risk for public health. This group of contaminants include non-dioxin-like PCBs, the brominated flame retardants (BFRs), polyfluorinated compounds, organotin compounds, organochlorine pesticides and phthalates (EC, 2008). The adverse health effects triggered by these compounds include carcinogenesis, neurotoxicity, nephrotoxicity, hepatotoxicity, disruption of immune and endocrine systems, as well as impairment on the reproduction and development of mammals, among others (FAO, 2014).

Considering this large list of toxic compounds in seafood, tools to combine and simplify large data collections are mandatory for risk managers and decision-makers. Some frameworks have been proposed to prioritize microbiological hazards according to qualitative and quantitative approaches (EFSA 2012; NZFSA 2004). Despite the efforts of scientific panels to harmonize the current methodologies, a framework for chemical hazards has not been reached yet. Among the most reported approaches, risk ranking systems allow displaying a prioritization list of chemicals according to a selection of parameters, e.g. physicochemical parameters (persistence, bioaccumulation and toxicity) (Fabrega et al., 2013; Nadal et al., 2008). In the past, also other parameters such as the consumption and concentration probabilities were integrated with the toxicity and antimicrobial resistance in a score-based risk ranking approach piloted with antibiotics (van Asselt et al., 2013). Considering seafood, the concentration of chemical pollutants can be determined by the physicochemical properties of each pollutant and the biological characteristics of seafood species. In turn, the consumption of seafood is highly determined by cultural and socio-economic factors, leading to a geographic distribution of these dietary patterns (Arnot and Mackay, 2008). Hence, the integration of these parameters by means of a "risk index" could draw a risk map to easily identify high risk regions and, therefore, helping to prioritize governmental interventions, either at national or European level.

In the framework of the FP7 European project ECsafeSEAFOOD, we aimed at developing a prioritization setting focused on chemical hazards consumed through seafood. Therefore, the toxicity data was integrated with concentration and consumption data, building a Risk Index able to draw a map of risk for each chemical and family of chemicals. The methodology was implemented in a pilot trial using a selection of European countries, fish species and pollutants, in order to check the performance of this novel tool.

2. Materials and Methods

2.1. Integrated exposure index

The integration of toxicity, concentration and consumption was performed as follows. At first, the risk index was computed for each chemical and region, according to specific seafood dietary patterns and concentration profiles (Equation 1).

$$Eq. 1) \qquad RI_{t,e} = \sum \frac{C_{e,f} X_{t,f}}{T_t}$$

Where [$RI_{t,e}$] was the global Risk Index for the contaminant [t] in the population [e]; [$C_{e,f}$] was the consumption of the seafood specie [f] by the population e and [$X_{t,f}$], represented the contamination of the chemical [t] in the seafood specie [f], and [T_t] was the toxicity reference value for the contaminant [t], in this case we used the lethal dose

50 (LD_{50}). Toxicity was estimated through ECOSAR™ tool which displays the fish toxicology based on the octanol/water partition coefficient (K_{ow}) levels. The final index was re-scaled to 0-100.

Subsequently, the integrated Risk Index from Seafood Contaminants (IRISC) from each region was established by combining the normalized RI from each pollutant, as follows (Equation 2):

$$Eq. 2) \qquad IRISC = \sum RI_t$$

2.2. Case study.

In order to check the applicability of the proposed methodology this approach was implemented on a selection of chemicals, four high consumed seafood species (sardine, canned tuna, salmon and mussels) and five European countries (Ireland, Spain, Portugal, Italy and Belgium).

2.2.1. Study area.

A selection of five European countries with markedly different dietary patterns was covered in this pilot trial. These countries represented Western (Ireland and Belgium) and Southern (Spain, Italy, Portugal) European populations, with large variety of dietary profiles of seafood consumption.

2.2.2. List of chemicals.

The list of chemicals was elaborated according to the availability of concentration data for each one of the seafood species. The final list of chemicals contained 16 PAHs, 18 PCBs, 17 PCDD/Fs, 5 PBDEs, 5 PCNs, 6 TEs and 8 EDCs (Table 1).

2.2.3. Contamination data.

The concentrations of the above listed chemical compounds in seafood species were gathered from the existing scientific literature, being most of the studies recently reviewed by Vandermeersch et al. (2015). The mean concentration levels of PAHs, PCBs, PCDD/Fs, PBDEs, PCNs, TE and EDCs in sardine, canned tuna, salmon and mussels are shown in Table 2.

2.2.4. Consumption data

Consumption data was provided by a survey performed in five countries in the framework of the ECsafeSEAFOOD project, aiming to establish the relationship between seafood consumption frequency and health risk-benefit perception of seafood. The questionnaires were administered during October 2013 by 2917 respondents aged between 18 and 75. A final sample of 2824 respondents was used as it was aimed to have a representative sample regarding the region (Jacobs et al., 2015). General self-reported seafood consumption frequency, as well as self-reported seafood consumption frequency for different species, was measured as the number of portions per week, indicating that one portion is about 150-200g. The response scale was recorded into frequencies according to the following formula: daily = 7.0, 5-6 times a week= 5.5, 3-4 times a week = 3.5, 2 times a week = 2.0, once a week = 1.0, less frequently = 0.25, and never = 0. The same recoding was done for the consumption frequency for the different species with exception of less frequently = 0.05 as the following response possibilities were added for this question: 2-3 times a month = 0.6, Once a month = 0.05, 1-5 times every 6 months = 0.15. The consumption frequencies of the different species were corrected with the general consumption frequency because of overestimation of the consumption when considering separate species. Finally, these corrected consumption frequencies for the four species were multiplied by 175g. The mean consumption frequency of sardine, canned tuna, salmon and mussels by the sample population is tabulated in Table 3.

3. Results and Discussion

The RI was computed for each chemical and consumption region, considering the consumption and contamination levels of sardines, canned tuna, salmon and mussels, as well as the toxicity. The RI allowed establishing a prioritization list for these chemicals, in this case also including the consumption and contamination from different seafood species. The grouped RIs for each chemical group (PAHs, PCBs, PCDD/Fs, PBDEs, PCNs, TE and EDCs) are represented on the maps Figure 1. The RIs allow the comparison between regions and between chemical groups. Western countries (Belgium and Ireland) are commonly showing lower RI values than the Southern countries (Portugal, Spain and Italy). Concerning the group of chemicals, toxic elements and PCDD/Fs had the highest RIs, whereas the PAHs and PCNs had the lowest estimates.

[Message for the Editor: please insert the Figure 2 around here**]**

[Figure 1.Risk Index maps for each chemical group and country. a) Integrated risk index for seafood contaminants, b) Polycyclic aromatic hydrocarbon, c) Polychlorinated biphenyls, d) Polychlorinated dibenzo-p-dioxins and dibenzofurans, e) Polybrominated diphenil ethers, f) Polychlorinated naphtalenes, g) Toxic elements, h) Endocrine disrupting compounds.]

Despite the differences of RI levels, the order of chemicals was quite similar between countries. The top of the list was reached by MeHg (RI; 14.1-65.0), OCDD (RI; 4.3-10.8), NP (RI; 1.7-5.9), Pb (RI; 1.3-2.8), Hg (RI; 0.5-1.6), PCB180 (RI; 0.5-1.9), PCB153 (RI; 0.3-1.1), OCDF (RI; 0.2-0.5), PCB138 (RI; 0.2-0.6), NPE (RI; 0.05-0.17), respectively. Through this approach we can also investigate the contribution of the considered seafood species to the RI of each chemical. A summary of this contribution of the different seafood species for each chemical group can be found in Figure 2. A similar profile can be seen when we compare the different countries but higher differences can be noticed when we compare the groups of chemicals. For example the contribution of canned tuna was mainly pointed out for EDCs, driven by the levels of BPA. In contrast, mussels had a relevant role on RIs of most of PAHs and toxic elements, whereas, sardine and salmon had higher contribution rates on the RIs of PCBs and PBDEs/PCNs, respectively.

***[Message for the Editor:** please insert the Figure 2 around here]*

***[Figure 2.**Mean relative contribution (%) of each seafood species to the relative Risk Index (RI) for each chemical compound group (PAHs, PCBs, PCDD/Fs, PBDEs, PCNs, toxic elements and EDCs).]*

IRISC and contribution of each group of contaminant to the integrated index is shown in the Figure 3. Portugal and Spain presented the highest IRISC, while Belgium was the region with the lowest rates. The contribution of each group of contaminants was very similar among countries, being toxic elements the major contributor, followed by PCBs, PCDD/Fs and EDCs.

***[Message for the Editor:** please insert the Figure 3 around here]*

***Figure 3.** Plots representing the IRISC for each country and the contribution of each group of chemical to the integrated index.]*

When we compare the total risk, accumulated by each seafood species, the results elucidated the high contribution of sardine, showing highest rates (54.9-76.1%) in the five countries. The higher concentration levels and also the high consumption frequency explained these estimates in comparison to the other pathways. Sardine was followed by canned tuna (15.1-21.7%), mussels (5.1-20.0%) and salmon (2.7-7.7%).

This proposed framework is mainly limited by the availability of data leading to accurate and sensitive scores. One of the main assumptions of the pilot trial was that the concentration levels of chemicals in seafood is the same around Europe, being the consumption frequency the most determinant parameter of the equation leading to a different exposure. This assertion can be certainly implemented for several species with a global trade such as salmon or tuna, but questioned for species mainly marketed and caught at regional level, where the concentration can be more influenced by geographical factors. Another limitation is the low availability of specific consumption data regarding selected seafood species. Despite the availability of information of global seafood consumption frequency at national level, the access to consumption data of specific species at individual level is a complicated task. Detailed raw consumption data sets would allow performing the analysis for target population groups, clustered by socio-demographic parameters, sex, age or dietary profiles. Other parameters affecting the exposure equation are external factors, such as cooking effect, or internal parameters (e.g. bioaccessibility). These factors are widely studied in most of the contaminants and fish species, but only some studies have demonstrated the potential effect on the final estimates (Maulvault et al., 2011; Perello et al., 2008).

4. Conclusions

It has been extensively demonstrated that seafood is the major pathway of human exposure to a number of environmental pollutants. The complexity and heterogeneity of these compounds trigger policy makers to apply regional and individualized policies. The proposed IRISC framework draws a new approach to screen the chemical hazards in seafood on the basis of both intrinsic parameters of each pollutant, and parameters related with the exposure equation. The Risk Index combines the consumption with contamination level of seafood and the toxicity of each compound. The final outcomes established a set of scores for each contaminant and seafood species, allowing an easy and friendly comparison between population groups. A pilot trial was applied on a sample of 74 pollutants, four seafood species and five European countries. According to these preliminary results Portugal and Spain presented the highest IRISC, while Belgium was the region with the lowest rates. The top of the list of contaminants contributing most to the IRISC was reached by MeHg, OCDD, NP, Pb, Hg, PCB180, PCB153, OCDF, PCB138 and NPE, respectively. The contribution of each group of contaminants was very similar among countries, being toxic elements the major contributor, followed by PCBs, PCDD/Fs and EDCs. When the accumulated RIs were compared among the four seafood species, the results elucidated the highest contribution of sardine, showing the highest rates (54.9-76.1) in the five countries. Other ongoing studies in the framework of the project ECsafeSEAFOOD are currently collecting concentration data of priority contaminants in high risk seafood species caught in European hotspots. Hence, in a subsequent phase the current framework will be implemented by using data of emerging contaminants highlighted in the Marine Strategy Framework Directive. Also additional consumption data from other countries, different from the five evaluated in this study, will be gathered to complement the European risk profile.

5. Acknowledgements

This study was supported by the European Commission, 7th Framework Programme (FP7/2007-2013) under the ECsafeSEAFOOD project (Grant agreement nº 311820). Isabelle Sioen is financially supported by the Research Foundation-Flanders (Grant nº: 1.2.683.14N.00).

6. References

Arnot, J. A., Mackay, D., 2008. Policies for chemical hazard and risk priority setting: can persistence, bioaccumulation, toxicity, and quantity information be combined? Environ Sci Technol. 42**,** 4648-54.

Bocio, A., et al., 2007. Concentrations of PCDD/PCDFs and PCBs in fish and seafood from the Catalan (Spain) market: estimated human intake. Environ Int. 33**,** 170-5.

Bocio, A., et al., 2004. Human exposure to polychlorinated diphenyl ethers through the diet in Catalonia, Spain. J Agric Food Chem. 52**,** 1769-72.

Cunha, S. C., et al., 2012. Determination of bisphenol A and bisphenol B in canned seafood combining QuEChERS extraction with dispersive liquid-liquid microextraction followed by gas chromatography-mass spectrometry. Anal Bioanal Chem. 404**,** 2453-63.

Dewailly, E., et al., 2008. Balancing the risks and the benefits of local fish consumption in Bermuda. Food Additives and Contaminants Part a-Chemistry Analysis Control Exposure & Risk Assessment. 25**,** 1328-1338.

Domingo, J. L., et al., 2007. Benefits and risks of fish consumption Part I. A quantitative analysis of the intake of omega-3 fatty acids and chemical contaminants. Toxicology. 230**,** 219-26.

Domingo, J. L., 2014. Nutrients and Chemical Pollutants in Fish and Shellfish.Balancing Health Benefits and Risks of Regular FishConsumption. Crit Rev Food Sci Nutr. DOI: 10.1080/10408398.2012.742985.

EC (European Commission), 2008. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). OJEU L164/19.

EFSA (European Food Safety Authority), 2012. Scientific Opinion on the developmentof a risk ranking framework on biological hazards. EFSA J. 10, 2724.

Fabrega, F., et al., 2013. Integrated Risk Index of Chemical Aquatic Pollution (IRICAP): case studies in Iberian rivers. J Hazard Mater. 263 Pt 1, 187-96.

FAO (Food and Agriculture Organization), 2014. Assessment and management of seafood safety and quality. Current practices and emerging issues. FAOfisheries and aquaculture technical paper 54. Rome.

Ferrara, F., et al., 2008. Alkylphenols and their ethoxylates in seafood from the Tyrrhenian Sea. Chemosphere. 72, 1279-85.

Ferrara, F., et al., 2005. Alkylphenols and alkylphenol ethoxylates contamination of crustaceans and fishes from the Adriatic Sea (Italy). Chemosphere. 59**,** 1145-50.

Jacobs, S., et al., 2015. European consumers' profile of risk-benefit perception of seafood for human health in association with their attitude toward the marine environment. Environ Res.

Lourenco, H. M., et al., 2012. Elemental composition of four farmed fish produced in Portugal. Int J Food Sci Nutr. 63**,** 853-9.

Llobet, J. M., et al., 2007. Human exposure to polychlorinated naphthalenes through the consumption of edible marine species. Chemosphere. 66**,** 1107-13.

Marti-Cid, R., et al., 2008. Human exposure to polychlorinated naphthalenes and polychlorinated diphenyl ethers from foods in Catalonia, Spain: temporal trend. Environ Sci Technol. 42**,** 4195-201.

Martorell, I., et al., 2010. Polycyclic aromatic hydrocarbons (PAH) in foods and estimated PAH intake by the population of Catalonia, Spain: Temporal trend. Environ Int. 36**,** 424-32.

Martorell, I., et al., 2011. Human exposure to arsenic, cadmium, mercury, and lead from foods in Catalonia, Spain: temporal trend. Biol Trace Elem Res. 142**,** 309-22.

Maulvault, A. L., et al., 2011. Bioaccessibility of Hg, Cd and As in cooked black scabbard fish and edible crab. Food and Chemical Toxicology. 49**,** 2808-2815.

Nadal, M., et al., 2008. Applicability of a neuroprobabilistic integral risk index for the environmental management of polluted areas: a case study. Risk Anal. 28**,** 271-86.

NZFSA (New Zealand Food Safety Authority), 2004. Ranking food safety risks a prototype methodology. FW0492. Christchurch, New Zealand.

Perello, G., et al., 2012. Assessmen**t** of the temporal trend of the dietary exposure to PCDD/Fs and PCBs in Catalonia, over Spain: health risks. Food Chem Toxicol. 50**,** 399-408.

Perello, G., et al., 2014. Human Health Risks Derived from Dietary Exposure to Toxic Metals in Catalonia, Spain: Temporal Trend. Biol Trace Elem Res.

Perello, G., et al., 2009. Concentrations of polybrominated diphenyl ethers, hexachlorobenzene and polycyclic aromatic hydrocarbons in various foodstuffs before and after cooking. Food Chem Toxicol. 47**,** 709-15.

Perello, G., et al., 2008. Effects of various cooking processes on the concentrations of arsenic, cadmium, mercury, and lead in foods. J Agric Food Chem. 56**,** 11262-9.

Podlipna, D., Cichna-Markl, M., 2007. Determination of bisphenol A in canned fish by sol–gel immunoaffinity chromatography, HPLC and fluorescence detection. European Food Research and Technology. 224**,** 629-634.

van Asselt, E. D., et al., 2013. Risk ranking of chemical hazards in food—A case study on antibiotics in the Netherlands. Food Research International. 54**,** 1636-1642.

Vandermeersch, G., Lourenço, H., Alvarez-Muñoz, D.; Cunha, S.; Diogene, J., Cano-Sancho, G., Sloth, J., Kwadijk, C., Barcelo, D., Allegaert, W., Marques, A., Robbens, J.,2015. Emerging environmental contaminants in seafood: a review. Environ Res. Submitted.

Table 1. List of chemical compounds included in the pilot study.

Group	Name	Abbreviations
Polycyclic aromatic hydrocarbons (PAHs)	Naphthalene	NPTH
	Acenaphthylene	ANTL
	Acenaphthene	ANA
	Fluorene	FL
	Phenanthrene	PH
	Anthracene	ANTH
	Fluoranthene	FLAN
	Pyrene	PY
	Benzo[a]anthracene	B[a]ANTH
	Chrysene	CH
	Benzo[b]fluoranthene	B[b]FLAN
	Benzo[k]fluoranthene	B[k]FLAN
	Benzo[a]pyrene	B[a]FLAN
	Dibenzo[a,h]anthracene	D[a,h]AN
	Benzo[g,h,i]perylene	B[ghi]PERY
	Indeno[1,2,3-cd]pyrene	I[123cd]PY
Polychlorinated biphenyl (PCBs)	PCB #28	PCB28
	PCB #52	PCB52
	PCB #77	PCB77
	PCB #81	PCB81
	PCB #101	PCB101
	PCB #105	PCB105
	PCB #114	PCB114
	PCB #118	PCB118
	PCB #123	PCB123
	PCB #126	PCB126
	PCB #138	PCB138
	PCB #153	PCB153
	PCB #156	PCB156
	PCB #157	PCB157
	PCB #167	PCB167
	PCB #169	PCB169
	PCB #180	PCB180
	PCB #189	PCB189
Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs)	2,3,7,8-TCDD	2378TCDD
	1,2,3,7,8-PeCDD	12378PeCDD
	1,2,3,4,7,8-HxCDD	123478HxCDD
	1,2,3,6,7,8-HxCDD	123678HxCDD
	1,2,3,7,8,9-HxCDD	123789HxCDD
	1,2,3,4,6,7,8-HpCDD	1234678HpCDD
	OCDD	OCDD
	2,3,7,8-TCDF	2378TCDF
	1,2,3,7,8-PeCDF	12378PeCDF

	2,3,4,7,8-PeCDF	23478PeCDF
	1,2,3,4,7,8-HxCDF	123478HxCDF
	1,2,3,6,7,8-HxCDF	123678HxCDF
	1,2,3,7,8,9-HxCDF	123789HxCDF
	2,3,4,6,7,8-HxCDF	234678HxCDF
	1,2,3,4,6,7,8-HpCDF	1234678HpCDF
	1,2,3,4,7,8,9-HpCDF	1234789HpCDF
	OCDF	OCDF
Polybrominateddiphenyl ethers (PBDEs)	Penta-BDE #99	BDE99
	Penta-BDE #100	BDE100
	Hexa-BDE #153	BDE153
	Hexa-BDE #154	BDE154
	Hepta-BDE #183	BDE184
Polychlorinated naphthalenes (PCNs)	TetraCN	TetraCN
	PentaCN	PentaCN
	HexaCN	HexaCN
	HeptaCN	HeptaCN
	OctaCN	OctaCN
Toxic elements (TE)	Arsenic	As
	Inorganic Arsenic	InAs
	Total mercury	Hg
	Methylmercury	MeHg
	Cadmium	Cd
	Lead	Pb
Endocrine Disrupting Compounds (EDCs)	Bisphenol A (BPA)	BPA
	Nonylphenol	NP
	Nonylphenol Diethoxylate	NPDE
	Nonylphenol Monoethoxylate	NPE
	Octylphenol	OP
	Hexachlorobenzene	HCB

Table 2. Summary of mean concentrations of chemical groups in sardine, canned tuna, salmon and mussels expressed in wet weight.

Chemical	Units	Sardine	Canned Tuna	Salmon	Mussels
NPTH[a]	ng/kg	412.50	1005.00	400.00	392.50
ANTL[a]	ng/kg	82.50	202.50	80.00	260.00
ANA[a]	ng/kg	82.50	242.50	80.00	77.50
FL[a]	ng/kg	82.50	202.50	80.00	132.50
PH[a]	ng/kg	82.50	202.50	80.00	587.50
ANTH[a]	ng/kg	82.50	202.50	80.00	420.00
FLAN[a]	ng/kg	82.50	577.50	80.00	2900.00
PY[a]	ng/kg	82.50	762.50	80.00	3600.00
B[a]ANTH[a]	ng/kg	33.00	130.00	32.25	640.00
CH[a]	ng/kg	33.00	200.00	32.25	1495.00
B[b]FLAN[a]	ng/kg	33.00	111.50	32.25	1950.00
B[k]FLAN[a]	ng/kg	33.00	81.50	32.25	695.00
B[a]FLAN[a]	ng/kg	53.25	81.50	32.25	335.00
D[a,h]AN[a]	ng/kg	33.00	81.50	32.25	71.00
B[ghi]PERY[a]	ng/kg	76.75	81.50	32.25	510.00
I[123cd]PY[a]	ng/kg	33.00	81.50	32.25	270.00
PCB28[b]	ng/kg	215.00	29.50	265.00	43.00
PCB52 [b]	ng/kg	445.00	31.50	430.00	61.50
PCB77 [b]	ng/kg	28.00	1.10	9.20	4.90
PCB81 [b]	ng/kg	1.00	0.10	0.60	0.30
PCB101 [b]	ng/kg	475.00	71.50	765.00	260.00
PCB105 [b]	ng/kg	435.00	15.50	200.00	41.00
PCB114 [b]	ng/kg	34.50	1.30	13.00	3.00
PCB118 [b]	ng/kg	1750.00	57.50	615.00	160.00
PCB123 [b]	ng/kg	37.50	1.10	9.10	8.00
PCB126 [b]	ng/kg	16.00	0.50	3.30	1.30
PCB138 [b]	ng/kg	5900.00	120.00	990.00	630.00
PCB153 [b]	ng/kg	10100.00	200.00	1550.00	1350.00
PCB156 [b]	ng/kg	355.00	7.30	59.50	23.00
PCB157 [b]	ng/kg	75.00	1.70	17.50	5.00
PCB167 [b]	ng/kg	230.00	5.70	38.00	22.50
PCB169 [b]	ng/kg	2.20	0.20	0.60	0.20
PCB180 [b]	ng/kg	4850.00	90.00	435.00	87.00
PCB189 [b]	ng/kg	72.50	1.00	6.60	3.90
2378TCDD [c]	ng WHO/TEQ kg	0.03	0.00	0.02	0.01
12378PeCDD [c]	ng WHO/TEQ kg	0.07	0.00	0.03	0.02
123478HxCDD [c]	ng WHO/TEQ kg	0.02	0.00	0.01	0.01
123678HxCDD [c]	ng WHO/TEQ kg	0.03	0.00	0.01	0.03
123789HxCDD [c]	ng WHO/TEQ kg	0.01	0.00	0.00	0.01

1234678HpCDD[c]	ng WHO/TEQ kg	0.08	0.01	0.02	0.15
OCDD[c]	ng WHO/TEQ kg	0.09	0.06	0.07	0.73
2378TCDF [c]	ng WHO/TEQ kg	0.39	0.01	0.33	0.17
12378PeCDF [c]	ng WHO/TEQ kg	0.11	0.01	0.05	0.03
23478PeCDF [c]	ng WHO/TEQ kg	0.27	0.01	0.08	0.05
123478HxCDF[c]	ng WHO/TEQ kg	0.23	0.00	0.01	0.01
123678HxCDF[c]	ng WHO/TEQ kg	0.02	0.01	0.01	0.01
123789HxCDF[c]	ng WHO/TEQ kg	0.00	0.00	0.00	0.00
234678HxCDF[c]	ng WHO/TEQ kg	0.03	0.00	0.01	0.01
1234678HpCDF[c]	ng WHO/TEQ kg	0.05	0.01	0.02	0.04
1234789HpCDF[c]	ng WHO/TEQ kg	0.00	0.00	0.01	0.01
OCDF[c]	ng WHO/TEQ kg	0.05	0.02	0.02	0.07
BDE99[d]	ng/kg	21.90	36.77	176.67	63.27
BDE100[d]	ng/kg	163.33	88.97	250.00	54.87
BDE153[d]	ng/kg	10.70	17.80	35.63	4.77
BDE154[d]	ng/kg	12.90	37.10	89.50	5.47
BDE184[d]	ng/kg	1.28	4.23	6.30	4.85
TetraCN[e]	ng/kg	7.70	6.10	62.80	14.90
PentaCN[e]	ng/kg	17.40	14.30	156.70	6.40
HexaCN[e]	ng/kg	3.70	3.20	7.00	0.30
HeptaCN[e]	ng/kg	0.40	0.30	0.40	0.20
OctaCN[e]	ng/kg	0.10	0.20	0.20	0.10
As[f]	µg/kg	3444.00	1282.80	2362.00	11065.40
InAs[f]	µg/kg	0.00	5.00	14.25	415.00
Hg[f]	µg/kg	37.00	377.30	94.58	29.08
MeHg[f]	µg/kg	5547.00	229.00	24.00	132.10
Cd[f]	µg/kg	9.50	7.25	10.00	186.00
Pb[f]	µg/kg	51.50	61.00	111.50	293.00
BPA[g]	µg/kg	0.00	16.24	0.00	0.00
NP[g]	µg/kg	0.00	347.50	0.00	96.00
NPDE[g]	µg/kg	0.00	25.90	0.00	20.65
NPE[g]	µg/kg	0.00	42.50	0.00	0.00
OP[g]	µg/kg	0.00	13.95	0.00	0.00
HCB[g]	µg/kg	0.37	0.14	2.04	0.02

[a](Martorell et al., 2010; Perello et al., 2009); [bc](Perello et al., 2012); [d](Perello et al., 2009); [e](Marti-Cid et al., 2008); [f](Lourenco et al., 2012; Perello et al., 2014); [g](Cunha et al., 2012; Ferrara et al., 2008; Ferrara et al., 2005; Perello et al., 2009; Podlipna and Cichna-Markl, 2007).

Table 3. Summary of the weekly mean seafood consumption frequency (g/week) by the adult sample population in five European countries.

	Belgium	**Ireland**	**Italy**	**Portugal**	**Spain**
N	540	575	560	588	561
Sardine	5.2	11.1	12.4	25.8	18.4
Canned Tuna	15.2	25.2	42.0	47.4	54.6
Salmon	18.6	30.1	17.1	31.4	20.5
Mussels	9.1	5.9	15.9	8.3	22.6