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STANDARD OPERATIONAL PROCEDURES FOR THE MONITORING OF MERCURY AND METHYLMERCURY IN FISH AND SHELLFISH

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GEF-funded project "Development of a Plan for Global Monitoring of Human Exposure to and Environmental Concentrations of Mercury".

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1 Introduction

1.1 Background

Mercury (Hg) and its compounds found in food pose a significant threat to human health. Particularly pregnant women, women of child bearing age and children are at risk of mercury exposure. In the ocean, inorganic mercury is transformed by micro-organisms to methylmercury (MeHg), which is accumulated by aquatic organisms over their lifetime and then passed up the aquatic food chain. Hence, predatory fish and mammals that are high up the food chain typically have the highest levels of mercury. The WHO and UNEP in the guidance "Development of a Plan for Global Monitoring of Human Exposure to and Environmental Concentrations of Mercury" defined fish and other marine species as one of the main source of exposure to mercury.

The Minamata Convention on Mercury was agreed in 2013 with the purpose of protecting human health and the environment from anthropogenic emissions and releases of mercury and its compounds. In its article 22 the Convention refer to effectiveness evaluation and to the necessary monitoring to observe trends for mercury concentration in the environment.

In 2015 UNEP and the WHO started implementing the GEF-funded project "Development of a Plan for Global Monitoring of Human Exposure to and Environmental Concentrations of Mercury". The list of the project outcomes include standard operating procedures for monitoring of mercury contamination of fish and shellfish in addition to human mercury biomonitoring in order to provide instruments for identification of mercury sources for humans at national level as well as potentially highly exposed population groups.

The current SOP relates to the monitoring of mercury level in fish and shellfish.

1.2 Aim of the SOP

The SOP is specifically focused on a monitoring plan to estimate the reduction of mercury and methylmercury level in fish and shellfish and to identify potentially highly-exposed population groups. It is assumed that the monitoring will be able to detect a 10% change of mercury concentration in fish over a 15-year period. It should be mentionned that the recommendations for sampling are based on available international data. Further refinements of the sampling plan may be accomplished by national authorities based on more accurate statistics regarding fish consumption and mercury occurrence in fish available from national market. Such refinement is likely to reduce the variability of fish consumption and fish contamination by mercury and to lead to decrease the number of samples needed.

1.3 Source of data

The main issue is related to the availability of data for UNEP/WHO in order to identify regions with the highest fish consumption, the most consumed fish species and fish with the highest mercury concentration.

There is no database recording the food/fish consumption worldwide at individual level. Consequently we used FAOSTAT that contains statistics of the world apparent consumption of fish and fishery product. The total fish available for apparent human consumption is derived by using the equation: total food supply equals production less reduction to meal and other non-food uses, plus imports, less exports and re-exports, plus or less variation in stocks. In 2011, global per capita consumption of fish was estimated at 18.9 kg. Behind this average, it exists significant differences between countries. The regions with the highest fish consumption are Oceania and particularly Micronesia (71 kg/per capita/year), Eastern Asia (34 kg/per capita/year) and Southern Europe (28 kg/per capita/year). This calculation is only available for 8 broad fish and shellfish groups and not by species. There are important variations between regions: demersal and pelagic fishes are more consumed in Oceania and Europe, while freshwater fishes are more consumed in Asia. The diversity of fish within these broad groups is considerable.

Regarding mercury contamination of fish, the available source of data is the GEMSFood WHO database. It contains more than 33 000 data on mercury concentration from 23 countries. The analysis of the data shows a substantial variability between fish groups, fish species and within the same species. The highest mercury contamination level are found in demersal fishes (mean 186 µg/kg; SD 388) and especially in sharks and rays. It is important to note that these last species are highly contaminated but represent a small part of the fish market. On their side, cods and haddocks have also a high level of contamination (even though, smaller than sharks and rays) but represent an important part of the demersal fish market. Pelagic fishes also present some high level of contamination (mean 122 µg/kg; SD 225) and specifically the tuna (mean 277 µg/kg; SD 334) which is also highly traded. Looking at more precisely the tuna, we observe an important variability of the level of contamination between countries and within the same countries. At the opposite, the inter-annual variability is for its part, quite low. These data are really useful to compare the mercury contamination of fish. Nevertheless, there is a limitation due to the regional scope as the database contains predominately European data (over 23 countries, 19 are Europeans countries).

Globally the analysis of available data shows that there is significant variability of both fish consumption and mercury contamination of fish.

2 Selection of samples

The review of certain existing mercury monitoring (Annex 1) shows the high heterogeneity of monitoring regarding their main objectives, type of data, level of details, selected species, number of samples and frequency of testing. Moreover, the analysis of available international data shows that there is significant variability of both fish consumption and mercury contamination of fish (Annex 2). The following considerations, based on these data, need to be taken into account when selecting the samples.

2.1 Criteria for selecting fish

2.1.1 General Criteria

The fish species need to be abundant, commonly captured and likely to be consumed and not endangered or threatened.

2.1.2 Species with the highest concentrations of mercury and frequently consumed

The selected fish species should combine high level of mercury concentration and be frequently consumed.

UNEP/WHO (2008) report shows that levels of methylmercury vary widely among different fish species and between the same species from different geographical areas. Predatory fish are more likely to contain higher levels of methylmercury in their muscles and other tissues. Other factors that influence mercury levels in the fish include age (indicated by girth, weight, or length), and characteristics of the water body (such as local contamination, pH, reduction-oxidation potential, and other factors). Because mercury biomagnifies in the aquatic food web, fish higher on the food web (or of higher trophic level) tend to have higher levels of mercury. Hence, apical predators, such as king mackerel, pike, shark, swordfish, walleye, barracuda, large tuna, scabbard, and marlin, as well as some marine mammals, such as seals and toothed whales, contain the highest concentrations.

In average, the most contaminated group is ‘marine fish’ including ‘other’ fish and mammals (454.5 µg/kg). Pelagic fish and demersal fish are then the most contaminated (respectively 122.6 and 86.7 µg/kg). The contamination of crustaceans, molluscs and cephalopods is the lowest (in average under 50 µg/kg) (table 1).

Table 1. Mercury contamination by fish groups (µg/kg)

	min	Q1	Median	Mean	Q3	Max	NA's	SD
Freshwater Fish	0	24	40	80.0	90	1880	13	115.8
Demersal Fish	0	18	52	86.7	110	1000	1	110.8
Pelagic fish	0	22	41	122.6	120	3370	18	225.2
Marine Fish, Other	0	110	200	454.5	450	9300	1	731.6
Crustaceans	0	10	20	49.4	53	1040	22	84.9
Molluscs, Other	0	0	15	24.2	30	750	3	41.4
Cephalopods	0	5	10	34.2	40	463.1		58.4
Unindentified	0	50	114	244.2	290	6890	112	386.6

NA: not available

Source: GEMSFood WHO database

It should be noted that the variability is significant for each fish groups. When looking the species within fish groups, we also see an important variability for each species.

In order to reduce the variability, a limited number of species by region should be monitored. Mercury concentration should be measured over a wide range of sizes (within the range consumed by the population) to eliminate the bias associated with differences in fish size among the samples collected.

The identification and selection of fish is complicated by the exposure pathway at both local and global scales. The majority of people consume fish from commercial market fish which combine locally harvested and imported fishes.

2.1.3 Fish considered as good bio-indicators of the levels of local mercury contamination

Alternatively some national monitoring may include some additional fish species if they are considered as good bio-indicators of the overall levels of mercury in the fish resource. It may be a less costly way to determine trends in mercury levels. UNEP/WHO (2008) highlights different examples like black piranhas (Serrasalmus rhombeus) living in the Amazon are an ideal bio-indicator because 80 % of their diet is fish based, their diet does not change seasonally, they do not make long migrations, and they mainly live in quiet waters. Elsewhere, other species, such as the Eurasian perch (Europe and Northern Asia), the walleye and the yellow perch (North America) also fit this description. These species might be of greater significance in the context of the use of surrogate data, again providing that compared species originate from similar environments.

2.2 Fish production vs fish consumption

The main issues of the monitoring is the non-availability of fish species consumption data for some countries and the variability of mercury contamination of the available data. Moreover, the fish market is globalized and the fish consumed may have very different origins and thus different concentration levels.

We suggest to implement the monitoring based on fish production and when possible at the regional level. This would enable better homogeneous data, lower data variability and a better control of the species analyzed than a monitoring based on fish consumption within a country (as the origin of fish are numerous).

Nevertheless, if a country decides to implement the monitoring based on fish consumption, the origin should be identified and collected.

2.3 Information to be collected

In order to homogenize data from different countries, it is necessary to collect the same information. It enables to compare data but also to reduce variability by pooling data in a more appropriate way. The information to be collected are the following:

- Mercury concentration (µg/kg)
- Limits of quantification (LODs, LOQs)
- Species (scientific name, common english name, fish group)
- Weight (kg), Lenght (cm)
- Technology used (e.g. Cold vapour generation atomic absorption spectrometry)
- Fish portion : edible / total fish

- Place of capture
- Date of capture
- Hot spot for mercury occurrence yes/no.

3 Number of samples to be collected and analyzed

The proposed number of samples is based on a statistical analysis performed on international available data (Annex 2).
We estimated the number of samples needed in order to observe a 10% variation of mercury contamination that gives 80% power and 95% confidence. The main issue in the current data is the intra-specie variability but also the intra and inter-countries variability. In order to discuss the results, we also estimated the number of samples to detect a 5% and 15% change for the different fish groups (table 2).
For the group of demersal fish, about 5100 samples would be necessary to observe a 10% change between two dates and about 4350 for the pelagic fish.

Table 2. Estimates of the number of samples for detection of a 5, 10, 15% change in mercury contamination

	Mercury contamination (µg/kg)		*n samples for detection of a 5, 10, 15 % change in the mean*		
	mean	SD	**5%**	**10%**	**25%**
Demersal Fish	186.1	388.4	22982	**5157**	843
Pelagic fish	122.6	225.2	17389	**4348**	652
Freshwater Fish	80.0	115.8	10400	2600	417
Crustaceans	49.4	84.9	22335	3574	621
Cephalopods	34.2	58.4	10400	4622	514
Molluscs, Other	24.2	41.4	20786	5197	578
Generic	244.2	386.6	12861	3216	498
Marine Fish, Other	2240.0	3964.0	15490	3873	620

The number of samples might be minimized by reducing the variability. For example, if we estimate the number of samples needed to observe a 10% change (that gives 80% power and 95% confidence) for mean at 100 (close to the pelagic fish) and a standard deviation at 100 (about half of the SD for pelagic fish), the number of needed sample is then 1237 (table 3).

Table 3. Estimates of the number of samples for detection of change in mercury contamination depending of SD

		n samples for detection of a 5, 10, 15 % change in the mean		
Mean	SD	**5%**	**10%**	**25%**
100	100	4947	**1237**	199

200	19785	4947	792

The existence of a more homogeneous national monitoring plan for mercury in fish should allow to calculate a lower number of samples adequate to observe a decrease in mercury concentration. In any case, the impact on the statistical power of the survey to detect differences between time periods should be carefully considered.

4 Quantification of mercury

In fish, the ratio between methyl mercury (MeHg) and total mercury ranges from 64% to 96% (Clemens et al., 2011). MeHg proportion also could be dependent on the fish species (Kuballa et al., 2011; Forsyth et al., 2004). Due to both technical and financial constrains most of the countries are quantifying total mercury in fish. Moreover due to the lack of sufficient international data on MeHg in fish, the statistical analysis in the current document was based on the distribution of total mercury.

4.1 Collection of samples

As it is mentioned in sections above, in order to observe a decrease in mercury concentration over time, the sampling plan should aim to collect individual samples for a single fish species captured in a considered fishing area. Analyzing pooled samples could be envisaged in order to reduce the analytical costs: this option would not allow the estimation of the variability between samples and would not permit a correct comparison of the trend with the background contamination.

Depending of the analytical method used, each laboratory should specify the quantity needed for the analysis, which is usually between 50 and 500 g of fresh weight. The minimum weight needed of each food can be estimated by considering that only the edible part will be analysed. Consideration should also be given to including one or more extra sub-samples to be stored for future testing should this be relevant.

4.2 Preparation of samples

The basic requirement is to obtain a representative and homogeneous laboratory sample without introducing secondary contamination. The fish samples should be mixed, ground and remixed to obtain homogeneous fish samples. The samples should be composed only of the comestible parts of the products. More precisely, fish should be filleted and skinned.

After preparation, samples should be stored at -20°C in suitable containers until the time of analysis.

4.3 Transporting and storage of samples

Each sample should be placed in a clean, inert container offering adequate protection from contamination, from loss of analytes by absorption to the internal wall of the container and against damage in transit. All necessary precautions should be taken to avoid any change in composition of the sample which might arise during transportation or storage.

Storage conditions (e.g. time, humidity and temperature) should be set related to the chemical substances to be analyzed. For mercury the storage temperature should be maintained at -20°C, throughout the transportation of the samples to the analytical laboratories in order to not modify the content of trace elements. Frozen samples should be delivered to the laboratory in a frozen condition.

4.4 Analysis of individual samples (Mg vs MeHg, LOD/LOQ, quality insurance)

Ideally the selected laboratory should be located in the country but emphasis should be on analytical proficiency as demonstrated by adequate quality assurance procedure and confirmed by successful participation in inter-laboratory studies. Wherever possible the trueness of analysis shall be estimated by including suitable certified reference materials in the analysis.

Wherever possible, apparatus and equipment coming into contact with the sample shall not contain those metals to be determined and be made of inert materials e.g. plastics such as polypropylene, polytetrafluoroethylene (PTFE) etc. These should be acid cleaned to minimize the risk of contamination. There are many satisfactory specific sample preparation procedures which may be used. Those described in the CEN Standard 'Foodstuffs — Determination of trace elements — Performance criteria, general considerations and sample preparation' have been found to be satisfactory but others may be equally valid.

Many laboratories analyzing mercury in fish are involved in testing regulatory compliance for which the analytical methods only requires sufficient precision to meet the prescribed maximum limits set in the legislation. In practice, for the purpose of mercury monitoring, detection/quantification limits (LODs and LOQs) of the analytical methods should be sufficiently sensitive for detecting background levels of mercury in fish which might typically be more than hundred times lower than the Maximum Level (ML) of 0.5 to 1 mg/kg.

5 Time frame

From the data analysis, there is no strong evidence to support a specific time frame. The inter-annual variability is low: in the available data, we don't see any difference between two consecutive years but we can see some small trends between 1 and 5 years.

Moreover, the current available data are not robust enough to observe the past trends of mercury emissions to air (emissions have increased in Asia and decreased in Europe) and cannot be used to predict a future trend and an appropriate time frame.

Finally, we cannot predict a linear reduction of mercury concentration for the next 10 years.

The time frame should be based on cost and feasibility considerations. The usual time frame for such a monitoring is 4 or 5 years.

6 Countries with “hot spots” of anthropogenic mercury emission

In order to be an indicator of the effectiveness of the Minamata Convention, the countries with known “hot spots” because of their source of anthropogenic emission (Annex 3) may reinforced the monitoring in their fish production areas. In such case the sampling plan should be designed to fit with the mercury concentration in fish from the area under consideration.

7 Limits of the assessment of the effectiveness of the Minamata Convention through the fish mercury monitoring

7.1 Improvement of the monitoring plan

In order to adjust the hypothetical expected 10% change (and the time frame), there is a need for estimates of the expected reduction emissions (globally and for the main contributors sectors) in the next 10-15 years and also models on the relation between mercury emission in air and mercury concentration in fish.

In order to improve the accuracy of the monitoring plan (fish species selection, number of specimen and time frame), more data are necessary from other regions than Europe, from existing mercury monitoring (USA, Canada, New Zealand, Baltic Areas, etc.) and from punctual regional/local study.

We suggest to gather more data from existing mercury monitoring from others regions than Europe and to expand the GEMSFood database so as to overcome the limitations due to the regional scope of the set of data. Data should ideally be on the same format (species name, mercury unit, no summary data, year of collection, location).

7.2 The effects of reduction in emissions will take time to become apparent

As highlighted in the Global Mercury Assessment (UNEP, 2013), anthropogenic emissions and releases over time have increased mercury loads in the environment, so the effects of reductions in emissions will often take time to become apparent.
Considering the mercury already stored and recycled, the report notes that “One consequence is that there will likely be a time-lag of years or decades, depending on the part of the water column, before emissions reductions begin to have a demonstrable effect on mercury levels throughout the environment and in the fish and marine mammals which are part of the human food-chain”.

7.3 Major sources of uncertainty

7.3.1 Fish consumption and mercury contamination data

We showed that both fish consumption data and mercury contamination data have some issues related to their availability, heterogeneity and regional scopes increasing their variability.

7.3.2 Potential effect of climate change

Global climate changes may also complicate the response of global ecosystems to mercury emission reductions, through its profound effects on many aspects of the movement and chemical transformation of mercury in the environment. For example, warmer temperatures may increase rates of organic productivity in freshwater and marine ecosystems, and rates of bacterial activity, possibly leading to faster conversion of inorganic mercury to methylmercury. Thawing of the enormous areas of northern frozen peatlands may release globally significant amounts of long-stored mercury and organic matter into Arctic lakes, rivers and ocean (UNEP, 2013).

7.3.3 Attribution of the source based on atmospheric concentrations

The mercury heath impacts are not directly related to the atmosphere burden but from localized exposure or from bioaccumulation in the food chain. On the other hand, observed environmental concentrations and human exposures result from a combination of natural and anthropogenic emissions, transported through different regional and global cycles, and including extensive recycling of mercury at the air water/terrestrial interface. These factors make attribution of the source based on atmospheric concentrations significantly more difficult than for other pollutants (UNECE, 2010)

7.3.4 Importance of large scale oceanographic currents

Global changes in open ocean mercury concentrations can be attributed to intercontinental mercury transport as part of the global pool and localized deposition of mercury plumes from large source regions such as northeastern Asia. In addition to atmospheric transport, large-scale oceanic transport can also be responsible for long-range transport of mercury from the original emissions source and likely impact marine fish concentrations globally. Additional research is needed on the importance of large scale oceanographic currents for redistributing mercury deposited in nearshore regions from concentrated source regions and coastal pollution sources (UNECE, 2010).

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9 Annexes

9.1 Annex 1. Existing monitoring programmes for mercury in fish and shellfish

Some countries have national mercury monitoring implemented in the framework of the Stockholm convention (comprising POPs and mercury monitoring) or implemented for other purposes. We will review some of them.

9.1.1 Existing monitoring programmes on POPs and mercury under the Stockholm Convention: example of the Northern Contaminants Programme (NCP)

Certain monitoring implemented under the Stockholm convention and primarily assessing POPs also include monitoring related to mercury. They might contribute to assess how the environment will respond to global actions to reduce mercury emissions under the new Minamata Convention. The Northern Contaminants Program (NCP) is an example.

The Northern Contaminants Program (NCP) was established in 1991 in response to concerns about human exposure to elevated levels of contaminants in wildlife species that are important to the traditional diets of northern Aboriginal peoples. Contaminants of concern to the NCP include POPs, mercury, and other “new” chemicals for which there is a reasonable probability of Arctic contamination resulting from long-range atmospheric and oceanic transport. It is led by Aboriginal Affairs and Northern Development Canada, and is Canada’s National Implementation Plan for the Arctic Monitoring and Assessment Programme (AMAP).

9.1.1.1 Objectives of the programme

The contaminant burdens in animals that are exposed through aquatic foodwebs can be affected by system changes in foodwebs, ice cover, ocean exchange and many other ocean climate variables. Accordingly, the research program has several objectives:

- Collect a set of baseline data for contaminants in Arctic seawater against which future trends, sources and sinks in the ocean may be evaluated.
- Collect the data in a way that will assist in modelling exchanges between water and the lower food web.

9.1.1.2 Species annually monitored for POPs and mercury

Ringed seal

Ringed seal, a widely distributed species found throughout the circumpolar Arctic, is an important traditional/country food species for Inuit. Ringed seals will be sampled annually under this program with the help of hunters from the communities of Sachs Harbour, Resolute, Arviat and Nain. These four locations represent very different regions in the Canadian Arctic that are experiencing varying degrees of climate change and contaminant input.

Beluga whales

Beluga whales are an important traditional/country food species for many Arctic communities. Samples of beluga have been collected from places such as the Mackenzie Delta, Hudson Bay and Pangnirtung at various times over the past twenty-five years and analyzed for contaminants. The existing temporal dataset for this species will be augmented with annual sampling at Hendrickson Island in the Mackenzie Delta, Cumberland Sound and Hudson Bay by hunters from Tuktoyaktuk, Pangirtung, and Sanikiluaq. This monitoring plan will allow researchers to compare beluga from the western and eastern Arctic as well as Hudson Bay. These areas have regional differences with respect to the impacts of climate change and contaminant inputs.

Polar bear

Polar bears are the top predators in the Arctic marine food chain and have the highest concentration of some contaminants found in the Arctic. Polar bear meat is consumed by Inuit and the animal has special sociocultural and economic importance (through commercial hunts) to Inuit communities. As with other species, polar bear have been sampled periodically in the past and analyzed for contaminants. The most extensive temporal dataset for contaminants in polar bear has been collected for Hudson Bay, which is also Canada's most southerly Arctic sea and is expected to undergo the most rapid climate change. Recent results from ongoing monitoring of polar bear in Hudson Bay suggest that the dietary habits of polar bear may already be changing as a result of climate change.

Seabird eggs

The eggs of seabirds have been used for long-term monitoring of contaminants since the 1970s. The Arctic is an important breeding ground for a large number of seabirds that nest on the rocky shores and cliffs of Arctic islands. During the nesting season seabird eggs are a popular food item for Inuit, for whom collecting and consuming eggs is an important spring tradition and source of nutrition. Eggs are ideal for monitoring because they are relatively easy to collect and do not involve killing an adult bird. Seabird eggs are also collected as part of monitoring programs in other Arctic countries, allowing for international comparisons. The two colonies selected for monitoring are located in the High Arctic: Prince Leopold Island and, further south in the mouth of Hudson Bay, Coats Island. These two sites provide opportunities to examine changes over time in two different ecosystems undergoing varying degrees of change. This program samples eggs for three additional species (black-legged kittiwake, black guillemot, glaucous gull) every five years, and adult birds of four species (thick-billed murre, northern fulmar, black-legged kittiwake, black guillemot) every ten years.

Sea-run arctic char

This type of Arctic char is widely distributed throughout the Arctic and is one of the most important traditional/country food species for Arctic people. Char represent a widely available and highly nutritious source of food and is promoted by public health authorities. Char is promoted because contaminant levels are thought to be relatively low in char compared with other traditional/country foods, and it is an excellent source of protein, polyunsaturated fatty acids and other micronutrients. Sea-run char have been collected from communities across the Canadian Arctic and the results confirm that contaminant levels are quite low, particularly in comparison with marine mammals. One location in the central/western Arctic (Cambridge Bay), has been selected for continued annual monitoring to ensure that contaminant levels remain low.

Land-locked arctic char

This species of char is also widely distributed in Arctic lakes and rivers. The NCP has been monitoring land-locked char in High Arctic lakes around the community of Resolute and on Ellesmere Island for the past twenty years and has built strong temporal datasets on contaminant levels. The lakes receive contaminants from the atmosphere and, therefore, are good indicators of changing atmospheric inputs of contaminants. High Arctic lakes are also undergoing significant changes related to climate change which could also influence contaminant levels in the fish.

Lake trout and burbot

Lake trout and, to a lesser extent, burbot are also important traditional/country food species for many northern communities and like char both are excellent sources of nutrition. Lake trout and burbot can, however, contain fairly high levels of mercury, especially older fish, which can be a significant source of mercury to people who consume it frequently. As with all of the species in the temporal trends program, trout and burbot have been monitored for over twenty years in Yukon and the NWT and represent valuable temporal trend datasets. The program will continue to monitor lake trout and burbot annually in the important fishery of Great Slave Lake; burbot caught in the Mackenzie River near Fort Good Hope; and lake trout in Lake Laberge and Kusawa Lake in Yukon.

Caribou

Caribou were selected for temporal trends monitoring because of their importance as a traditional/country food and because there is good historical information on contaminant levels in some herds. Contaminant levels in caribou, however, are among the lowest of any traditional/country food species, and the monitoring program has verified this over the past five years by sampling and analyzing several herds across the Arctic for heavy metals.

9.1.2 Existing monitoring programmes for mercury in fish and shellfish

9.1.2.1 Canada: Freshwater Inventory and Surveillance of Mercury (FISHg) Network

Freshwater Inventory and Surveillance of Mercury (FISHg) Network is a national aquatic mercury monitoring network that was established in 2008 as part of the Mercury Science Program of the Clean Air Regulatory Agenda (CARA). The network encompasses lakes across Canada that are in proximity to point-source mercury emissions, as well as reference lakes in remote regions.

9.1.2.2 Canada: Great Lakes Surveillance Programme

Great Lakes Surveillance Program is delivered as part of Canada’s commitment to the Canada–United States Great Lakes Water Quality Agreement. Environment Canada maintains water-quality monitoring stations within each of the four Canadian Great Lakes, along with several additional stations within basin watersheds. The monitoring stations provide long-term data on regionally representative concentrations of toxic substances, including PAHs, current-use and banned organochlorine pesticides, congener-specific PCBs, mercury, and trace elements. The Great Lakes

Surveillance Program, lead by scientists at the Ontario office of Water Quality Monitoring and Surveillance, has monitored water quality in the Great Lakes for over 40 years. The program provides some of the most comprehensive, systematic and detailed information that is available in the world for large lakes.

Approximately 100 stations are monitored on Lake Ontario, 55 stations on Lake Erie, 68 stations on Lake Huron, and 26 stations on Georgian Bay. Approximately 73 stations were historically monitored on Lake Superior, but this has been reduced since the mid-1990s and currently approximately 50 stations are monitored. All regions of the lakes are monitored, including U.S. waters.

9.1.2.3 Baltic region: COMBINE programme

HELCOM (Baltic Marine Environment Protection Commission - Helsinki Commission) is the governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area, known as the Helsinki Convention. The Contracting parties are Denmark, Estonia, the European Union, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. HELCOM was established about four decades ago to protect the marine environment of the Baltic Sea from all sources of pollution through intergovernmental cooperation.

Objectives of the COMBINE Programme

The Cooperative Monitoring in the Baltic Marine Environment - COMBINE - was instituted in 1992 in order to integrate all the different programmes into a common structure. This Manual defines the contributions made by all Contracting Parties and regulates all methods used.

The aims of COMBINE, as decided by HELCOM are:

- To identify and quantify the effects of anthropogenic discharges/activities in the Baltic Sea, in the context of the natural variations in the system
- To identify and quantify the changes in the environment as a result of regulatory actions.

In this framework, the actions related to the levels of contaminants are:

- To compare the level of contaminants in selected species of biota (including different parts of their tissues) from different geographical regions of the Baltic Sea in order to detect possible contamination patterns, including areas of special concern (or ´hot spots´).
- To measure levels of contaminants in selected species of biota at specific locations over time in order to detect whether levels are changing in response to the changes in inputs of contaminants to the Baltic Sea.
- To measure levels of contaminants in selected species of biota at different locations within the Baltic Sea, particularly in areas of special concern, in order to assess whether the levels pose a threat to these species and/or to higher trophic levels, including marine mammals and seabirds.

Specific Information on measures of mercury concentration from the Environmental monitoring of mercury in Estonian fishes

The Environmental monitoring of mercury in Estonian fishes based on the National Environmental Monitoring Programme (NEMP) used the HELCOM-COMBINE methodology[1].

The mercury concentrations are measured in Baltic herring (Clupea harengus membras) in open sea areas and in pearch (Perca fluviatilis) in coastal waters[2].

Mercury concentrations are measured in fish muscles (skinless fillet) and liver.

Baltic herring samples are collected annually from 3 open sea areas – eastern and western part of the Finnish Gulf and from the Riga Bay. In coastal water bodies a 6-years rotation is used in perch monitoring. Annually 3-4 coastal water bodies are monitored with respect to hazardous substances, including mercury. Perch samples are collected from all coastal water bodies, ie all 16 water bodies are covered at least once per 6 years with Hg monitoring. Perch samples are collected in July-September and herring samples in September-October from fishery catches. All biological characteristics of captured individuals (length, weight, age, sex, gonad stage) are measured. Muscle and liver samples for chemical analyses are composed from 2-3 years old female-herrings (at least from 20 fishes) and from female-perches with a length of 15-20 cm.

9.1.2.4 New Zealand: Heavy Metal Monitoring Programme

The NZFSA runs a 'Heavy Metal Monitoring Programme'. Each year, selected species from New Zealand's Exclusive Economic Zone are targeted to build a set of representative data for all commercially and recreationally important species. Each year a number of fish species are checked, and normally 60 samples of each species are taken for analysis. Data is held on approximately 85 species – mainly marine finfish, but some shellfish, crustaceans and freshwater fish are also included. Information collected includes species, area of catch, data on the individual fish (e.g. length, weight and sometimes age) and mercury, cadmium and lead levels. Data from the programme provides information for public health initiatives in New Zealand, and is used as a basis for official assurances to accompany fish exports.

9.1.2.5 European Monitoring and Evaluation Programme (EMEP)

The European Monitoring and Evaluation Programme (EMEP) is a scientifically based and policy driven programme under the Convention on Long-range Transboundary Air Pollution (CLRTAP) for international co-operation to solve transboundary air pollution problems.

EMEP defined an indicator that describes the level and trends in European seas of concentrations of eight hazardous substances in marine biota, based on the individual assessment of monitoring for the following substances: Mercury (Hg) and its compounds, Cadmium (Cd) and its compounds, Lead (Pb) and its compounds, Hexachlorobenzene (HCB), Polychlorinated

[1] Information gathered by UNEP request to the governments : "existing country-specific or regional monitoring efforts relating to fish and marine mammal in the food supply", nov 2010

[2] i.e coastal water bodies according to the EU Water Framework Directive 2000/60/EU

biphenyl (PCB), Pesticide DDT, Pesticide Lindane, Polyaromatic hydrocarbon (PAH) Benzo(a)pyrene (BAP).

The indicator is based on data for substances measured in organisms from the regional seas as follows:

- Baltic Sea – Atlantic herring *(Clupea harengus)*
- North-East Atlantic Ocean – blue mussel *(Mytilus edulis)*, Atlantic cod *(Gadus morhua)*, flounder *(Platichtys flesus)*
- Mediterranean Sea – Mediterranean mussel *(Mytilus galloprovinicialis)*
- Black Sea - Mediterranean mussel *(Mytilus galloprovinicialis)*

The assessment based on results for 2003-2012 shows that concentrations of mercury in recent years were generally classified as Moderate in mussels and fish of the North-East Atlantic and the Baltic Sea, and mussels in the Mediterranean. There is a majority of upward trends in the North-East Atlantic.

9.1.3 Conclusion

This review of certain existing mercury monitoring is not exhaustive but already shows the high heterogeneity of the monitoring regarding main objectives, type of data, level of details, selected species, number of samples and frequency of testing.
In view of the objectives of the Minamata Convention, obtaining the analyses and results would gain in efficiency if the data from these various monitoring could be analyzed together or, in the future, standardized.

9.2 Annex 2. Identification of fish/shellfish to be considered as the main contributors to human exposure

Fish and shellfish may be considered as the main contributors to human exposure because of either their high concentration and/or their high consumption worldwide or within a country or region.

Young children and children of women who are exposed to methylmercury during pregnancy are among the populations most at risk of adverse neurodevelopmental effects from methylmercury exposures. Other high-risk groups include tribal populations and various ethnic minorities who consume much larger quantities of fish than the general population. Exposure can be significant in populations consuming meat (muscle and organs) from marine mammals, such as seals and whales. The kidney and liver of marine mammals in particular can have extremely high levels of mercury (UNEP/WHO, 2008).

The review in UNECE (2010) shows that Individual seafood consumption choices also play a large role in determining exposures and resulting risks. Fish consumption patterns differ across geographic regions and vary according to traditional diets, recreational activities, and proximity to supply of fresh seafood products. Individual variability in mercury exposures across populations reflects these differences as well as the types and origins of seafood products consumed.

We present and analyze the available data for WHO in order to identify the highest fish consumption and highest fish mercury contamination.

9.2.1 Data sources

9.2.1.1 FAO- Fishery and Aquaculture Statistics

There is no international database containing the global fish consumption by countries. The most updated and global data on fish production and market are in the FAO Fishery and Aquaculture Statistics[3]. It contains global statistics on capture fishery production, aquaculture production, commodities and apparent fish consumption derived from food balance sheets as well as statistics on fleets and employment of major producing countries. The last updated data is FAOstat yearbook, 2011.

We use the apparent fish consumption per capita as estimated by FAO.

Fish apparent consumption is available for huit “food groups”: Aquatic Animals, Others; Cephalopods; Crustaceans; Demersal Fish; Freshwater Fish; Marine Fish, Other; Molluscs, Other; Pelagic Fish. Data are available for 187 countries. We associated to each country its ISO2 code together with the region in 11 modalities ; Asia (ex. Near East); Baltics; C.W. of ind. States; Estern Europe; Latin Amer. & Carib; Near East; Northern Africa; Northern America; Oceania; Sub-saharan Africa; Western Europe.

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[3] ftp://ftp.fao.org/FI/CDrom/CD_yearbook_2012/index.htm

9.2.1.2 GEMS/Food database

The GEMS/Food databases[4] on chemicals in food and the total diet have a large number of records for mercury in food. Although data from every region and country are not currently available, much information has been collected through monitoring and surveillance activities.

We extracted data selecting all regions and as food category “fish and other sea food” and as contaminants, “mercury” and “methylmercury”. Initially there were 33745 lines in the dataset concerning either mercury or methylmercury. We converted all the units to ug/kg.

Because the data on methylmercury were few (1224 data), we excluded them with the following distribution across countries: Czech Republic (56), Hong Kong (76), Australia (98), Spain (206), Germany (788). Another approach would have been to keep them and apply a conversion factors (Claisse, 2001).

The collection extends from 1972 to 2014 (38 years have data in this 43 year period). The distribution of data is not homogenous over the period and the data are more numerous between 2006 and 2010 (Figure 1). New Zealand is the only country to report data prior to 1998 (78% of their total data are prior to 1998). After 2011, data are very few. In 2011, only three countries ‘Germany, Italy and Spain) reported data.

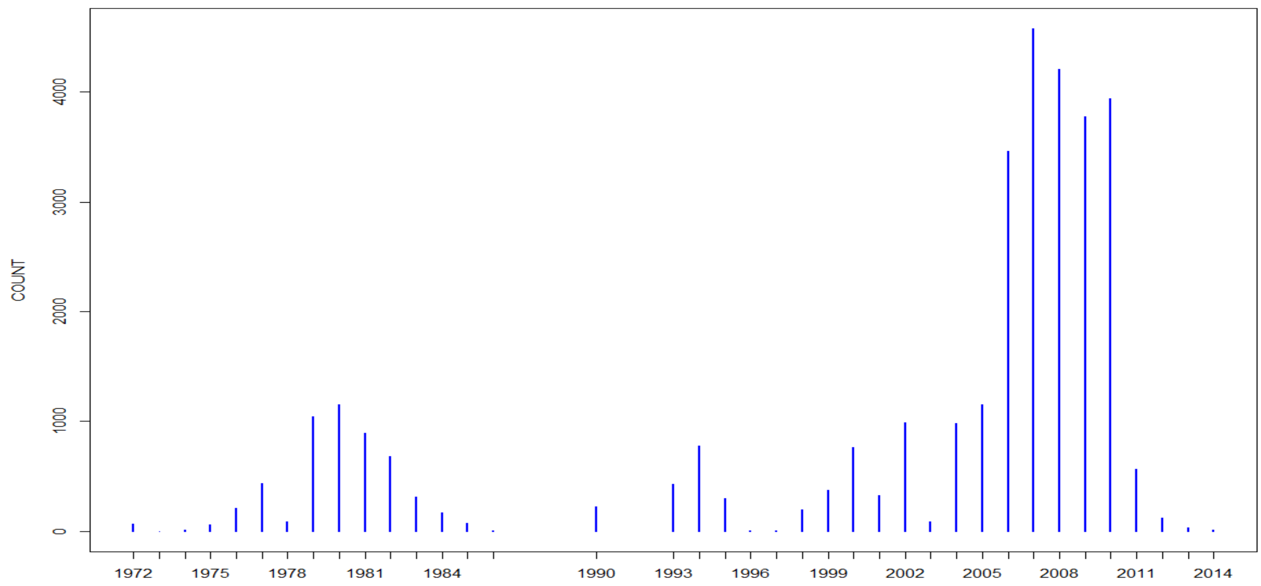
Data are collected from 23 countries but mainly in Europe: 2 countries in Asia (Hong Kong and Singapore), 2 in Ocenia (Australia and New Zealand) 19 in Europe. Data on mercury in fish are distributed between 34 food categories, some of which are fish species and other are broad categories as “Marine fishes” or “fishes”.

We matched the fish species (when mentioned) with the 8 FAO fish groups. Finally, some data are aggregated and sum up the analysis of several samples. Actually, one line of the database actually sums up the results of the analyses of 20 samples, in this case the mean, quantiles are given (87 lines concerned summarizing 793 samples).

Some data show censorship problem (3297/33745=9.6%) and will be excluded of the contamination level analysis (83 lines concerned).

[4] https://extranet.who.int/gemsfood/

Figure 1. Collected data on fish mercury contamination per year for all countries



9.2.2 Most consumed fish and shellfish

9.2.2.1 Overview of the market

Global total production of fish, crustaceans, molluscs and other aquatic animals has continued to increase and reached 158 million tonnes in 2012. Aquaculture production has continued to show strong growth, increasing at an average annual growth rate of 6.1 percent from 36.8 million tonnes in 2002 to 66.6 million tonnes in 2012.

China is the top-ranking fishing country in terms of quantity followed by Indonesia, the United States of America, India and Peru. Nineteen countries caught more than one million tonnes each in 2012, accounting for over 75 percent of global catches.

In 2012, about 73 percent of total fisheries imports in value were in developed countries, with the United States of America and Japan together accounting for 27 percent of the total. Imports by the European Union (Member Organization) represented a share of 36 percent of total world imports. However, if intraregional trade among its member countries is excluded, the share declines to 23 percent of world imports. This still makes the Union the largest market in the world.

China is by far the main exporting country, followed by Norway, Thailand and Vietnam. Developing countries play a major role in such exports, with the top ten exporters accounting for 77 percent of the developing country total by value. The share of developing countries in total fishery exports was about 54 percent by value and 60 percent by quantity (live weight equivalent) in 2012. The fishery net exports of developing countries (i.e. the total value of their exports less the total value of their imports) have shown a continuing rising trend in recent decades, growing from USD11.5 billion in 1992 to USD17.4 billion in 2002 and USD35.1 billion in 2012.

Shrimp continues to be the most important commodity traded in value terms, accounting for about 15 percent of the total value of internationally traded fish products in 2012. The other main groups of exported species were salmon and trouts with more than 14 percent, followed by groundfish (9 percent, e.g. hake, cod, haddock and Alaska pollock) and tuna (8 percent).

9.2.2.2 Derivation of apparent consumption

The total fish available for apparent human consumption is derived by using the following equation: total food supply equals production less reduction to meal and other non-food uses, plus imports, less exports and re-exports, plus or less variation in stocks. All calculations have been made in terms of live-weight equivalent. The estimate of the total supply available for human consumption divided by the population total.

Statistics of apparent consumption for fish and shellfish are divided into the following eight broad groups of species:

- Freshwater and Diadromous fish: including carps, barbels, tilapias, sturgeons, eels, salmons, trouts, shads, etc.
- Demersal fish: including flatfishes, cods, hakes, haddocks, redfishes, sharks, coastal demersal fish, etc.
- Pelagic fish: including anchovies, herrings, sardines, tunas, mackerels, etc.
- Marine fish, other: including unidentified marine fish.
- Crustaceans: including crabs, lobsters, shrimps, krill, etc.
- Molluscs excl. Cephalopods: including abalones, oysters, mussels, scallops, clams, etc.
- Cephalopods: including squids, cuttlefishes, octopuses, etc.
- Aquatic animals, others: including frogs, turtles, sea-cucumbers, sea-urchins, etc.

In 2011, global per capita consumption of fish was estimated at 18.9 kg. Obviously, there is a very important diversity of consumption worldwide expanding from 1.5 kg/per capita/year in Central Asia to 70.7 kg/per capita/year in Micronesia (Table 4). Moreover, disparity between fish species consumed is also significant. Figures 2 to 6 show the profile of the 6 regions in terms of type of groups of consumed fish.

In Africa (figure 1), the average consumption is 10.8 kg/per capita/year and the most important contribution comes from pelagic fish (3.7 kg/per capita/year), freshwater fish (3.6 kg/per capita/year) and demersal fish (2.3 kg/per capita/year). There is no consumption of molluscs, crustaceans and cephalopods.
In Americas (figure 3), the average consumption is 14.1 kg/per capita/year distributed between pelagic fish, crustaceans, demersal fish and freshwater fish with each a consumption equals to 3 kg/per capita/year.

Europe (figure 4) and Oceania (figure 6) have a different fish consumption profile in which pelagic fish and demersal fish represent the majority of the consumption, but in superior quantity in Oceania. In Europe, the average consumption is 21.9 kg/capita/year; demersal fish contribute to 6.7 kg/capita/year and pelagic fish to 5.8 kg/capita/year. In Oceania, the average consumption is 26.9; demersal fish contribute to 8.1 kg/capita/year and pelagic fish to 6.5 kg/capita/year.

In Asia (figure 5), the average consumption is 21.4 demersal fish contribute to 6.7 kg/capita/year and pelagic fish to 5.8 kg/capita/year and fresh water fish is the most consumed group (9 kg/capita/year) with an average of 0.8 kg/capita/year in Central Asia and 13.7 kg/capita/year in Eastern Asia, followed by the consumption of molluscs (3.2 kg/capita/year).

The figures show some very different profiles with some region with a well distributed consumption among the different fish group (e.g. Americas) and some regions with a highly specific consumption (e.g. Oceania). They also show an important variability within a same region due to the difference between countries in the same region.

Figures 7 to 14 show the consumption of each group of fish in regions with the distinction among the 23 sub-regions. Pelagic fish (figure 7) are really specific of the consumption in Oceania but with some important differences within the region. In Micronesia and Polynesia, consumption of pelagic fish is respectively 70.7 and 39.4 kg/capita/year while in Melanesia and Australia, the average consumption is respectively 25.3 and 24 kg/capita/year. These two last level of consumption are equivalent to the consumption in Nothern Europe (23.9 kg/capita/year) and is inferior to the consumption in Southern Europe (28.4 kg/capita/year).

Figure 8 shows that the demersal fish consumption is more important in Europe and Australia (the profile of Australia being closer to European countries than to the other sub-region of Oceania). Fresh water (figure 9) are clearly most consumed in Eastern and Southern Asia and (respectively 13.7 and 11.2 kg/capita/year) and not at all in the sub region of Oceania (except Australia with an average of 2 kg/capita/year). In Europe, this consumption is quite equivalent in all sub-regions (between 3.3. and 4.4 kg/capita/year). Molluscs (Figure 10), are very consumed in Eastern Asia (8.1 kg/capita/year), crustaceans (figure 11) are more consumed in Polynesia, Australia and Eastern Asia (respectively, 6.6, 4.3 and 3.8 kg/capita/year). Cephalopods (figure 12) is clearly very specific of the consumption in Southern Asia (3.1 kg/capita/year) and in a less extent Eastern Asia (1.3 kg/capita/year). The average consumption in all the other sub-regions is under 1 kg/capita/year. The consumption of aquatic animals (including frogs and turtles) is very low (figure 13) with the highest level in Eastern Asia (0.7 kg/capita/year). Marine fish (figure 14) are “others” and “unidentified fish”.

These figures show that fish groups are not consumed in an equivalent way in all sub-regions with important difference within regions and the plot boxes show important variability. Moreover, fish groups include very different fish species in term of consumption and methylmercury contamination.

9.2.2.3 Summary/Conclusion

There is no database recording the fish consumption worldwide. Consequently we used FAOSTAT that contains statistics of the world apparent consumption of fish and fishery product. The total fish available for apparent human consumption is derived by using the equation: total food supply equals production less reduction to meal and other non-food uses, plus imports, less exports and re-exports, plus or less variation in stocks. In 2011, global per capita consumption of fish was estimated at 18.9 kg. Behind this average, it exists significant differences between countries. The regions with the highest fish consumption are Oceania and particularly Micronesia (71 kg/per capita/year), Eastern Asia (34 kg/per capita/year) and Southern Europe (28 kg/per capita/year).

This calculation is only available for 8 broad fish and shellfish groups and not by species. There are important variations between regions: demersal and pelagic fishes are more consumed in Oceania and Europe, while freshwater fishes are more consumed in Asia. The diversity of fish within these broad groups is considerable and, therefore, the level of the data is insufficient for the purpose of the monitoring.

Table 4. Apparent consumption of fish (kg/per capita/per year)

Continent	Regions\Fish groups	Aquatic Animals, Others		Cephalopods		Crustaceans		Demersal Fish		Freshwater Fish		Marine Fish, Other		Molluscs, Other		Pelagic Fish		TOTAL	
Africa	Eastern Africa	0	**0**	0	**0**	0,1	**0**	0,1	**2,3**	3,7	**3,6**	0,7	**1**	0	**0**	0,2	**3,7**	**4,1**	**10,8**
	Middle Africa	0		0		0,2		2,9		3,7		2,1		0		5,9		**12,7**	
	Northern Africa	0		0,1		0,4		2,3		5,4		0,7		0		3,6		**11,8**	
	Southern Africa	0		0,1		0,3		1,3		0,2		0,1		0,3		3,4		**5,6**	
	Western Africa	0		0		0,1		4,7		3		1,3		0,1		6,9		**14,8**	
Americas	Northern America	0	**0**	0,3	**0,3**	6	**3**	4,3	**2,9**	4,3	**2,9**	0,1	**0,6**	3,4	**1,7**	3,4	**3**	**21,7**	**14,1**
	Central America	0,1		0,3		1,4		0,8		1,2		1,6		0,8		3,2		**7,8**	
	Caribbean	0		0		0,5		1,2		1,2		2,7		0,3		3,5		**6,7**	
	South America	0		0,3		0,7		2,7		2,6		0,5		0,7		2,6		**9,6**	
Asia	Central Asia	0	**0**	0	**0,6**	0	**2**	0	**2,3**	0,8	**9**	0,4	**1,6**	0	**3,2**	0,7	**2,6**	**1,5**	**21,4**
	Eastern Asia	0,7		1,3		3,8		4,2		13,7		1,8		8,1		1,9		**33,7**	
	Southern Asia	0		0		0,3		0,4		5,1		0,3		0		0,9		**6,7**	
	South-Eastern Asia	0,2		0,9		1,8		3,1		11,2		5,4		0,8		9,7		**27,7**	
	Western Asia	0		0,1		0,3		1,9		1,2		0,6		0,2		2,7		**6,4**	
Europe	Eastern Europe	0	**0**	0,3	**0,8**	0,4	**2**	4,4	**6,7**	4,4	**4,1**	0,4	**0,6**	0,3	**1,9**	6,2	**5,8**	**16**	**21,9**
	Northern Europe	0		0,1		4		8,1		4,2		0,3		1,2		6,3		**23,9**	
	Southern Europe	0,4		3,1		2,5		9,6		3,3		1,5		3,7		5,8		**28,4**	
	Western Europe	0,1		0,2		2,5		7,1		4,3		0,4		3,2		4,8		**22,2**	
Oceania	Australia & New Zealand	0,4	**0**	0,9	**0,8**	4,3	**4**	8,7	**8,1**	2	**1,9**	2	**2,5**	2,8	**2,7**	4,9	**6,5**	**24**	**26,9**
	Melanesia	0		0		0,5		1,6		0		7,4		1,1		22,1		**25,3**	
	Micronesia	0		0		0		20,2		0		0		0		50,5		**70,7**	
	Polynesia	0		0		6,6		0		0		8,7		4,4		28,4		**39,4**	
	TOTAL	**0,7**		**2,5**		**10,7**		**22,3**		**21,5**		**6,3**		**9,5**		**21,6**		18,9	

Source: FAO Stat 201

Figure 2. Apparent fish consumption in Africa (kg/capita/year)

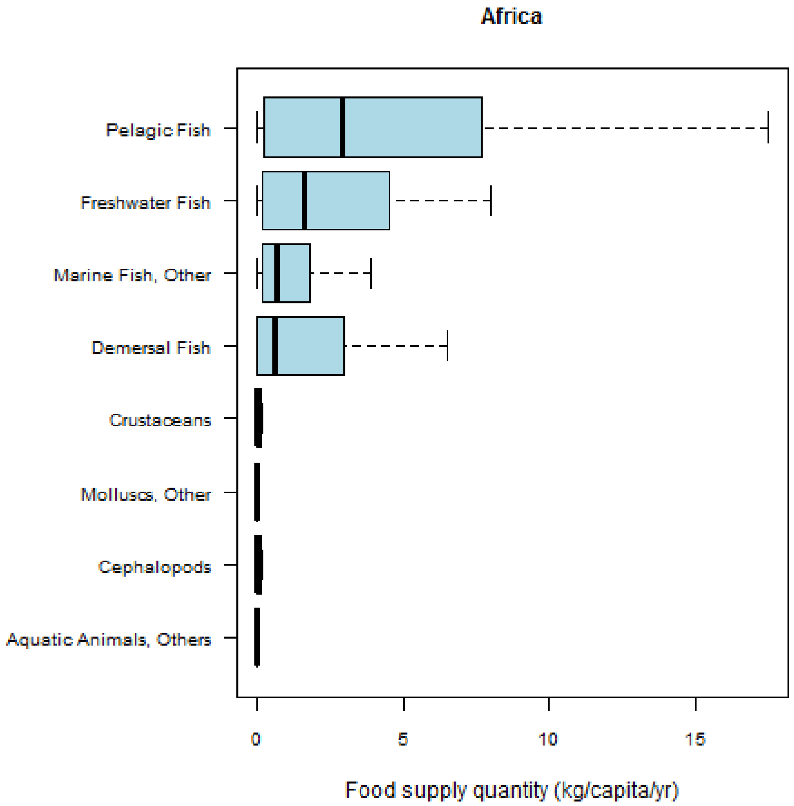


Figure 3. Apparent fish consumption in Americas (kg/capita/year)

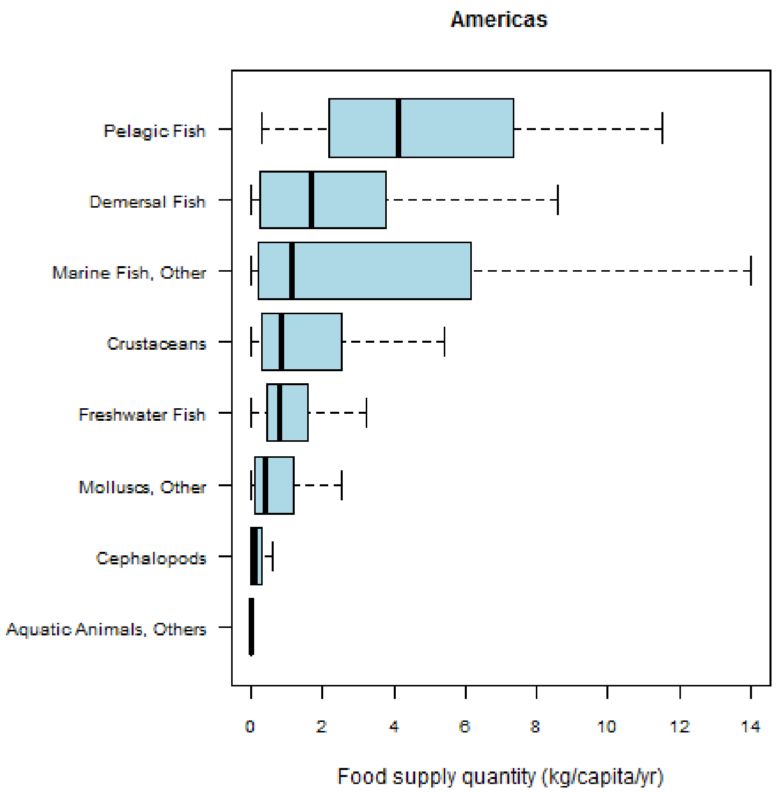


Figure 4. Apparent fish consumption in Europe (kg/capita/year)

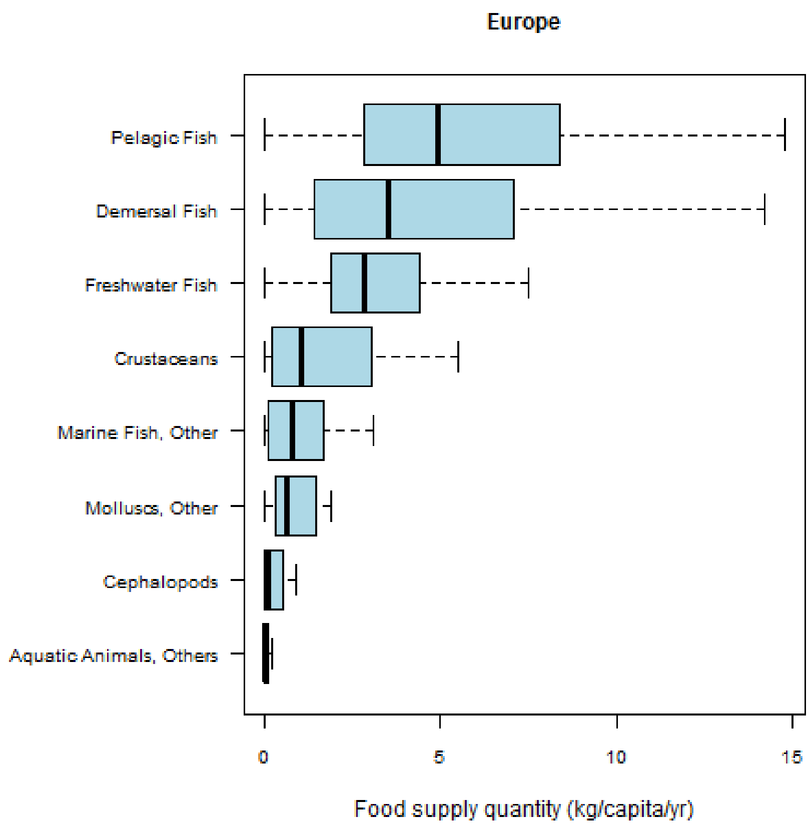


Figure 5. Apparent fish consumption in Asia (kg/capita/year)

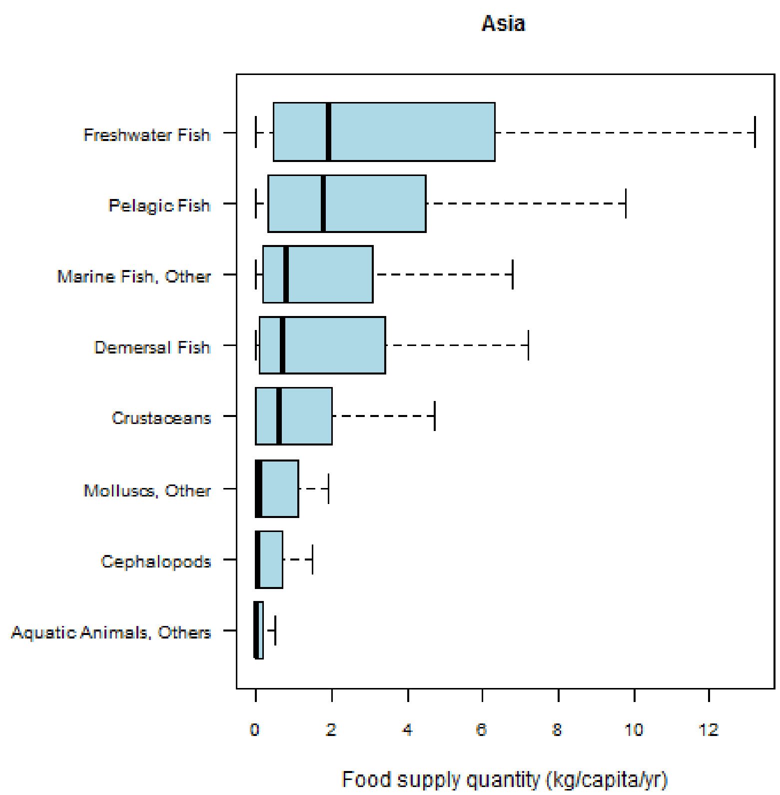


Figure 6. Apparent fish consumption in Oceania (kg/capita/year)

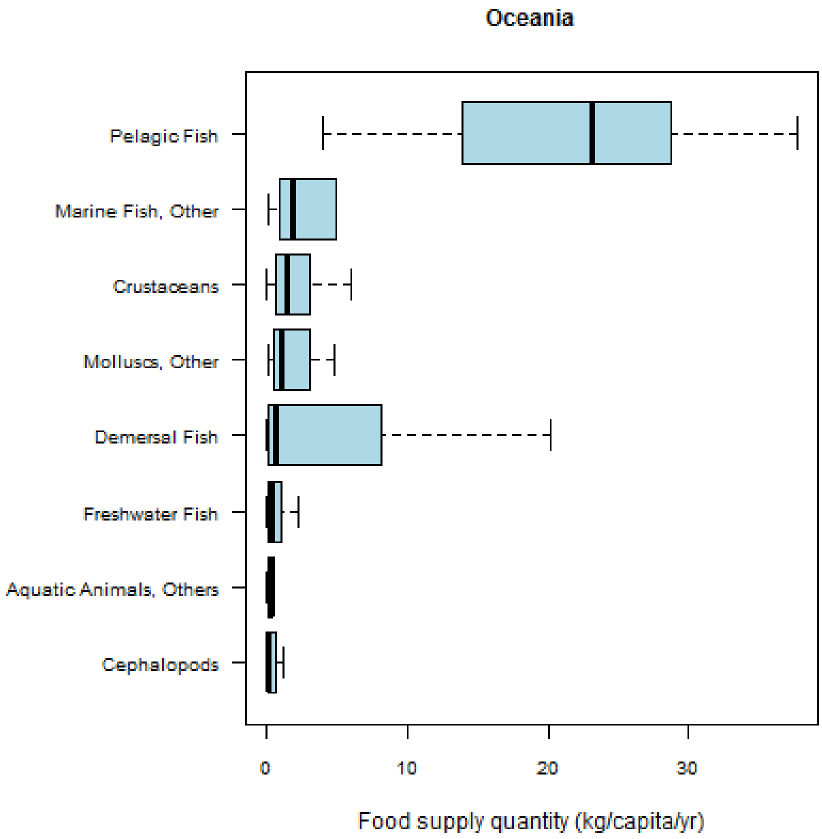


Figure 7. Consumption of pelagic fish in the 23 sub regions

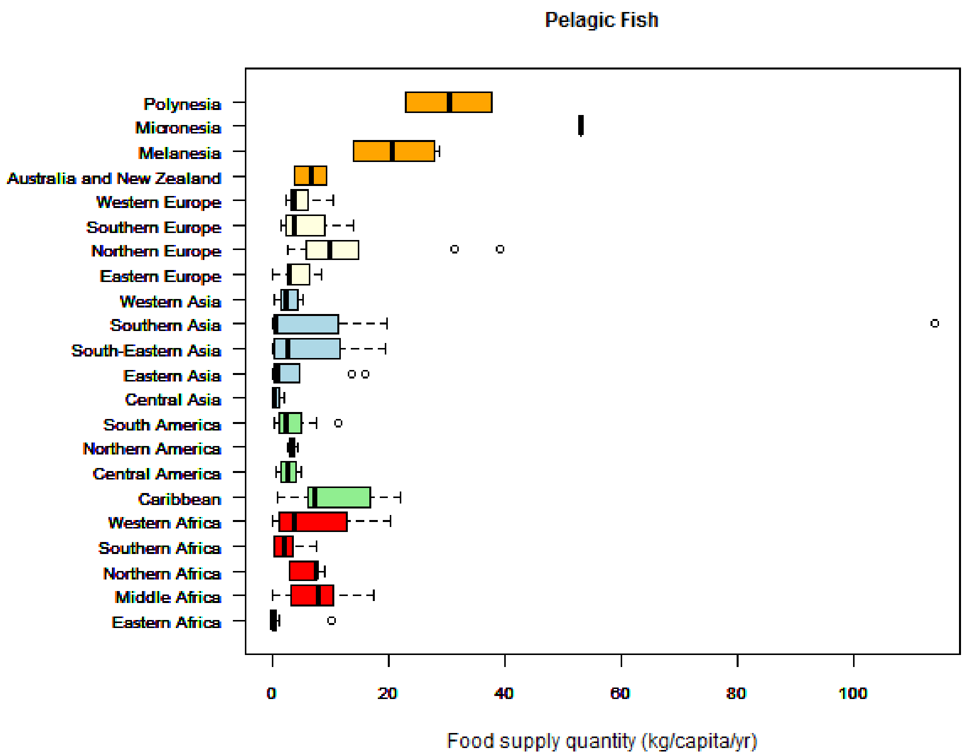


Figure 8. Consumption of demersal fish in the 23 sub regions

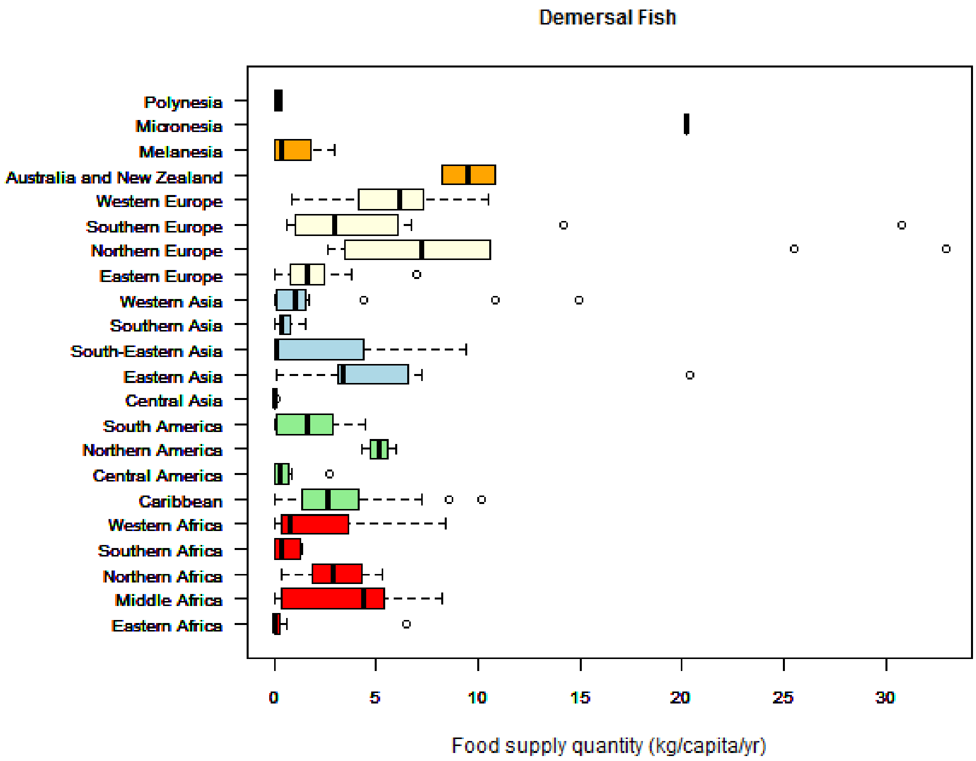


Figure 9. Consumption of freshwater fish in the 23 sub regions

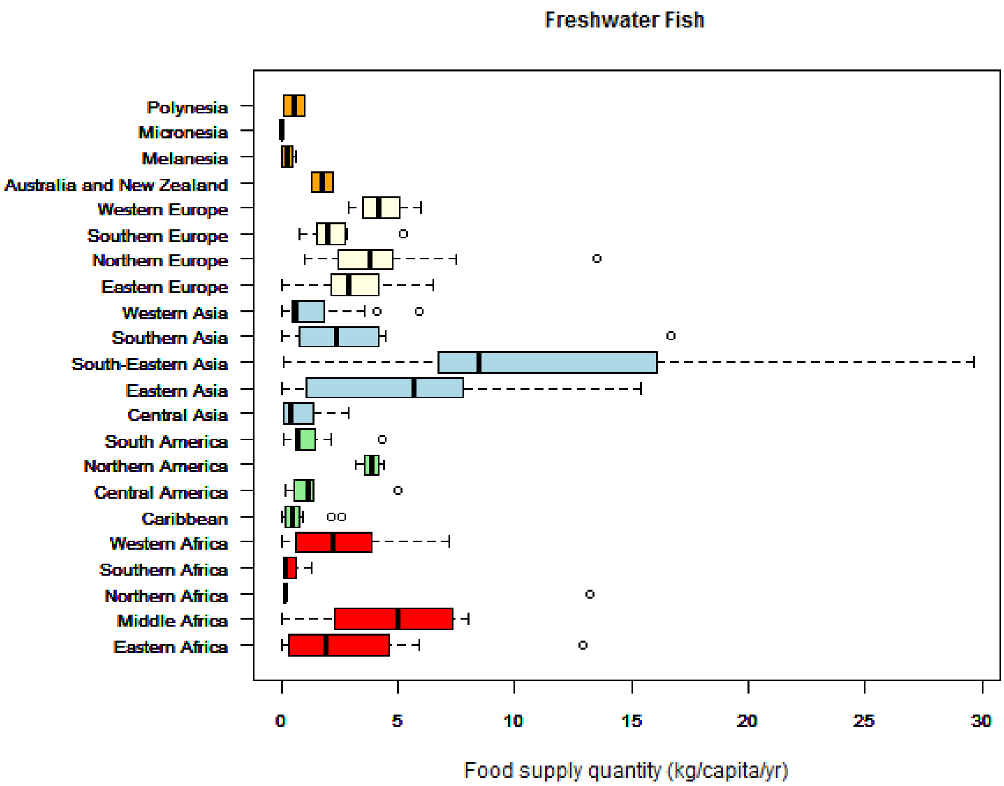


Figure 10. Consumption of molluscs, other in the 23 sub regions

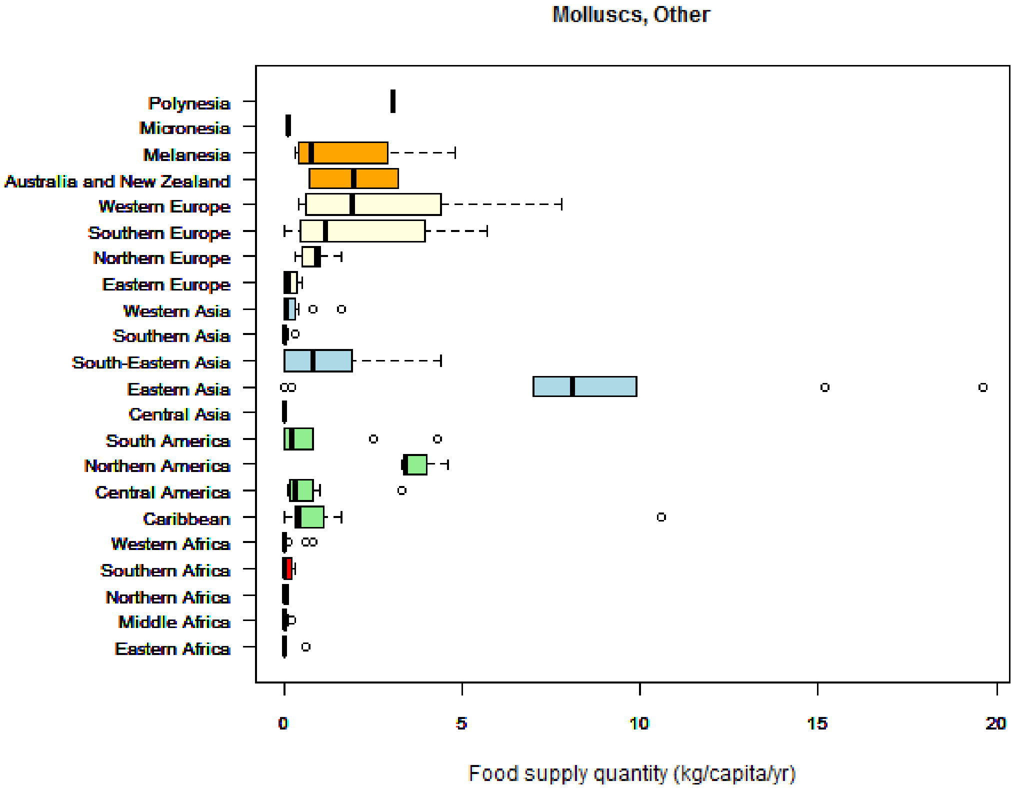


Figure 11. Consumption of crustaceans in the 23 sub regions

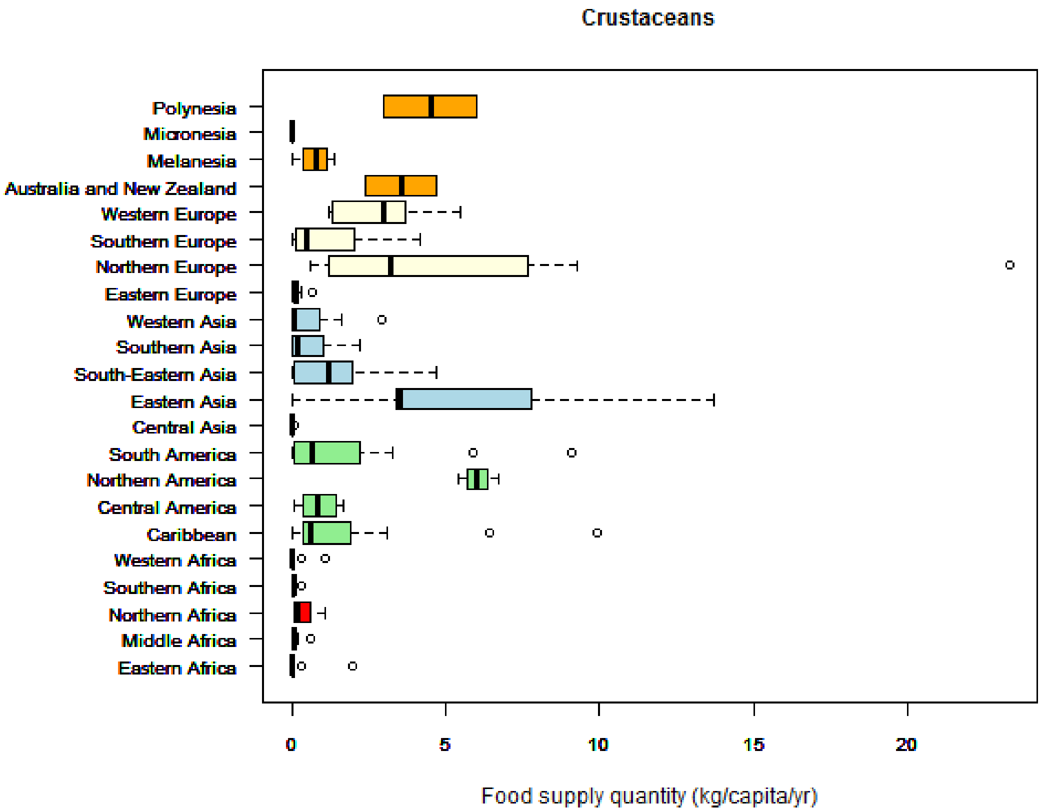


Figure 12. Consumption of cephalopods in the 23 sub regions

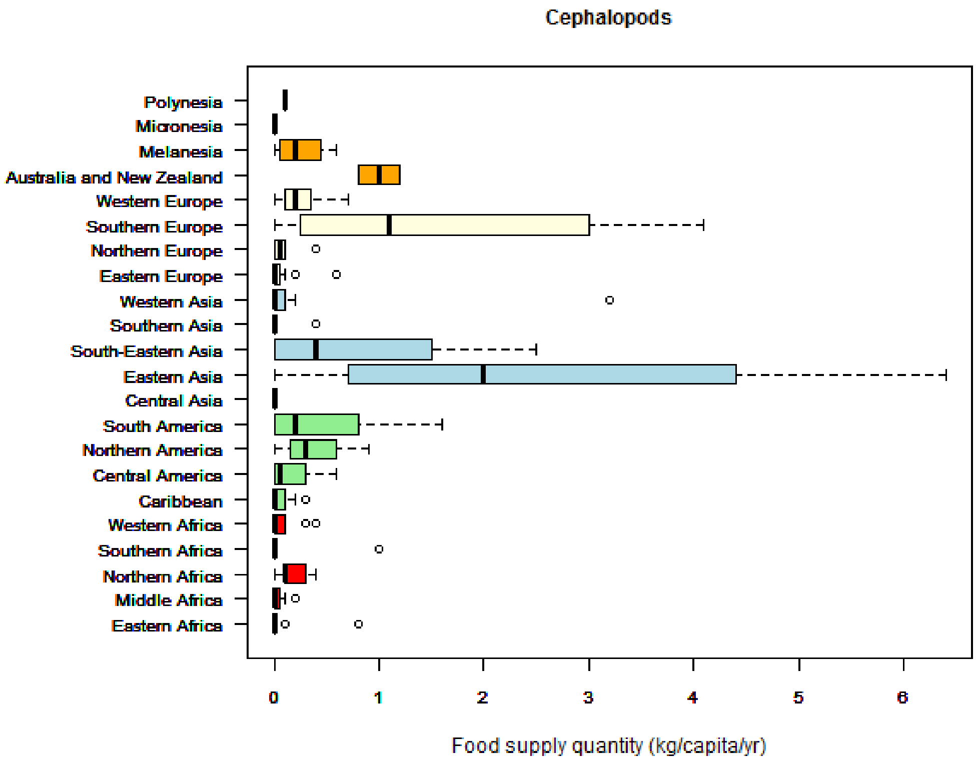


Figure 13. Consumption of aquatic animal, other in the 23 sub regions

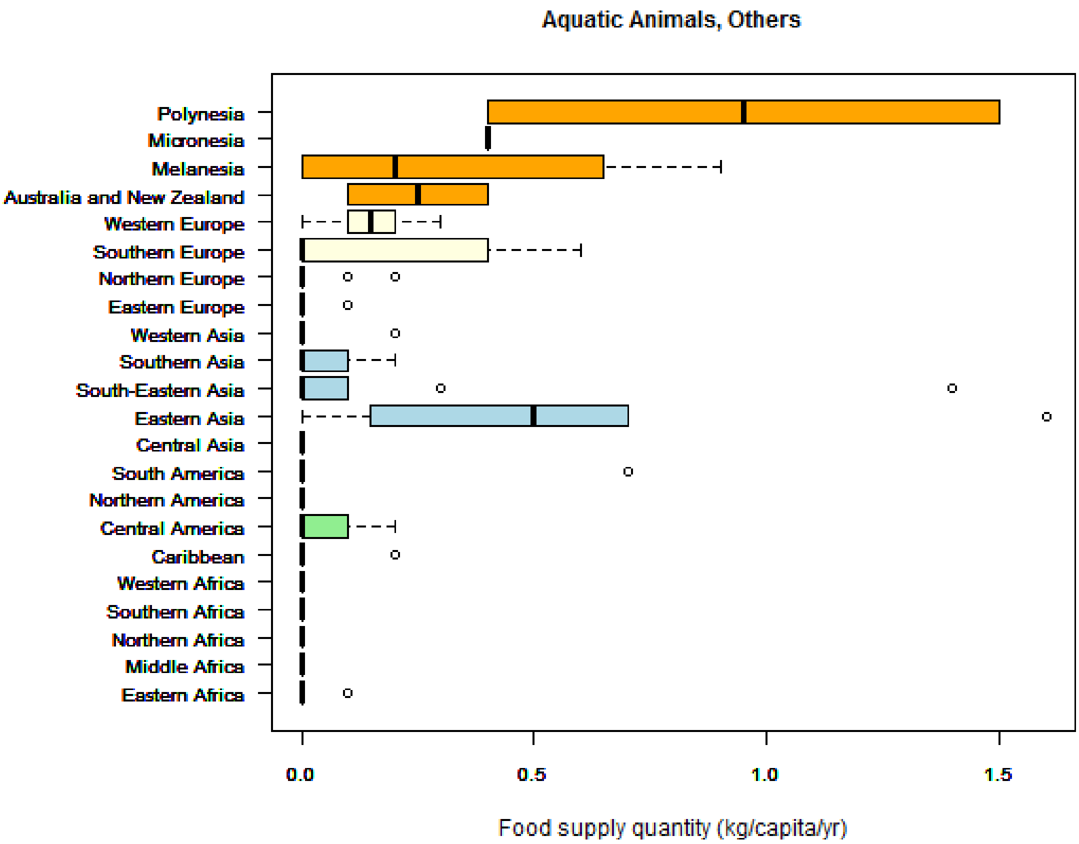
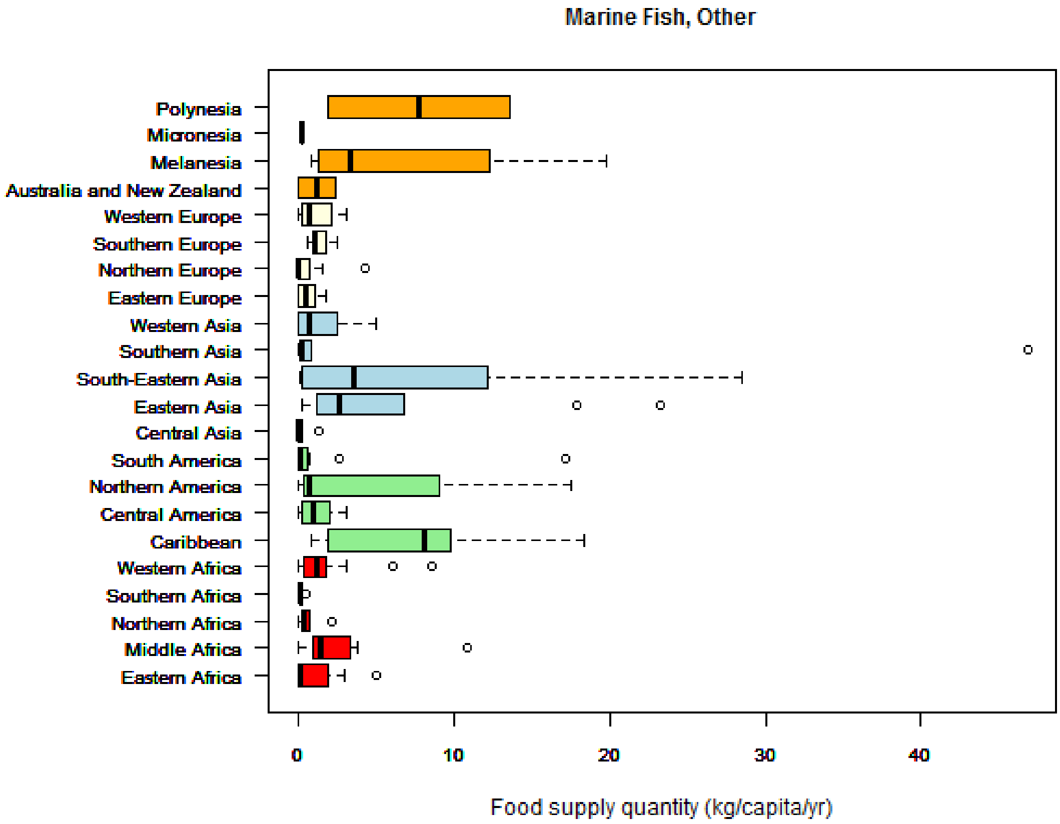


Figure 14. Consumption of marine fish, other in the 23 sub regions



9.2.3 Most contaminated fish and shellfish

UNEP/WHO (2008) report shows that levels of methylmercury vary widely among different fish species and between the same species from different geographical areas. Predatory fish are more likely to contain higher levels of methylmercury in their muscles and other tissues. Other factors that influence mercury levels in the fish include age (indicated by girth, weight, or length), and characteristics of the water body (such as local contamination, pH, reduction-oxidation potential, and other factors). Because mercury biomagnifies in the aquatic food web, fish higher on the food web (or of higher trophic level) tend to have higher levels of mercury. Hence, apical predators, such as king mackerel, pike, shark, swordfish, walleye, barracuda, large tuna, scabbard, and marlin, as well as some marine mammals, such as seals and toothed whales, contain the highest concentrations.

In addition to the food-web structure, fish methylmercury levels depend on atmospheric loading rates and ecosystem-specific properties. Fish mercury concentrations vary both within and across species and tend to reflect contaminant levels in their ecosystems of origin.

The identification and selection of fish is complicated by the exposure pathway at both local and global scales. The majority of people consume fish from commercial market fish which combine locally harvested and imported fishes. For example, migratory pelagic marine species such as tuna and swordfish from the commercial market account for more than half of U.S. population-wide mercury intake. Most fish consumed globally are marine and estuarine species harvested from open ocean environments (UNECE, 2010).

9.2.3.1 Analysis of the mercury contamination of fish species

Table 5 shows the contamination level of the different fish groups. In average, the most contaminated group is 'marine fish' including 'other' fish and mammals (454.5 µg/kg). Pelagic fish and demersal fish are then the most contaminated (respectively 122.6 and 86.7 µg/kg). The contamination of crustaceans, molluscs and cephalopods is the lowest (in average under 50 µg/kg).

Table 5. Mercury contamination by fish groups (µg/kg)

	min	Q1	Median	Mean	Q3	Max	NA's	SD
Freshwater Fish	0	24	40	80.0	90	1880	13	115.8
Demersal Fish	0	18	52	86.7	110	1000	1	110.8
Pelagic fish	0	22	41	122.6	120	3370	18	225.2
Marine Fish, Other	0	110	200	454.5	450	9300	1	731.6
Crustaceans	0	10	20	49.4	53	1040	22	84.9
Molluscs, Other	0	0	15	24.2	30	750	3	41.4
Cephalopods	0	5	10	34.2	40	463.1		58.4
Unindentified	0	50	114	244.2	290	6890	112	386.6

NA: not available

Among the most contaminated fish groups, pelagic and demersal are also, globally, the most consumed, followed by freshwater fish in certain regions.

It should be noted that the variability is significant for each fish groups. When looking the species within fish groups (figure 15), we also see an important variability for each species. In the group of demersal fish, sharks and rays have the highest level of mercury concentration in average (respectively 541 and 267 µg/kg). In the group of pelagic, the tuna is the specie with the highest level (287 µg/kg). In the group of freshwater fish, the most contaminated species are perch and eels.

Figures 16 and 17 show the mercury contamination for fish species included in demersal and pelagic fish groups. The most contaminated demersal fish (figure 16) are sharks and rays (with a significant variability); the other species are less contaminated. Nevertheless, it is necessary to put into balance the level of contamination with the quantity of fish on the market. Then, if sharks and rays are highly contaminated, they are very few consumed and thus have a low contribution to human exposure. FAO Stat (table 3) shows that the global annual capture of sharks and rays is 765 422 tonnes in 2012 while the global capture of cod, hakes and haddocks is 10 times superior (7 698 812 tonnes).

Regarding pelagic fish (figure 17), tuna is the most contaminated specie but also very consumed. The global capture represents, together with bonitos and billfishes, 7 181 723t in 2012 (table 6). Herrings and sardines (together with anchovies) dominate the global fish capture, with 17 549 124t caught and accounting for 27 percent of the global capture but have low level of mercury concentration.

Figure 15. Mercury contamination by fish species (µg/kg)

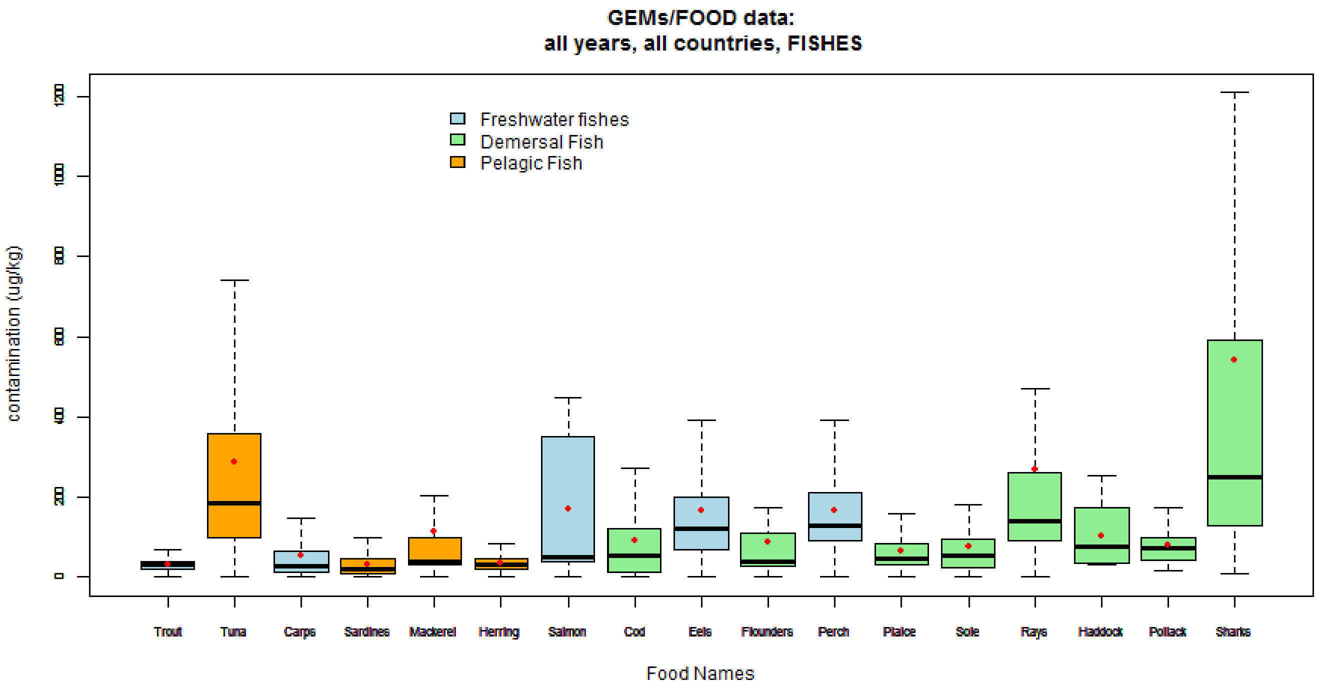


Figure 16. Mercury contamination of demersal fishes (µg/kg)

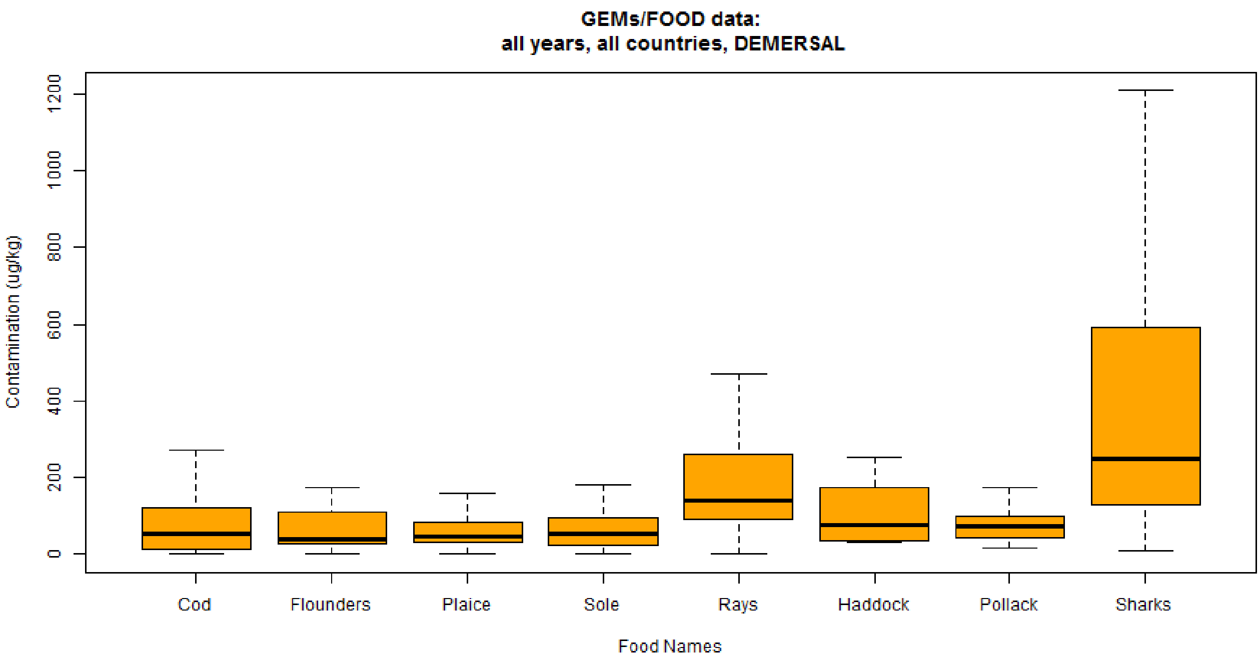


Figure 17. Mercury contamination of pelagic fishes (µg/kg)

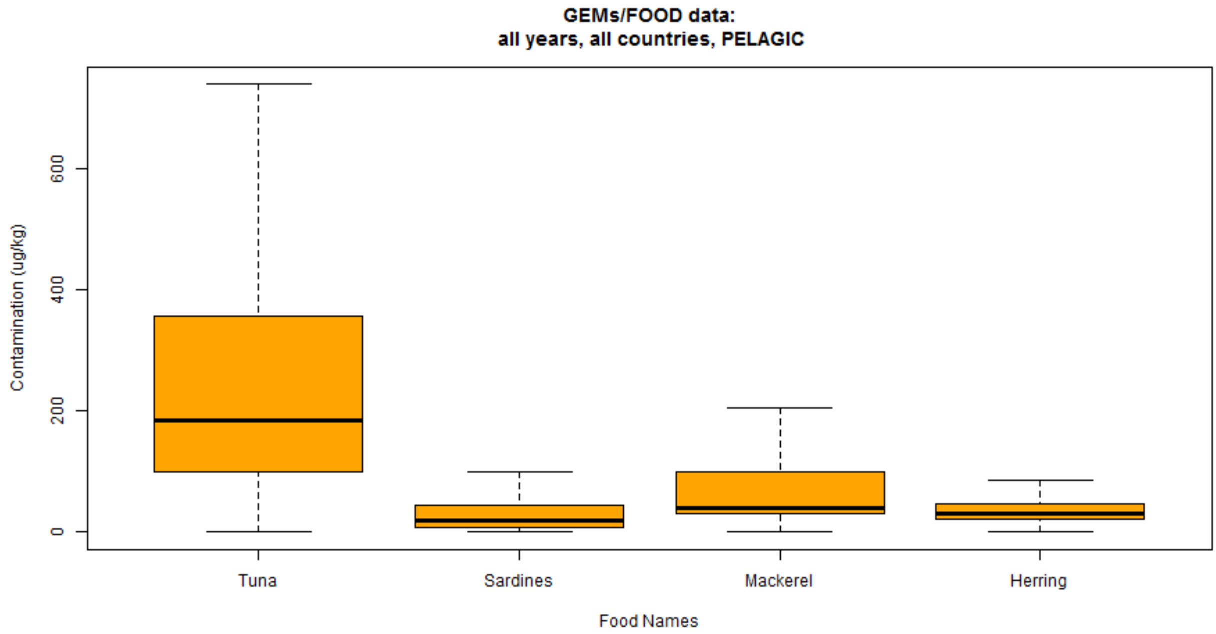


Table 6. Capture production, 2012 (tonnes)

Species	*Capture production (t)*
Demersal fish	
Cod, Hakes, Haddocks	7 698 812
Flounders, halibuts, soles	990 427
Sharks, rays, chimaeras	765 422
Pelagic fish	
Tunas, bonitos, billfishes	7 181 723
Herrings, sardines, anchovies	17 549 124

Source : FAO Stats

Finally, the variability of the contamination within the same species is significant. The only levels of contamination are insufficient to select the species to be monitored. They need to be crossed with the production of the species.

9.2.3.2 The case of tuna

Tuna is a good example for the monitoring because it is highly consumed and highly contaminated. The objective is to look at the variability of one specie among countries and years. The mean of mercury contamination of tuna is 277 µg/kg with a standard deviation of 334 (table 7). Looking at the level of contamination in the different countries including in the GemsFood database (table 8, figure 18), it appears that the variability is significant among different countries, notably because of an important heterogeneity of the number of data available per countries. On the contrary, the variability across years is less important and data are quite stable over the time (table 9, figure 19).

Table 7. Contamination of tuna (µg/kg)

MIN	0
Q1	90
Q2	176
MEAN	277.1
Q3	348.8
MAX	3370.0
SD	334.1768

Table 8. Mercury contamination of tuna in the countries of Gemsfood database (µg/kg)

Country	*Mean*	*SD*	*Count*
Austria	186.6	141.3	21
Australia	115.9	78.6	17
Cyprus	1207.7	22.7	3
Germany	278.2	333.0	225
Denmark	261.3	183.5	23
Spain	365.1	366.3	331
Finland	73.5	56.2	11
France	319.6	279.9	79
Italy	724.5	830.6	6
Malta	425.0	382.0	22
Netherlands	210.7	124.8	20
Norway	103.3	70.8	6
New Zealand	293.4	392.6	166
Portugal	1600.0	NA	1
Romania	46.2	32.8	4
Slovenia	133.2	199.4	116
Slovakia	97.7	166.6	35

Table 9. Mercury contamination of tuna per year - Gemsfood database (µg/kg)

Year	*Mean*	*SD*	*Count*
1980	1467.5	708.5	12
1982	172.9	57.6	90
1999	260.6	319.2	35
2000	176.7	57.2	9
2002	409.1	247.3	32
2003	267.5	223.5	8
2004	150.3	265.5	45
2005	226.7	345.2	72
2006	300.3	346.5	240
2007	264.0	307.0	106
2008	270.2	282.7	160
2009	311.2	410.9	95
2010	319.9	341.8	118
2011	317.3	255.6	63
2013	137.9	NA	1

Even when we focused only on one specie like tuna for which the data are numerous, the variability is still significant because data covers very different type of tuna. The family Thunnini comprises fifteen species, the sizes of which vary greatly, ranging from the bullet tuna (max. length: 50 cm) up to the Atlantic bluefin tuna (max. length: 4.6 m and is believed to live for up to 50 years. The level of mercury varies significantly between these different tuna species.

9.2.3.3 Summary/conclusion

Regarding mercury contamination of fish, the available source of data is the GEMSFood WHO database. It contains more than 33 000 data on mercury concentration from 23 countries. The analysis of the data shows a substantial variability between fish groups, fish species and within the same species. The highest mercury contamination level are found in demersal fishes (mean 186 µg/kg; SD 388) and especially in sharks and rays. It is important to note that these last species are highly contaminated but represent a small part of the fish market. On their side, cods and haddocks have also a high level of contamination (even though, smaller than sharks and rays) but represent an important part of the demersal fish market. Pelagic fishes also present some high level of contamination (mean 122 µg/kg; SD 225) and specifically the tuna (mean 277 µg/kg ; SD 334) which is also highly traded. Looking at more precisely the tuna, we observe an important variability of the level of contamination between countries and within the same countries. At the opposite, the inter-annual variability is for its part, quite low. These data are really useful to compare the mercury contamination of fish. Nevertheless, there is a limitation due to the regional scope as the database contains predominately European data (over 23 countries, 19 are Europeans countries).

Figure 18. Mercury contamination of tuna in the countries of Gemsfood database (µg/kg)

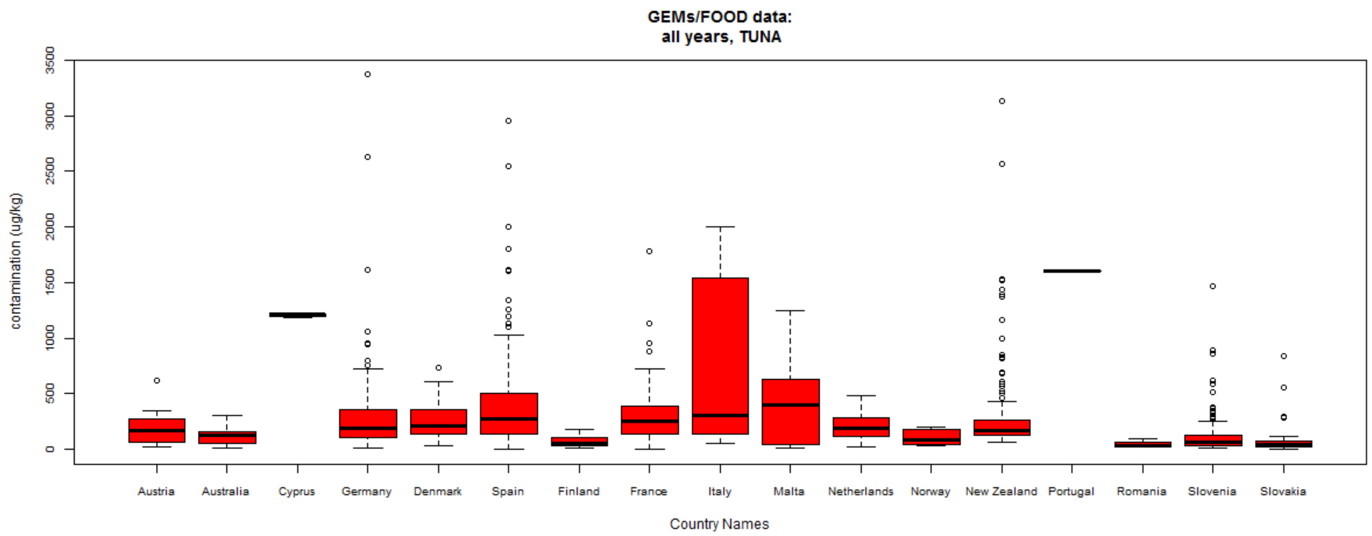
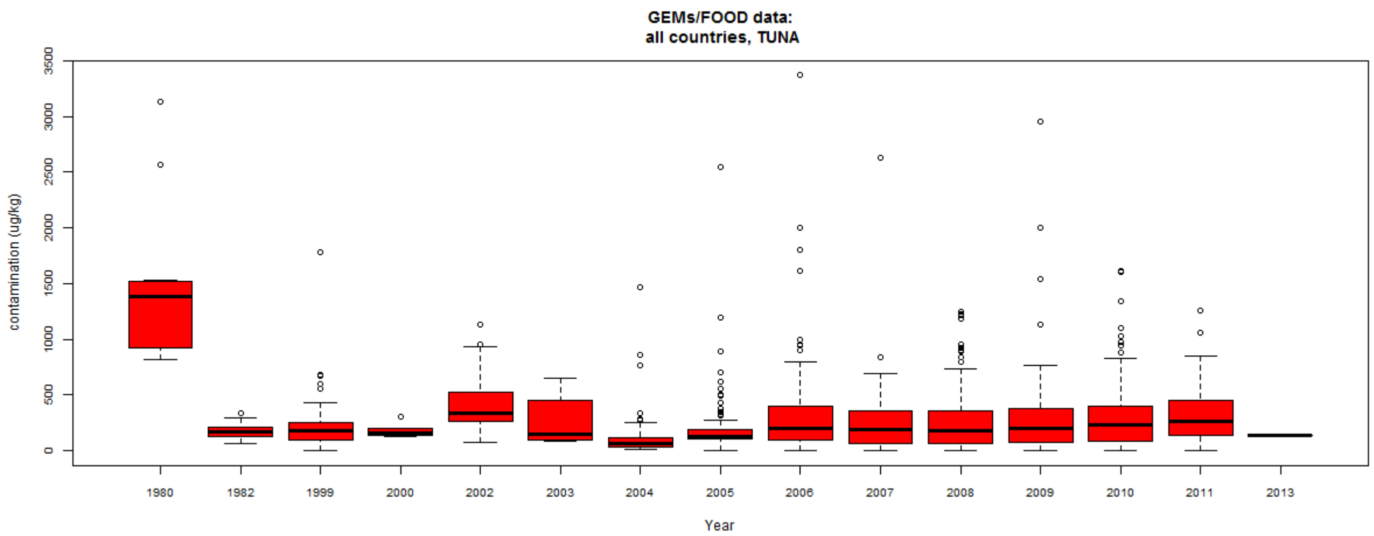


Figure 19. Mercury contamination of tuna per year- Gemsfood database (µg/kg)



9.3 Annex 3. “Hot spots” of anthropogenic mercury emissions

9.3.1 The major sources of anthropogenic mercury emissions to air

The Global Mercury Assessment 2013 (UNEP 2013) estimates that the global emissions to air from anthropogenic sources in 2010 is 1960 tonnes (range of 1010-4070 tonnes). Current anthropogenic sources are responsible for about 30% of annual emissions of mercury to air. Another 10% comes from natural geological sources, and the rest (60%) is from ‘re-emissions’ of previously released mercury that has built up over decades and centuries in surface soils and oceans.

The assessment confirms the role of artisanal and small-scale gold mining (ASGM) and coal burning as the largest components of anthropogenic emissions, followed by the production of ferrous and non-ferrous metals, and cement production. Annual emissions from ASGM are estimated at 727 tonnes, making this the largest sector accounting for more than 35% of total anthropogenic emissions. Coal burning emitted some 475 tonnes of mercury in 2010, the majority of which is from power generation and industrial use.

Increasing industrialization has made Asia the main source region of mercury emissions to air, with East and Southeast Asia accounting for about 40% of the global total, and South Asia for a further 8%.

9.3.1.1 Anthropogenic releases of mercury to water

The Global Mercury Assessment 2013 (UNEP 2013) is the first attempt to compile a global inventory of aquatic releases. The report considers three type of sources: point sources, contaminated sites and ASCG evaluated separately.

Releases of mercury to aquatic systems from point sources

The global estimate of mercury release to water from point sources has been derived from the atmospheric emissions assessment and the approach employed in the UNEP Toolkit to partition total mercury releases between air, land, and water. Point sources are industrial sites such as power plants or factories, and they release an estimated 185 tonnes of mercury per year (range of estimate, 42.6 - 582).The main contributors sectors are the non-ferrous metal production (92.5 tonnes; range of estimate, 19.3 - 268) and consumer product waste (89.4 tonnes, range of estimate, 22.2 - 308).

Diffuse releases of mercury to aquatic systems from contaminated sites

Contaminated sites, including old mines, landfills, and waste disposal locations, release 8 - 33 tonnes per year. The main contributors sectors are mining sites (6.7 – 26.6 tonnes) and precious metal production sites (1.4 – 5.5 tonnes).

Artisanal and Small-Scale Gold Mining (ASGM) activities

Much of the mercury released from artisanal and small-scale gold mining goes into rivers, lakes, soils and sediments, and tailings. From soils and tailings, it may be re-mobilized by leaching and erosion. In addition, mining may disturb mercury containing soils and sediments that may then erode more quickly, releasing more mercury than would otherwise have become available from natural erosion. Total worldwide releases of mercury to land and water from ASGM were estimated at over 800 tonnes per year. How much of this is released to water cannot yet be determined.

Approximately 15 million people, including approximately 3 million women and children, participate in the ASGM industry in 70 countries. These countries are found primarily in East and Southeast Asia, Sub-Saharan Africa, and South America. Some ASGM activity also occurs in South Asia and the Commonwealth of Independent States (former Soviet republics) and other European countries) (WHO, 2013).

Other sources

Deforestation, especially in the Amazon Basin, can lead to extensive soil erosion and thus the release of mercury previously accumulated in soils. Using 2010 figures for deforestation rates around the world, and an estimate of soil concentrations of mercury, as much as 260 tonnes of mercury may have been released into rivers in 2010 as a result of deforestation worldwide. Other sources remain to be quantified, and so these estimates comprise only a partial total.

9.3.1.2 Conclusion

Anthropogenic releases to waters are likely to be at least 1000 tonnes per year. The estimated releases and inputs of mercury to aquatic environments are associated with large uncertainties and the results should be treated with great caution. It is nonetheless clear that anthropogenic sources and human activity contribute hundreds of tonnes of mercury to aquatic environments each year and that ASGM represents one of the most important sources of mercury emissions to the global environment attributable to human activities.

The identification of regions of concern from anthropogenic sources of mercury is difficult. In order to estimate a reduction of mercury concentration in aquatic environment over time and identify potentially highly exposed population groups, monitoring should be reinforced in regional areas with the highest mercury releases to aquatic systems, i.e. areas of ASM activities and non-ferrous metal production. The increase of mercury levels in the fish can lead to additional mercury exposures through fish consumption for people involved in these activities, as well as for other people who live in the vicinity of these activities.