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Report

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Levels of contaminants in *Sardinella aurita* caught at Mauritanian coast prior to and following produced formation water discharges from Berge Helene FPSO at Chinguetti field

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Summary

Two sampling rounds of *Sardinella aurita* were conducted in the waters off the coast of Mauritania to evaluate levels of contamination prior to the commencement of oil production (pre-PFW) and following the start of produced formation water discharge (post-PFW). The pre-PFW sampling round was carried out in January 18, 2006 at location 18°23'N–16°20'W and the post-PFW sampling round in July 1, 2006 at 20°02'N–17°36'W.

Three pooled and homogenized samples were prepared from each sampling round and each sample was analyzed for 38 analytes: 14 metals (Mercury (Hg), Arsenic (As), Copper (Cu), Cadmium (Cd), Lead (Pb), Zinc (Zn), Antimony (Sb), Beryllium (Be), Cobalt (Co), Manganese (Mn), Tin (Sn), Aluminium (Al), Nickel (Ni) and Chromium (Cr)), Radium 226 and 228, total petroleum hydrocarbons, BTEX (benzene, toluene, ethylbenzene, xylene) and 16 EPA polycyclic aromatic hydrocarbons. Sb, Be, Pb, ^{226}Ra, ^{228}Ra, BTEX and higher molecular weight PAHs were not detected in any of the samples, indicating that these elements and compounds were either absent or in quantities too low to detect. The levels of 11 metals (Hg, As, Cu, Cd, Zn, Be, Co, Mn, Sn, Al, Ni, and Cr), total petroleum hydrocarbons and lower molecular weight PAHs were detected in at least one of the samples.

Statistically significant difference between the pre- and post-PFW samples was found for Hg, As, Cu, Co, Al and six PAHs (naphthalene, acenaphthene, fluorene, phenanthrene, fluoranthene and pyrene). The levels of Hg, As and six PAHs were higher in the post-PFW samples, while levels of Cu, Co and Al were higher in the pre-PFW samples. Although the difference is statistically significant, the differences were not very large and could be attributed to differences in the environment in which the fish reside and also to age differences between the two sampling rounds.

Comparison of the measured concentrations with the concentrations reported for fish and food in scientific literature shows that levels of contaminants in *Sardinella aurita* from Mauritania are generally low. Higher concentrations than the background levels reported from elsewhere were detected only for aluminium, nickel, chromium and cadmium. Although the levels of aluminium, nickel and chromium were higher than those reported for raw fish samples, they were in the same range as levels reported for processed fish and food (*e.g.* canning, baking). The concentration of cadmium found in *Sardinella aurita* samples is higher than the maximum permitted limit set by European Commission for fish marketed in European Union countries. However, the increased concentrations of cadmium in fish and molluscs from Mauritanian coastal waters has been reported before and have been attributed to natural processes, such as the high levels of cadmium brought to surface waters through the upwelling of deep nutrient rich waters that takes place along the Western Atlantic coast.

1. Introduction

This document provides a report on the levels of contaminants in *Sardinella aurita* caught off the Mauritanian coast. Compounds of interests are: metals (Hg, As, Cu, Cd, Pb, Zn, Sb, Be, Co, Mn, Sn, Al, Ni, and Cr), radium (^{226}Ra and ^{228}Ra), total petroleum hydrocarbons, BTEX and 16 EPA PAHs (naphthalene, acenaphthane, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(e)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenzo(ah)anthracene, benzo(ghi)perylene and indeno(123cd)pyrene). The levels are reported for pooled samples of fish caught in two sampling rounds. The first was conducted to collect baseline information prior to oil production, while the second sampling round was conducted following PFW discharge to evaluate any increases in observed levels of contaminants. The levels found in both sampling rounds are compared and contrasted with levels reported in published scientific literature for other locations and with food and feed regulation and guideline levels set by official bodies.

The sampling and transport of the samples to IMARES was conducted by Dutch trawlers operating in the area around the Berge Helene FPSO. Sample preparation consisted of fish pooling and homogenization and was performed by IMARES. Analysis of the samples for priority contaminants was performed by IMARES and sub-contracting laboratories.

The report covers the following:

- Sampling of *Sardinella aurita*
- Sample preparation
- Analysis of fish homogenates
- Results of analyses
- Results of literature search on levels reported for other locations
- Results of search for regulation and guideline levels
- Comparison of the results for *Sardinella aurita* with literature data and regulation and guideline levels

2. Methods and materials

2.1 Sampling and transportation of the samples to IMARES

Two samples of *Sardinella aurita* were collected in waters off the Mauritanian coast. Fish were caught by the Dutch fishing vessel operating in the region. First sampling round (pre-PFW) was performed on January 18, 2006, *i.e.* before any discharge of PFW from the FPSO had started. The second set (post-PFW) were collected on July 1, 2006, approximately 2 months after the regular (everyday) discharges of the PFW had begun.

Sardinella aurita is known to migrate annually up and down the north-western African coast between 12° and 22°N (Boely 1982; Garcia 1982). Migration starts off Senegal in May, and by August most of stock is distributed in the northern part of the Mauritanian EEZ. Acoustic surveys by the R/V Dr. Fridtjof Nansen during the last decade have confirmed this high abundance of round sardinella in Mauritanian waters up until December (FAO 2006). In early wintertime, the species moves rapidly to the south again. This migratory route is assumed to be closely linked to the seasonal variation in the annual sea surface temperature (SST) cycle, in which a warm-water front comes in the Mauritanian zone from the south in May, moving north during the summer and cooling down in wintertime again (Vakily 1995).

Sampling locations (see Figure 1) were therefore selected to be closed to the oil production field but taking into account the migration pattern of *Sardinella aurita*. In the pre-PFW sampling round, 264 pieces of Sardinella were caught at the position 18°23'N-16°20'W. Water temperature was 17.9°C. Sardinellas were frozen and stored in two paper boxes (one containing 125 and another one 139 pieces) onboard the vessel until 03.03.2006, when they

were delivered to IMARES. Before processing, fish were stored at -25°C. In the post-PFW sampling round, 135 pieces of Sardinella were caught at the position 20°02'N–17°36'W. Water temperature was 21.0°C. Sardinellas were frozen and stored in two paper boxes (one containing 67 pieces and other one 68 pieces) onboard the vessel until 02.10.2006, when they were delivered to IMARES. Before processing, fish were stored at -25°C.

Table 1. Summary of sampling details

Species	Country	Position	Sampling date	Delivery date	Water temperature
Sardinella	Mauritania	18°23'N–16°20'W	18.01.2006	03.03.2006	17.9 °C
Sardinella	Mauritania	20°02'N–17°36'W	01.07.2006	02.10.2006	21.0 °C

Figure 1. *Position of the oil production (FPSO and Tiof) and fish sampling (Pre- and Post-PFW) overlaid with migration pattern of Sardinella aurita.*

2.2 Sample preparation

Sample preparation procedures for pre-PFW and post-PFW samples are described in this section. In total, three preparations were performed, two pre-PFW samples and one post-PFW.

Preparation of the pre-PFW samples was repeated, because samples were not cooled during the 1st preparation and a Stephan cutter was used in the preparation process. Not cooling the samples may have led to evaporation of volatile BTEX compounds and the use of a Stephan cutter for homogenization may have led to contamination of the samples by Al, Cr and Ni.

1st preparation of pre-PFW samples (samples A (2006/0527), B (2006/0528) and C (2006/0529))

One box (containing 125 fish) from the pre-PFW sampling round was defrosted at laboratory temperature (*ca.* 20°C) from March 10, 2006 till March 13, 2006, when samples for analysis were prepared. Preparation procedure is schematically shown in Figure 2. Fish were pooled based on their length into 7 groups. In order to provide 3 representative samples, 33 fish of the 27-28 cm group were mixed with 21 fish of the 26-27-cm group and 21 fish of 28-29-cm group. This operation provided a pool of 75 fish, from which 3 sub-pools A, B and C – each containing 25 fish – were created by random selection. Weights and lengths of the individual fish in each sub-pool are given in Annex 1. Samples A, B and C were prepared by cutting off head and tail of each fish, mincing of individual body remains (including skin, bones and viscera) and consequent homogenization of the total meat volume. Mincing was performed using mincer DRC compact 92 (Refrigere, France) and homogenization using a Stephan cutter (Stephan Machines, Almelo, the Netherlands) for 3 minutes. All sample preparation was performed at laboratory temperature. Fish homogenate was then placed into several glass jars, which were stored in the refrigerator at -25°C till their analysis at IMARES or their transport to sub-contracting laboratory.

Length range (cm)	Number
24-25	5
25-26	20
26-27	31
27-28	33
28-29	29
29-30	6
30-31	1
Total	125

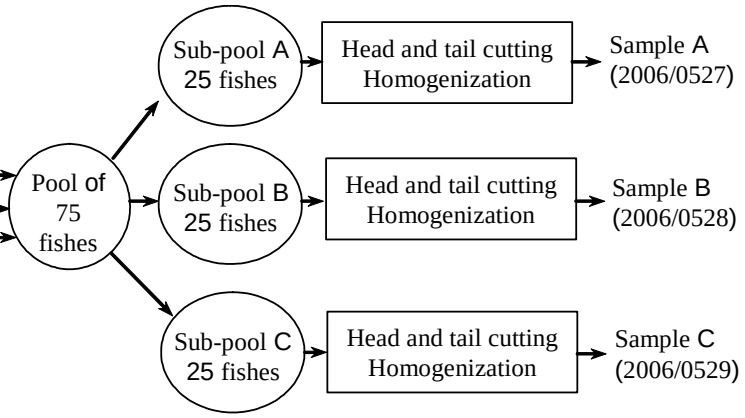

Figure 2. *Details on the 1st preparation of the pre-PFW samples*

2nd preparation of the pre-PFW samples (samples D (2006/0928), E (2006/0929), F (2006/0930))

A second box (containing 139 fish) from the pre-PFW sampling round was defrosted at 0°C from September 13, 2006 till September 18, 2006, when samples for analysis were prepared. Preparation procedure is schematically shown in Figure 3. Fish were pooled based on their length into 10 groups. In order to provide 3 representative samples, 15 fish of the 25-26 cm group were mixed with 42 fish of the 26-27-cm group and 18 fish of 27-28-cm group. This operation provided a pool of 75 fish, from which 3 sub-pools D, E and F – each containing 25 fish – were created by random selection. Weights and lengths of individual fish in each sub-pool are given in Annex 2. Samples D, E and F were prepared by cutting off head and tail of each fish and mincing of body remains (including skin, bones and viscera) together using a DRC compact 92 mincer (Refrigere, France). Sample preparation was performed while keeping fish and homogenates on ice to eliminate losses of analytes by evaporation. Fish homogenate was then placed into several glass jars, which were stored at -25°C until their analysis at IMARES or their transport to a sub-contracting laboratory.

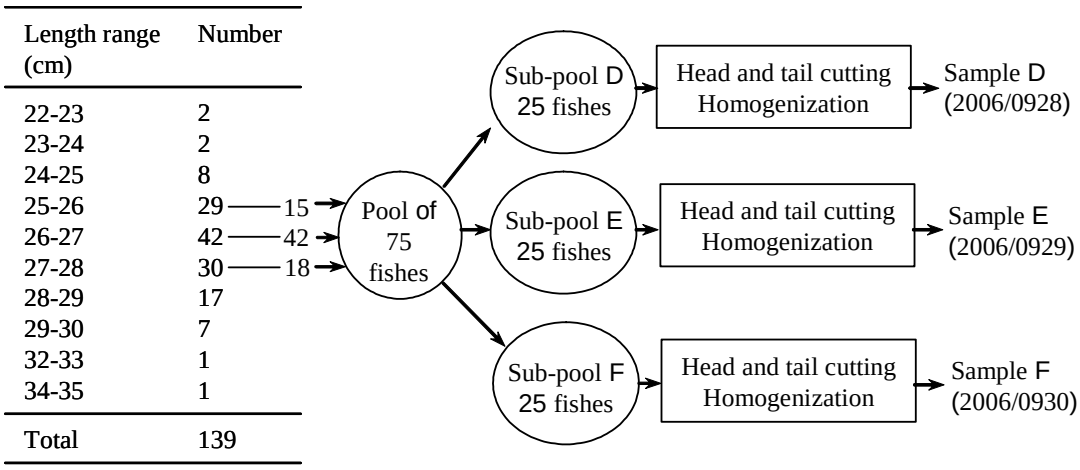

Figure 3. *Details on the 2nd preparation of the pre-PFW samples*

Preparation of post-PFW samples (samples G (2006/0893), H (2006/0894), I (2006/0895))

Both boxes (containing 139 fish in total) from the post-PFW sampling round were defrosted at 0°C from October 2, 2006 till October 4, 2006, when samples for analysis were prepared. The preparation procedure is schematically shown in Figure 4. Fish were pooled based on their length into 10 groups. In order to provide 3 representative samples, 35 fish of the 31-32 cm group were mixed with 37 fish of the 32-33-cm group and 3 fish of 33-34-cm group. This operation provided a pool of 75 fish, from which 3 sub-pools G, H and I – each containing 25 fish – were created by random selection. Weights and lengths of individual fish in each sub-pool are shown in Annex 3. Samples G, H and I were prepared by cutting off the head and tail of each fish and mincing of body remains (including skin, bones and viscera) together using a DRC compact 92 mincer (Refrigere, France). Sample preparation was performed while keeping fish and homogenates on ice to eliminate losses of analytes by evaporation. Fish homogenate was then placed into several glass jars, which were stored at -25°C until their analysis at IMARES or transport to a sub-contracting laboratory.

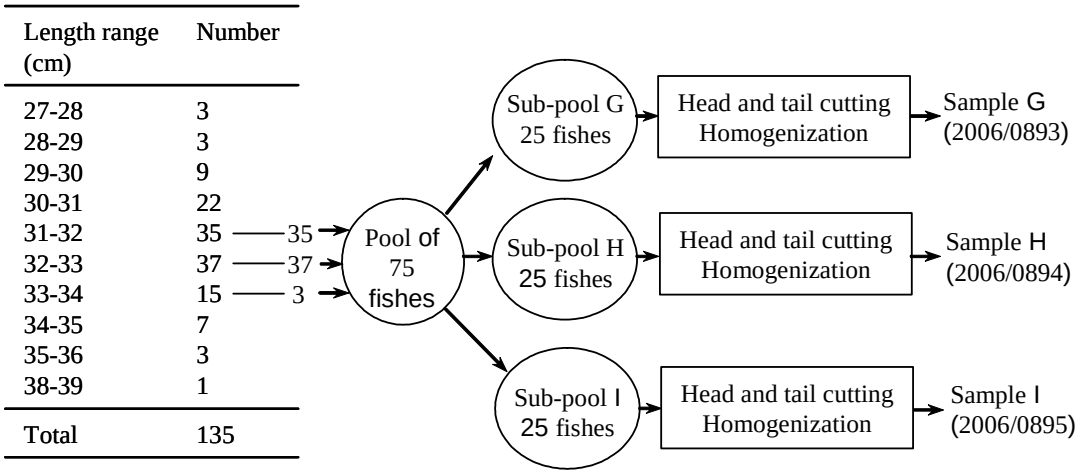

Figure 4. *Details on the preparation of the post-PFW samples*

2.3 Transport of samples

Samples for analysis by sub-contracting laboratories were transported from IMARES by courier service. Samples were sent in cool-boxes filled with ice-packs to keep samples as cool as possible during transport. Samples for IMROP were sterilized before sending using a Muvero-

Mat sterilizer (type 90E) for 45 minutes at 122°C (pressure 1.4 bar, heating-time: 90 min, cooling time: 20 min).

2.4 Analytical procedure

Determination of selected analytes was performed in the fish homogenates by IMARES or sub-contracting laboratories using the analytical procedures described in this section. In order to minimize analytical variation between the measurements, the analyses of the pre- and post-PFW samples were performed together in the period from October 10 till November 30, 2006. The only exception was the analysis of selected metals (Hg, As, Cu, Cd, Pb, Zn, Sb, Be, Co, Mn, Sn) and PAHs, which was performed in May and July respectively, to provide comparison values for IMROP's inter-laboratory validation as soon as possible.

Metals (Be, Co, Cr, Mn, Ni, Sn, Sb, Cd, Pb, Zn, Cu)
Fish homogenate was digested with nitric acid in a temperature and pressure controlled microwave digester. Solution was then quantitatively transferred into a volumetric flask and the concentration of metals was analyzed by an inductively coupled plasma – mass spectrometer. For sample introduction a cross-flow nebulizer was used and quantification was done by standard addition to eliminate matrix effects.

Metals (Al)
Fish homogenate was digested with nitric acid in a temperature and pressure controlled microwave digester. The solution was then quantitatively transferred into a volumetric flask and the concentration of aluminium was analyzed by an inductively coupled plasma – atomic emission spectrometer.

Metals (As, Hg)
Fish homogenate was digested with nitric acid in a temperature and pressure controlled microwave digester. The solution was then quantitatively transferred into a volumetric flask and the concentration of arsenic and mercury was analyzed by atomic absorption spectrometry with hydride generation.

Radium 226
The radium isotopes were initially co-precipitated with lead and barium sulphates from a faintly acid sample. The precipitate was isolated by centrifuging, then redissolved in an alkaline solution of ethylenediaminetetraacetic acid (EDTA) and triethanolamine (TEA). The radium isotopes were then co-precipitated with barium sulphate from acetic acid medium free of lead contamination. The barium sulphate was then further purified by a series of precipitations and finally mounted as a thin source on a 5 cm diameter stainless-steel planchet. After a 21-day ingrowth period, the source was then counted for gross alpha activity on a Berthold LB770 low-level proportional counter for 1000 minutes. This determines the alpha activity of the Ra-226 and its daughters in secular equilibrium (Rn-222, Po-218 and Po-214). The Ra-226 activity is given by dividing the gross alpha activity by four.

Radium 228
Radium-228 was measured using gamma spectrometry technique. This measurement technique is based on the use of germanium detectors coupled to a computerised analytical system. The detectors are calibrated for efficiency using a mixed radionuclide standard, which covers an energy range of approximately 120-2000 keV. Efficiencies at lower energies are determined on an individual basis. Stored spectra are analysed using the software Fitzpeaks for photopeak identification and subsequent quantification.

Total petroleum hydrocarbons
Fish homogenates were Soxhlet extracted for 12 h by hexane:dichloromethane (3:1). The extracts were then saponified by adding 20 mL of 0.7M KOH and 30 mL of water and refluxing for 2 h. The resulting mixture was transferred into a separatory funnel and extracted 3 times

with hexane. The extracts were then combined, filtered through glass wool and dried with anhydrous sodium sulphate. The extract was concentrated by rotary evaporation down to about 3 mL. Finally, the extract was cleaned up by passing it through a silica/alumina column. The cleaned sample was then determined using gas chromatography with flame ionization detector. Quantification was performed based on the RIVM oil standard, which has a similar composition profile to oil from Mauritania. Decane and tetracontane were used as internal standards.

Benzene, Toluene, Ethylbenzene, Xylenes (BTEX)
Fish samples were transferred to a 25 ml vial. After addition of water and internal standard, the homogenate was treated in an ultrasonic bath (20 min at 0°C) to further disrupt the tissue. The glass vessel was then connected to a purge and trap apparatus coupled to a gas chromatograph-mass spectrometer (GC-MS). The BTEX were forced out of the tissue by purging with a stream of helium gas, while heating at 70°C and trapped onto a sorbent trap. After purging, the trap was backflushed while being rapidly heated to 250°C and the analytes were desorbed and, next, trapped in a cryofocusing module (-120°C) connected to the analytical column. The analytes were injected into the column by rapidly heating the module from -120°C to 200°C in 0.75 min.

Polycyclic aromatic hydrocarbons
30 g of fish homogenate was transferred to a 250 mL conical flask and was dissolved by shaking (for at least 3 hours in a shaker) with ethanolic potassium hydroxide. The mixture was then transferred to a separation funnel and hexane extracted three times. Hexane extracts were combined and cleaned within a silica-aluminiumoxide column. The clean extract was evaporated to almost dryness and re-dissolved in acetonitrile. The PAHs were determined by HPLC with a fluorescence detector.

Dry weight and fat content
Dry weight was determined gravimetrically by drying the sample at 103°C.
Fat content was determined according to Bligh and Dyer method, in which fat is extracted from the homogenate and its content is determined gravimetrically after evaporation of the solvent.

3. Results

Analyte concentrations measured in pooled *Sardinella aurita* samples from the pre-PFW and post-PFW sampling rounds are shown in Annexes 4 and 5. Each analyte was measured in three samples from the pre-PFW sampling round and in three samples from the post-PFW sampling round. The data in Annex 4 are given on wet (fresh) weight basis and in Annex 5 on dry weight basis.
Comparison of the average concentrations from the pre- and post-PFW sampling round and indication if there is a statistically significant difference (tested by *t*-test) between the two sampling rounds are shown in Tables 2 and 3. The concentrations shown in the tables are average values of three measurements or three limit-of-detection (LOD) values. The values calculated as the average of the three LOD values are indicated in the tables by a '<' symbol. In cases when from the three measurements one or two were below LOD, the concentration shown is the average of the measured value and limit-of-detection value(s). Such averages are conservative estimates of the real concentration and they are often called in legislation texts as upper-bound values or the worst-case scenario values. They are indicated in the tables by the symbol 'a'. The t-test was not performed for means which are below LOD, because such comparison would not compare analyte concentrations but performance of the analytical procedure. Before the t-test was applied, the data were tested using F-test (Microsoft Excel) whether the data have equal variance. Depending on the results of the F-test, t-test (Microsoft Excel) for equal or unequal variances was selected.
Discussion of the results for each group of analytes, which includes comparison of the measured concentrations with the literature data, with maximum tolerable residue levels set in legislation texts or with recommended levels by health organizations is given in the next section.

Table 2. Comparison of average concentrations (on wet weight basis) of priority pollutants in *Sardinella aurita* caught before (pre-PFW) and after (post-PFW) start of PFW discharge.

	pre-PFW sampling		post-PFW sampling			*t*-test (α=0.05)
Metals	Average	STDEV	Average	STDEV	Units	significant difference
Mercury (Hg)	0.0041[a]	0.0005[a]	0.0099	0.0002	mg/kg ww	yes** (*P=4.64e-5*)
Arsenic (As)	1.4	0.1	1.9	0.06	mg/kg ww	yes** (*P=0.0008*)
Copper (Cu)	1.3	0.00	1.2	0.00	mg/kg ww	yes** (*P=1.3e-27*)
Cadmium (Cd)	0.35	0.01	0.40	0.036	mg/kg ww	no** (*P=0.0712*)
Lead (Pb)	<0.04	–	<0.04	–	mg/kg ww	–
Zinc (Zn)	14	1.0	12	0.6	mg/kg ww	no** (*P=0.0668*)
Antimony (Sb)	<0.04	–	<0.02	–	mg/kg ww	–
Beryllium (Be)	<0.007	–	<0.005	–	mg/kg ww	–
Cobalt (Co)	0.059	0.003	0.044	0.003	mg/kg ww	yes** (*P=0.0029*)
Manganese (Mn)	1.7	0.2	1.5	0.23	mg/kg ww	no** (*P=0.2377*)
Tin (Sn)	0.17[a]	0.08[a]	<0.025	–	mg/kg ww	–
Aluminium (Al)	12.3	0.58	8.0	1.1	mg/kg ww	yes** (*P=0.0037*)
Nickel (Ni)	0.20	0.078	0.12	0.024	mg/kg ww	no** (*P=0.1717*)
Chromium (Cr)	0.14[a]	0.14[a]	0.038	0.007	mg/kg ww	no* (*P=0.2094*)
Radium						
Ra-226	<0.001	–	<0.001	–	Bq/kg ww	–
Ra-228	<2.3	–	<5	–	Bq/kg ww	–
TPHs						
TPHs	7.3	1.9	35.8	18.4	mg/kg ww	no* (*P=0.1124*)
BTEX						
Benzene	<3	–	<3	–	µg/kg ww	–
Toluene	<3	–	<3	–	µg/kg ww	–
Ethylbenzene	<3	–	<3	–	µg/kg ww	–
p,m-Xylene	<3	–	<3	–	µg/kg ww	–
o-Xylene	<3	–	<3	–	µg/kg ww	–
PAHs						
Naphthalene	0.28[a]	0.24[a]	4.5	1.4	µg/kg ww	yes* (*P=0.0345*)
Acenaphthene	0.033[a]	0.006[a]	0.27	0.06	µg/kg ww	yes* (*P=0.0195*)
Fluorene	<0.05	–	0.33	0.058	µg/kg ww	yes (no t-test)
Phenanthrene	0.18[a]	0.19[a]	1.6	0.2	µg/kg ww	yes** (*P=0.0009*)
Anthracene	<0.1	–	0.07	0.01	µg/kg ww	–
Fluoranthene	<0.1	–	0.37	0.06	µg/kg ww	yes (*no t-test*)
Pyrene	<0.05	–	0.2	0.00	µg/kg ww	yes (*no t-test*)
Benzo(a)anthracene	<0.05	–	0.043[a]	0.006[a]	µg/kg ww	–
Chrysene	<0.03	–	0.063[a]	0.038[a]	µg/kg ww	–
Benzo(e)pyrene	<0.03	–	<0.06	–	µg/kg ww	–
Benzo(b)fluoranthene	<0.03	–	<0.31	–	µg/kg ww	–
Benzo(k)fluoranthene	<0.03	–	<0.11	–	µg/kg ww	–
Benzo(a)pyrene	<0.02	–	<0.06	–	µg/kg ww	–
Dibenzo(ah)anthracene	<0.02	–	<0.48	–	µg/kg ww	–
Benzo(ghi)perylene	<0.02	–	<0.21	–	µg/kg ww	–
Indeno(123cd)pyrene	<0.02	–	<0.2	–	µg/kg ww	–
Dry weight	29.1	0.4	34.2	0.6	% ww	yes** (*P=0.0003*)
Lipid content	5.9	0.3	12.9	0.6	% ww	yes** (*P=5e-5*)

[a] LOD(s) value was included in calculation; * t-test assuming unequal variances (*df=2*); ** t-test assuming equal variances (*df=4*)

Table 3. Comparison of average concentrations (on dry weight basis) of priority pollutants in *Sardinella aurita* caught before (pre-PFW) and after (post-PFW) start of PFW discharges.

	pre-PFW sampling		post-PFW sampling			*t*-test (α=0.05)
Metals	Average	STDEV	Average	STDEV	Units	significant difference
Mercury (Hg)	0.014[a]	0.001[a]	0.029	0.000	mg/kg dw	yes** (*P=3.4e-5*)
Arsenic (As)	4.0	0.15	5.5	0.2	mg/kg dw	yes** (*P=0.0009*)
Copper (Cu)	4.5	0.06	3.5	0.1	mg/kg dw	yes** (*P=5.2e-5*)
Cadmium (Cd)	1.2	0.03	1.2	0.1	mg/kg dw	no** (*P=0.8058*)
Lead (Pb)	<0.14	–	<0.12	–	mg/kg dw	–
Zinc (Zn)	48	2.8	36	1	mg/kg dw	yes** (*P=0.0027*)
Antimony (Sb)	<0.1	–	<0.058	–	mg/kg dw	–
Beryllium (Be)	<0.02	–	<0.014	–	mg/kg dw	–
Cobalt (Co)	0.17	0.01	0.13	0.01	mg/kg dw	yes** (*P=0.0027*)
Manganese (Mn)	5.0	0.5	4.3	0.7	mg/kg dw	no** (*P=0.2389*)
Tin (Sn)	0.51[a]	0.23[a]	<0.073	–	mg/kg dw	–
Aluminium (Al)	42	2.6	23	3.7	mg/kg dw	yes** (*P=0.0018*)
Nickel (Ni)	0.68	0.26	0.36	0.07	mg/kg dw	no** (*P=0.1020*)
Chromium (Cr)	0.48[a]	0.47[a]	0.11	0.02	mg/kg dw	no* (*P=0.3044*)
Radium						
Ra-226	<0.003	–	<0.003	–	Bq/kg dw	–
Ra-228	<7.8	–	<15	–	Bq/kg dw	–
TPHs						
TPHs	25	6	104	53	mg/kg dw	no* (*P=0.1218*)
BTEX						
Benzene	<10	–	<8.8	–	µg/kg dw	–
Toluene	<10	–	<8.8	–	µg/kg dw	–
Ethylbenzene	<10	–	<8.8	–	µg/kg dw	–
p,m-Xylene	<10	–	<8.8	–	µg/kg dw	–
o-Xylene	<10	–	<8.8	–	µg/kg dw	–
PAHs						
Naphthalene	0.95[a]	0.80[a]	13	4	µg/kg dw	yes* (*P=0.0401*)
Acenaphthene	0.12[a]	0.02[a]	0.78	0.18	µg/kg dw	yes* (*P=0.0228*)
Fluorene	<0.17	–	1.0	0.2	µg/kg dw	yes (*no t-tests*)
Phenanthrene	0.62[a]	0.64[a]	4.8	0.5	µg/kg dw	yes** (*P=0.0010*)
Anthracene	<0.34	–	0.20	0.03	µg/kg dw	–
Fluoranthene	<0.34	–	1.1	0.2	µg/kg dw	yes (*no t-test*)
Pyrene	<0.17	–	0.58	0.01	µg/kg dw	yes (*no t-test*)
Benzo(a)anthracene	<0.17	–	0.13[a]	0.01[a]	µg/kg dw	–
Chrysene	<0.10	–	0.18[a]	0.11[a]	µg/kg dw	–
Benzo(e)pyrene	<0.10	–	<0.18	–	µg/kg dw	–
Benzo(b)fluoranthene	<0.10	–	<0.91	–	µg/kg dw	–
Benzo(k)fluoranthene	<0.10	–	<0.32	–	µg/kg dw	–
Benzo(a)pyrene	<0.069	–	<0.17	–	µg/kg dw	–
Dibenzo(ah)anthracene	<0.069	–	<1.4	–	µg/kg dw	–
Benzo(ghi)perylene	<0.069	–	<0.62	–	µg/kg dw	–
Indeno(123cd)pyrene	<0.069	–	<0.59	–	µg/kg dw	–
Dry weight	29.1	0.4	34.2	0.6	% ww	yes** (*P=0.0003*)
Lipid content	20.1	1.3	37.8	1.4	% dw	yes** (*P=8.8e-5*)

[a] LOD(s) value was included in calculation; * t-test assuming unequal variances (*df=2*); ** t-test assuming equal variances (*df=4*)

4. Discussion

4.1 Metals (Hg, As, Cu, Cd, Ni, Pb, Zn, Al, Sb, Be, Cr, Co, Mn, Sn)

Fourteen metals were measured in the *Sardinella aurita* samples from the pre- and post-PFW sampling round. Figure 5 shows comparison of the levels between the two rounds. As can be seen from the figure, ten metals (Zinc, Aluminium, Arsenic, Copper, Cadmium, Manganese, Mercury, Nickel, Chromium and Cobalt) were detected in samples from both sampling rounds, one (Tin) was detected only in the samples from the pre-PFW sampling round and three (Lead, Antimony and Beryllium) were not detected (below LOD) in any of the sampling rounds. The highest concentration was detected for Zinc and Aluminium, followed by Arsenic, Manganese, Copper, Cadmium and then by the rest of analysed metals. Statistically significant differences between mean concentrations from the pre and post-PFW sampling rounds was found (using *t*-test (α=*0.05*)) for Aluminium, Arsenic, Copper, Mercury, and Cobalt and no difference was found for Zinc, Cadmium, Manganese, Nickel and Chromium. Concentrations of Aluminium, Copper and Cobalt found in the post-PFW sampling round were lower than in the pre-PFW sampling round, while concentrations of Arsenic and Mercury were higher than in the pre-PFW sampling round. Although differences were observed between the two sampling rounds, they are certainly not dramatic and can be attributed to variation between the two samples (*e.g.* fat content and age of fish). The discussion on differences and levels for each of the metals is given below.

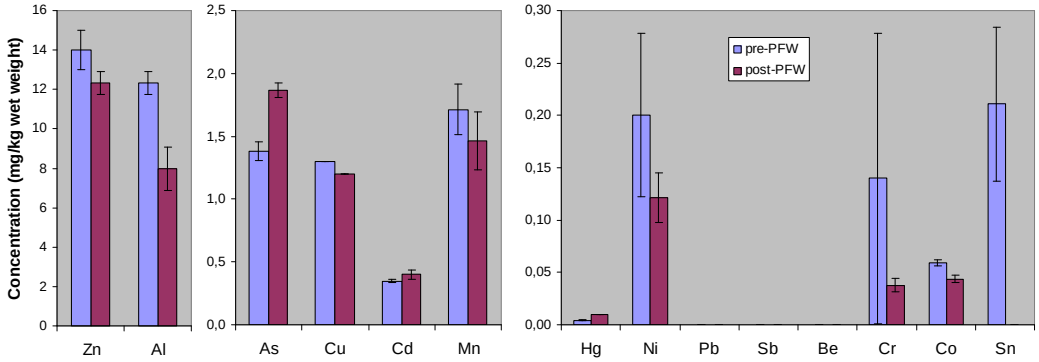

Figure 5*. Average levels of metals in Sardinella aurita from the pre- and post-PFW sampling round performed off Mauritanian coast. Where no values are shown, the level was below the limit of detection.*

Zinc (Zn)

Table 4 shows levels of Zn measured in pre- and post-PFW samples and their comparison with the levels reported in the scientific literature and with regulation and guideline levels. The concentration of Zinc was found to be the highest from all measured metals. The levels of Zn are 12 and 14 mg/kg ww in pre- and post-PFW samples, respectively. There is no statistically significant difference between the two samples .

The published data shows that Zn is an essential nutrient that is present in all organisms, it bioconcentrates moderately in aquatic organisms but it does not biomagnify through terrestrial food chain. A bioconcentration factor (BCF) of 1000 was reported for both aquatic plants and fish, and a value of 10000 was reported for aquatic invertebrates (Fishbein 1981). A recent study shows that bioaccumulation of zinc in fish is inversely related to the aqueous exposure (McGeer 2003). This evidence suggests that fish placed in environments with lower zinc concentrations can sequester zinc in their bodies.

As Table 4 shows, the levels of Zn found in *Sardinella aurita* from this study are in the same range as in fish from elsewhere. Interestingly, one study was located which reports levels of Zn in fish species (including *Sardinella aurita*) sampled in 1996 at Mauritania coast close to

Nouakchott (Romeo 1999). The comparison presented in Table 4 clearly shows that the levels are very similar.
As for the regulation and guideline levels, Food and Agricultural Organization has set permissible limits at 30 mg/kg ww and US EPA has recommended health criteria at 480 mg/kg ww. The levels found in *Sardinella aurita* samples are well below these levels.

Table 4. Comparison of Zn levels from the pre- and post-PFW sampling round with levels reported in the scientific literature and with the regulation and guideline levels.

Place	Date	Species	Matrice	mg/kg ww	mg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	Sardinella aurita	Whole fish	14	48	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	Sardinella aurita	Whole fish	12	36	Post-PFW
Mauritania (18°N–16°W)	5.11.1996	Sardinella aurita	Muscle	–	23	(Romeo 1999)
Mauritania (18°N–16°W)	5.11.1996	Pelagic species	Muscle	–	32–42	(Romeo 1999)
Mauritania (18°N–16°W)	11/1996 & 2/1997	Benthic species	Muscle	–	11–20	(Romeo 1999)
Mauritania (18°N–16°W)	11/1996 & 2/1997	Benthic species	Gills	–	45–120	(Romeo 1999)
Mauritania (18°N–16°W)	11/1996 & 2/1997	Benthic species	Liver	–	100–507	(Romeo 1999)
Coast of Qatar	2000–2001	Demersal species	Muscle	–	5.8–67	(Mora 2004)
Coast of Qatar	2000–2001	Demersal species	Liver	–	143–356	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Muscle	–	1.8–23.3	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Liver	–	184–2400	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Muscle	–	16–27	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Liver	–	295–421	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Muscle	–	10–13	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Liver	–	1335–1714	(Mora 2004)
Coast of California	1978–1989	Various species	Whole fish	36.8[b]	–	(Cohen 2001)
Coast of the Netherlands	2003	Various species	Muscle	3.1–26	–	(IMARES 2006)
Georgia and Alabama	2003	Canned fish	–	0.14–98	–	(Ikem 2005)
Saudi Arabia	2004	Canned fish	–	3.8–24	–	(Ashraf 2006)
Russia, Krasnoyarsk	1997–1998	Crucian carp	Muscle	–	50.5[a]	(Gladyshev 2001)
Russia, Krasnoyarsk	1997–1998	Perch	Muscle	–	104[a]	(Gladyshev 2001)
Permissible limits of Food and Agricultural Organization (FAO)				30	–	(Ikem 2005)
US EPA health criteria				480	–	(Ikem 2005)

[a] average from more values
[b] the value is the 85th percentile which corresponds to approximately 1.5 SD above the mean of a normally distributed data set

Aluminium (Al)

Aluminium concentrations were found to be the second highest, at 12 and 8.0 mg/kg ww in the pre- and post-PFW samples, respectively. The difference between the two sampling rounds is statistically significant, but it is clearly not very big.
The literature data shows that aluminium is ubiquitous, the third most common element of the earth's crust. Accumulation in biota was shown to be pH-dependent. A bioconcentration factor (BCF) of 215 was reported for brook trout at pH=5.3, 123 at pH=6.1 and 36 at pH=7.2 (Cleveland 1986). Generally, aluminium is not bioaccumulated in fish to a significant extent (BCF<300), partly because of its high toxicity (Rosseland 1990; DHHS 2006).
Comparison of the measured levels with levels reported in the scientific literature is given in Table 5. The typical levels in raw muscle tissues of fish caught in North Sea, Northeast Atlantic, Barents Sea, Greenland waters and Baltic sea varies between 0.021 and 0.35 mg/kg ww (Ranau 2001b). Various authors have shown that the food processing (using aluminium foil or instruments) increases the concentration of aluminium in fish by a factor of 2 – 70. The typical levels in prepared fish dishes vary between 0.2 and 20 mg/kg ww. Other food items, such as Coca-Cola or beer from aluminium cans contain aluminium in the range of 0.05 and 0.7 mg/kg and some foodstuffs containing aluminium additives (*e.g.* processed cheese, grain products and grain-based desserts) can have aluminium concentration up to 500 mg/kg ww.
It is obvious that the levels reported for *Sardinella aurita* in this study are significantly higher when compared to the data reported for raw muscle tissues and that they are in the upper part of the range for processed foodstuffs. Although there are various explanations for the increased levels of aluminium in Sardinella samples – *e.g.* increased levels of aluminium in coastal waters of Mauritania or significantly higher aluminium content in whole-fish homogenate (*i.e.* including viscera and bone tissues) compared to muscle tissue – the most probable reason

is contamination of the sample homogenate during the mincing process of pooled samples. Further investigation is therefore required before a final conclusion can be drawn regarding the aluminium content in *Sardinella aurita* samples from Mauritania. However, even if no contamination during homogenization can be proven, consumption of Sardinella would not pose a significant human exposure risk for aluminium. The reported levels in Sardinella are still lower than in some of the processed foodstuffs. Consumption of half a kilo of Sardinella would be equivalent to the estimated total daily intake of aluminium, which is in the range of 2 to 6 mg/day (Gramiccioni 1996; Scancar 2004) and is far below the maximal permitted intake of 60 mg Al per day for an adult man, established by the FAO/WHO Expert Committee on Food Additives (WHO 1989b).
As for the regulation and guideline levels, no data were located for aluminium in fish or foodstuffs.

Table 5. Comparison of Al levels from the pre- and post-PFW sampling round with levels reported in the scientific literature and with the regulation and guideline levels.

Place	Date	Species	Matrice	mg/kg ww	mg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	*Sardinella aurita*	Whole fish	12	42	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	*Sardinella aurita*	Whole fish	8.0	23	Post-PFW
Russia, Krasnoyarsk	1997–1998	Crucian carp	Muscle	–	31[a]	(Gladyshev 2001)
Russia, Krasnoyarsk	1997–1998	Perch	Muscle	–	27[a]	(Gladyshev 2001)
Kuwait	2001	Various dishes	dishes	<3–56	–	(Dashti 2004)
	1985	Cod (food)	Muscle (cooked)	0.4	–	(Greger 1985)
	1989	Salmon (food)	Muscle (cooked)	5.4	–	(Schenk 1989)
	1989	Herring (food)	Muscle (cooked)	0.13	–	(Schenk 1989)
United Kingdom	1999	Fish (food)	Muscle (cooked)	6.1	–	(MAFF 1999)
North Sea	1999	*Gadus morhua*	Muscle	0.033–0.19	–	(Ranau 2001a)
North Sea	1999	*Pollachius virens*	Muscle	0.032–0.16	–	(Ranau 2001a)
North Sea	1999	*Scomber scombrus*	Muscle	0.040–0.10	–	(Ranau 2001a)
Northeast Atlantic	1999	Ocean perch	Muscle	0.065–0.13	–	(Ranau 2001a)
North Sea	1999	Lean fish (<1.5%)	Muscle	0.021–0.35	–	(Ranau 2001b)
North Sea	1999	Fatty fish (>1.5%)	Muscle	0.040–0.30	–	(Ranau 2001b)
North Sea	1999	Flat fish	Muscle	0.040–0.18	–	(Ranau 2001b)
Northeast Atlantic	1999	Lean fish (<1.5%)	Muscle	0.026–0.18	–	(Ranau 2001b)
Northeast Atlantic	1999	Fatty fish (>1.5%)	Muscle	0.055–0.17	–	(Ranau 2001b)
Northeast Atlantic	1999	Flat fish	Muscle	0.021–0.27	–	(Ranau 2001b)

[a] average value from more measurements

Arsenic (As)

Table 6 shows the levels of arsenic measured in pre- and post-PFW samples and their comparison with the levels reported in scientific literature and with regulation and guideline levels. Concentrations found in pre- and post-PFW samples are 1.4 and 1.9 mg/kg ww, respectively. The difference between the two sampling rounds is statistically significant but it is clearly not very large and could be attributed to difference in fat content and age of fish.
Arsenic bioconcentrates moderately and is mainly accumulated in the livers of fish. Bioconcentration factors (BCFs) of freshwater fish ranged from 0 to 17 (EPA 1980a) and from 200-800 in fish livers (Lither 1995). Although fish take in arsenic, which may build up in tissues, most of this arsenic is in an organic form (mainly arsenobetaine and arsenocholine, also referred to as "fish arsenic"), which does not appear to be harmful to humans and is excreted, rapidly and unchanged, in urine.
Low levels of arsenic are commonly found in food. Shellfish and other marine foods contain the highest arsenic concentrations and are the largest dietary source of arsenic. As table 6 shows, arsenic levels in fish are usually about 0.3–5 mg/kg ww and the levels reported for *Sardinella aurita* in this study are within this range.
The maximum permissible limit of 1 mg/kg ww is set by Australia for inorganic arsenic in foodstuffs. Since the total arsenic was analysed in Sardinella, it is not possible to make a proper comparison. However, the recommended values for arsenic by New Zealand and Hong Kong are 2 and 6 mg/kg ww respectively and they are not exceeded in the Sardinella samples.

Table 6. Comparison of arsenic levels from the pre- and post-PFW sampling round with levels reported in the scientific literature and with the regulation and guideline levels.

Place	Date	Species	Matrice	mg/kg ww	mg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	*Sardinella aurita*	Whole fish	1.4	4.0	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	*Sardinella aurita*	Whole fish	1.9	5.5	Post-PFW
Coast of Qatar	2000–2001	Demersal species	Muscle	–	2.2–10	(Mora 2004)
Coast of Qatar	2000–2001	Demersal species	Liver	–	2.4–22	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Muscle	–	1.9–5.0	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Liver	–	1.5–19	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Muscle	–	1.2–14	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Liver	–	2.2–2.8	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Muscle	–	0.83–2.9	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Liver	–	2.61–12	(Mora 2004)
Coast of California	1978–1989	Various species	Whole fish	0.5[b]	–	(Cohen 2001)
Georgia and Alabama	2003	Canned fish	–	0.0–1.72	–	(Ikem 2005)
USA	1991–1997	Canned tuna	Muscle	0.61–1.5	–	(Tao 1999)
USA	1991–1997	Fish sticks	Muscle	0.38–2.8	–	(Tao 1999)
USA	1991–1997	Haddock	Muscle	0.51–10	–	(Tao 1999)
Maximum permissible limit stipulated by Australia for inorganic arsenic				1	–	(Munoz 2000; Ikem 2005)
Recommended value by New Zealand				2	–	(Ikem 2005)
Recommended value by Hong Kong				6	–	(Ikem 2005)

[b] the value is the 85th percentile which corresponds to approximately 1.5 SD above the mean of a normally distributed data set

Copper (Cu)

Table 7 shows levels of copper measured in pre- and post-PFW samples and their comparison with levels reported in the scientific literature and the regulation and guideline levels. The levels of copper are 1.3 and 1.2 mg/kg ww for pre- and post-PFW samples, respectively. Although the difference between the two values is very small, the difference is significant.

Copper is an essential element that is present in all organisms and it has a low potential for bioconcentration. The bioconcentration factor of fish from various field studies was between 10-667 (Perwak 1980).

Table 7. Comparison of copper levels from the pre- and post-PFW sampling round with levels reported in the scientific literature and with the regulation and guideline levels.

Place	Date	Species	Matrice	mg/kg ww	mg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	*Sardinella aurita*	Whole fish	1.3	4.5	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	*Sardinella aurita*	Whole fish	1.2	3.5	Post-PFW
Mauritania (18°N–16°W)	5.11.1996	*Sardinella aurita*	Muscle	–	2.8	(Romeo 1999)
Mauritania (18°N–16°W)	5.11.1996	Pelagic species	Muscle	–	1.6–1.7	(Romeo 1999)
Mauritania (18°N–16°W)	11/1996 & 2/1997	Benthic species	Muscle	–	0.3–1.6	(Romeo 1999)
Mauritania (18°N–16°W)	11/1996 & 2/1997	Benthic species	Gills	–	1.4–3.1	(Romeo 1999)
Mauritania (18°N–16°W)	11/1996 & 2/1997	Benthic species	Liver	–	8.1–49	(Romeo 1999)
Coast of Qatar	2000–2001	Demersal species	Muscle	–	0.49–0.59	(Mora 2004)
Coast of Qatar	2000–2001	Demersal species	Liver	–	34–91	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Muscle	–	0.37–20	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Liver	–	9.3–39	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Muscle	–	0.24–0.59	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Liver	–	76–276	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Muscle	–	0.51–0.58	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Liver	–	39–164	(Mora 2004)
Coast of California	1978–1989	Various species	Whole fish	3.4[b]	–	(Cohen 2001)
Georgia and Alabama	2003	Canned fish	–	0.01–5.3	–	(Ikem 2005)
Saudi Arabia	2004	Canned fish	–	0.13–4.3	–	(Ashraf 2006)
Russia, Krasnoyarsk	1997–1998	Crucian carp	Muscle	–	4.3[a]	(Gladyshev 2001)
Russia, Krasnoyarsk	1997–1998	Perch	Muscle	–	5.1[a]	(Gladyshev 2001)
Northwest Atlantic	1990	cod	Muscle	–	<1.2–1.5	(Hellou 1992b)
Northwest Atlantic	1990	cod	Liver	–	5–10	(Hellou 1992b)
Permissible limits of Food and Agricultural Organization (FAO) and World Health Organization				30	–	(Ikem 2005)
US EPA health criteria				120	–	(Ikem 2005)

[a] average value of more measurements

[b] the value is the 85th percentile which corresponds to approximately 1.5 SD above the mean of a normally distributed data set

As Table 7 shows, the levels of copper found in *Sardinella aurita* from this study are in the same range as the levels in fish from elsewhere. One study was located which reports levels of Cu in fish species (including *Sardinella aurita*) sampled in 1996 in Mauritania waters close to Nouakchott (Romeo 1999). The comparison presented in the table shows that the levels presented in this study are slightly higher. This can however be explained by the fact that the published data are for muscle tissue and in this study whole-fish homogenate was analysed, which is expected to have higher concentrations due to higher bioconcentration of copper in viscera than in muscle tissues.
As for regulation and guideline levels, the Food and Agricultural Organization (FAO) has set permissible limits at 30 mg/kg ww and US EPA has recommended health criteria at 120 mg/kg ww. The levels found in *Sardinella aurita* samples are well below these levels.

Cadmium (Cd)
Table 8 shows the levels of cadmium measured in the pre- and post-PFW samples and the levels reported in scientific literature and regulation and guideline levels. Concentrations of cadmium in pre- and post-PFW samples were 0.35 and 0.40 mg/kg ww, respectively. The difference between the two sampling rounds was not statistically significant.
Cadmium concentrates in freshwater and marine animals to concentrations hundreds to thousands of times higher than the surrounding water. Reported bioconcentration factors range from 3 to 4190 for fresh water aquatic organisms, and from 5 to 3160 for saltwater organisms.
Cadmium has been detected in nearly all samples of food analyzed with sufficient sensitive methods. In foods obtained from unpolluted areas, the cadmium concentration is usually lower than 0.1 mg/kg ww. Milk, dairy products, eggs and beef usually contain <0.01 mg/kg ww while higher concentrations, 0.01-0.10 mg/kg, are typically found in vegetables, fruits, and grains (Elinder 1992). As demonstrated in Table 8, concentrations in muscle tissue of fish are usually <0.01 mg/kg ww, occasionally around 0.1 mg/kg ww, however, significantly higher concentrations, 0.11–195 mg/kg dw, were reported for liver tissue.
The levels reported for Cadmium in this report are significantly higher compared to data published in the literature. The levels in *Sardinella aurita* exceed the maximum permitted levels in fish set by European Commission and they are close also to permissible limits set by the FAO.

Table 8. Comparison of cadmium levels from the pre- and post-PFW sampling round with levels reported in the scientific literature and with the regulation and guideline levels.

Place	Date	Species	Matrice	mg/kg ww	mg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	*Sardinella aurita*	Whole fish	0.35	1.2	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	*Sardinella aurita*	Whole fish	0.40	1.2	Post-PFW
Mauritania (18°N–16°W)	5.11.1996	*Sardinella aurita*	Muscle	–	0.02	(Romeo 1999)
Mauritania (18°N–16°W)	5.11.1996	Pelagic species	Muscle	–	0.03–0.04	(Romeo 1999)
Mauritania (18°N–16°W)	11/1996 & 2/1997	Benthic species	Muscle	–	0.02–0.06	(Romeo 1999)
Mauritania (18°N–16°W)	11/1996 & 2/1997	Benthic species	Gills	–	0.06–0.23	(Romeo 1999)
Mauritania (18°N–16°W)	11/1996 & 2/1997	Benthic species	Liver	–	4.7–51	(Romeo 1999)
Coast of Qatar	2000–2001	Demersal species	Muscle	–	0.001–0.013	(Mora 2004)
Coast of Qatar	2000–2001	Demersal species	Liver	–	0.11–1.5	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Muscle	–	<0.001–0.001	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Liver	–	0.11–9.9	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Muscle	–	<0.001–0.002	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Liver	–	0.369–2.1	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Muscle	–	<0.005–0.014	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Liver	–	11.2–195	(Mora 2004)
Coast of California	1978–1989	Various species	Whole fish	0.1	–	(Cohen 2001)
Coast of the Netherlands	2003	Various species	Muscle	<0.004–0.032	–	(IMARES 2006)
Georgia and Alabama	2003	Canned fish	-	0.000–0.054	–	(Ikem 2005)
Saudi Arabia	2004	Canned fish	-	0.01–0.69	–	(Ashraf 2006)
Permissible limits of Food and Agricultural Organization (FAO)				0.5	–	(Ikem 2005)
Maximum permitted level in fish set by European Commission				0.05-0.30	–	(EC 2002)

Higher levels of cadmium in *Sardinella aurita* could originate from water, sediment and food. High levels of cadmium have already been found in a mollusc species, *Venus verrucosa*, collected in Mauritanian waters in 1987 (Romeo 1988; Sidoumou 1991). Elevated concentrations (4.5 – 51 mg/kg dw) were also reported in livers from fish caught off the town of Nouakchott, although concentrations in muscles of the same fish were on a background level (0.02 – 0.06 mg/kg dw) (Romeo 1999). The elevated levels in those two studies were attributed by the authors to natural processes, such as the high levels of Cd brought into the surface waters through the upwelling of deep nutrient-rich waters which takes place along the Western Atlantic coast. It has been shown that Cd but also Zn have nutrient-type distributions in Atlantic waters (Bruland 1983b) and dissolved Cd maintains a one to one relationship with phosphate concentrations in upwelling waters (Bruland 1983a). Since phosphate rocks are very common in Mauritania but also in neighbouring Senegal (which extracts and exports this fertiliser) (Romeo 1999), leaching of phosphate rocks may increase phosphate concentrations in waters and thus further increase cadmium concentration. Cadmium could be then readily bioaccumulated in the lower portion of the food chain and passed along and eventually bioconcentrate to elevated levels in *Sardinella aurita*. It is however interesting to note that the limited data for Cd in the livers of commercial deep-sea fish were not particularly elevated (Mormede 2001) and the concentrations found in this study seems to be higher than those reported from the Mauritania coast in 1996. Therefore, the elevated level of Cd in fish is clearly a topic of regional interest that merits further investigation.

Manganese (Mn)

Table 9 shows levels of manganese measured in pre- and post-PFW fish samples and their comparison with levels reported in scientific literature. Concentrations of manganese in the pre- and post-PFW samples are 1.7 and 1.5 mg/kg ww, respectively. The difference between the two sampling rounds is not statistically significant.

The literature data shows that manganese in water may be significantly bioconcentrated at lower trophic levels. Folsom (1963) estimated that the BCF of manganese was 2500–6300 for phytoplankton, 300–5500 for marine algae, 800–830 for intertidal mussels, and 35–930 for coastal fish. Similarly, Thomson et al (Thompson 1972) estimated that the BCF of manganese was 10000–20000 for marine and freshwater plants, 10000–40000 for invertebrates, and 100–600 for fish.

Table 9. Comparison of manganese levels from the pre- and post-PFW sampling round with levels reported in the scientific literature.

Place	Date	Species	Matrice	mg/kg ww	mg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	*Sardinella aurita*	Whole fish	1.7	5.0	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	*Sardinella aurita*	Whole fish	1.5	4.3	Post-PFW
Coast of Qatar	2000–2001	Demersal species	Muscle	–	0.18–0.35	(Mora 2004)
Coast of Qatar	2000–2001	Demersal species	Liver	–	2.4–4.2	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Muscle	–	0.06–0.14	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Liver	–	3.2–5.2	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Muscle	–	0.26–0.68	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Liver	–	2.8–5.3	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Muscle	–	0.087–0.20	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Liver	–	1.9–4.8	(Mora 2004)
Georgia and Alabama	2003	Canned fish	–	0.01–2.6	–	(Ikem 2005)
Russia, Krasnoyarsk	1997–1998	Crucian carp	Muscle	–	7.8[a]	(Gladyshev 2001)
Russia, Krasnoyarsk	1997–1998	Perch	Muscle	–	2.4[a]	(Gladyshev 2001)
Canada	1992	Bluefin tuna	Muscle	–	0.16–0.31	(Hellou 1992a)

Manganese is a natural component of most foods. The highest concentrations (up to 50 mg/kg ww) are found in nuts, tea, pineapples, and whole grains, with lower levels (up to 5 mg/kg ww) found in milk products, meats, fish and eggs (Pennington 1986; Davis 1992). As demonstrated in Table 9, the levels of manganese in fish muscle tissue typically range from 0.06 to 0.7 mg/kg dw, while higher concentrations, 1.9–5.3 mg/kg dw were found in liver tissues. The levels found in *Sardinella aurita* samples are higher compared to those typical values. It can be partly explained by the fact that the whole-fish homogenate was analysed instead of muscle

tissue, but regional and species differences should be considered as well. Although the levels in *Sardinella aurita* are higher than those reported elsewhere, they are in the same range (up to 5 mg/kg ww) as some other foodstuffs, e.g. meat, milk or eggs.
As for the guideline levels, US national research council has recommended safe and adequate daily intake levels for manganese that range from 0.3 to 1mg/day for children up to 1 year, 1-2 mg/day for children up to age 10, and 2-5 mg/day for children 10 and older. The upper tolerable intake level of manganese for children (1-3 years old) and males/females (19-70 years old) is 2 and 11 mg/day, respectively (IMNA 2003; Ikem 2005).

Mercury (Hg)
Table 10 shows levels of mercury measured in the pre- and post-PFW fish samples and their comparison with the levels reported in scientific literature and regulation and guideline levels. Concentrations of mercury in pre- and post-PFW samples were 0.0044 and 0.0099 mg/kg ww, respectively. The difference between the two sampling rounds is statistically significant. The higher concentration in the post-PFW sampling round can be explained by older age of the fish compare to those in pre-PFW sampling round. Mercury bioaccumulate in fish tissue and total mercury concentration is known to generally increase with age (DHHS 1999).
The concentration of mercury measured in *Sardinella aurita* in this study was very low. The levels are lower than any other levels reviewed in Table 10. Interestingly, levels measured in this study are lower even in comparison to the levels reported for the fish species (including *Sardinella aurita*) sampled from the Mauritania coast in 1996 and are very low compared to the maximum permitted level in fish set by the European Commission.

Table 10. Comparison of mercury levels from the pre- and post-PFW sampling round with levels reported in the scientific literature and with the regulation and guideline levels.

Place	Date	Species	Matrice	mg/kg ww	mg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	*Sardinella aurita*	Whole fish	0.0044	0.015	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	*Sardinella aurita*	Whole fish	0.0099	0.029	Post-PFW
Mauritania (18°N–16°W)	5.11.1996	*Sardinella aurita*	Muscle	–	0.09	(Romeo 1999)
Mauritania (18°N–16°W)	5.11.1996	Pelagic species	Muscle	–	0.30	(Romeo 1999)
Mauritania (18°N–16°W)	11/1996 & 2/1997	Benthic species	Muscle	–	0.12–0.42	(Romeo 1999)
Mauritania (18°N–16°W)	11/1996 & 2/1997	Benthic species	Gills	–	0.05–0.15	(Romeo 1999)
Mauritania (18°N–16°W)	11/1996 & 2/1997	Benthic species	Liver	–	0.15–0.86	(Romeo 1999)
Coast of Qatar	2000–2001	Demersal species	Muscle	–	0.34–1.04	(Mora 2004)
Coast of Qatar	2000–2001	Demersal species	Liver	–	0.333–1.3	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Muscle	–	0.452–2.35	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Liver	–	0.587–4.65	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Muscle	–	0.669–0.740	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Liver	–	0.287–2.1	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Muscle	–	0.435–0.522	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Liver	–	0.398–1.3	(Mora 2004)
Coast of the Netherlands	2003	Various species	Muscle	0.016–0.10	–	(IMARES 2006)
Georgia and Alabama	2003	Canned fish	–	0.015–0.74	–	(Ikem 2005)
Maximum permitted level in fish set by European Commission (species dependent)				0.50–1.0	–	(EC 2002)

Nickel (Ni)
Table 11 shows the levels of nickel measured in pre- and post-PFW samples and compares them with the levels reported in the scientific literature. Concentrations of nickel in pre- and post-PFW samples are 0.20 and 0.12 mg/kg ww, respectively. The difference between the two samples is not statistically significant.
The literature data shows that nickel is not accumulated in significant amounts by aquatic organisms (Birge 1980; Zaroogian 1984) and the bioconcentration factor for aquatic organisms (*e.g.* algae, arthropods, molluscs, and fish) was reported to be below 100 (Birge 1980; McGeer 2003).
Jenkins (Jenkins 1980) has compiled levels of nickel in aquatic species from scientific literature. For areas thought to be uncontaminated, they reported nickel concentrations in freshwater fish

to be in the range <0.2–2.0 mg/kg ww and in marine fish not detected – 4.0 mg/kg ww. A more recent surveys data (Table 11) are in the range <0.01–0.11 mg/kg dw for raw fish and 0.00–2.1 mg/kg ww for processed fish. The levels reported in the *Sardinella aurita* are higher than those data shown for raw fish. This can be attributed to differences in environmental conditions and the species analysed, but one should keep it mind that it is possible the samples experienced contamination from the mincer during the homogenization process.
As for guideline levels, the upper tolerable intake level of nickel for children (1-3 years old) and males/females (19-70 years old) is 7 and 40 mg/day, respectively (IMNA 2003; Ikem 2005).

Table 11. Comparison of nickel levels from the pre- and post-PFW sampling round with levels reported in the scientific literature.

Place	Date	Species	Matrice	mg/kg ww	mg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	*Sardinella aurita*	Whole fish	0.20	0.68	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	*Sardinella aurita*	Whole fish	0.12	0.36	Post-PFW
Coast of Qatar	2000–2001	Demersal species	Muscle	–	0.03–0.09	(Mora 2004)
Coast of Qatar	2000–2001	Demersal species	Liver	–	<0.01–0.08	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Muscle	–	<0.01	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Liver	–	<0.01–0.08	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Muscle	–	<0.01–0.09	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Liver	–	0.039–0.085	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Muscle	–	<0.05–0.111	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Liver	–	<0.05–0.10	(Mora 2004)
Coast of California	1978–1989	Various species	Whole fish	0.2	–	(Cohen 2001)
Georgia and Alabama	2003	Canned fish	–	0.000–0.78	–	(Ikem 2005)
Saudi Arabia	2004	Canned fish	–	0.12–2.13	–	(Ashraf 2006)
Russia, Krasnoyarsk	1997–1998	Crucian carp	Muscle	–	2.2[a]	(Gladyshev 2001)
Russia, Krasnoyarsk	1997–1998	Perch	Muscle	–	0.46[a]	(Gladyshev 2001)

[a] average value of more measurements

Lead (Pb)
Table 12 shows levels of lead measured in pre- and post-PFW fish samples and comparison with levels reported in the scientific literature and regulation and guideline values. Concentrations of lead in both pre- and post-PFW samples are below the limit of detection, 0.04 mg/kg ww.
Comparison given in Table 12 shows that the levels of lead in *Sardinella aurita* from Mauritania are not higher than levels reported for other species and locations and they are far below the maximum permitted level in fish set by European Commission or the FAO.

Table 12. Comparison of lead levels from the pre- and post-PFW sampling round with levels reported in the scientific literature and with the regulation and guideline levels.

Place	Date	Species	Matrice	mg/kg ww	mg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	*Sardinella aurita*	Whole fish	<0.04	<0.14	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	*Sardinella aurita*	Whole fish	<0.04	<0.12	Post-PFW
Coast of Qatar	2000–2001	Demersal species	Muscle	–	0.108–0.551	(Mora 2004)
Coast of Qatar	2000–2001	Demersal species	Liver	–	0.074–0.276	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Muscle	–	<0.01–0.119	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Liver	–	0.085–0.308	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Muscle	–	0.005–0.028	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Liver	–	<0.001–0.012	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Muscle	–	0.011–0.025	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Liver	–	0.076–0.426	(Mora 2004)
Coast of California	1978–1989	Various species	Whole fish	0.3	–	(Cohen 2001)
Coast of the Netherlands	2003	Various species	Muscle	<0.068–0.19	–	(IMARES 2006)
Georgia and Alabama	2003	Canned fish	–	0.000–0.031	–	(Ikem 2005)
Saudi Arabia	2004	Canned fish	–	0.03–1.97	–	(Ashraf 2006)
Russia, Krasnoyarsk	1997–1998	Crucian carp	Muscle	–	0.21[a]	(Gladyshev 2001)
Russia, Krasnoyarsk	1997–1998	Perch	Muscle	–	0.12[a]	(Gladyshev 2001)
Permissible limits of Food and Agricultural Organization (FAO)				0.5	–	(Ikem 2005)
US EPA health criteria				4	–	(Ikem 2005)
Maximum permitted level in fish set by European Commission (species dependent)				0.20–0.40	–	(EC 2002)

[a] average value of more measurements

Antimony (Sb)

Table 13 shows levels of antimony measured in pre- and post-PFW samples and comparison with levels reported in scientific literature. Concentrations of lead in both pre- and post-PFW samples are below limit of detection which is 0.04 mg/kg ww for pre-PFW samples and 0.02 mg/kg ww for post-PFW samples.

Antimony levels reported for other locations were located only for fish from the Gulf. Similarly to results for *Sardinella aurita* from Mauritania, the levels were below or around the limit of detection, which was 0.001 mg/kg dw. No regulation and guideline levels were located for antimony in fish or foodstuffs.

Table 13. Comparison of antimony levels from the pre- and post-PFW sampling round with levels reported in the scientific literature.

Place	Date	Species	Matrice	mg/kg ww	mg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	*Sardinella aurita*	Whole fish	<0.04	<0.1	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	*Sardinella aurita*	Whole fish	<0.02	<0.058	Post-PFW
Coast of Qatar	2000–2001	Demersal species	Muscle	–	<0.001	(Mora 2004)
Coast of Qatar	2000–2001	Demersal species	Liver	–	<0.001	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Muscle	–	<0.001	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Liver	–	<0.001	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Muscle	–	<0.001	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Liver	–	<0.001–0.002	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Muscle	–	<0.005–0.012	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Liver	–	<0.005	(Mora 2004)

Beryllium (Be)

Table 14 shows levels of beryllium measured in pre- and post-PFW samples and their comparison with the levels reported in scientific literature. Concentrations of beryllium in both pre- and post-PFW samples are below the limit of detection which is 0.007 mg/kg ww for the pre-PFW samples and 0.005 mg/kg ww for the post-PFW samples.

Beryllium does not bioconcentrate in aquatic organisms. A measured bioconcentration factor of 19 was reported for beryllium in bluegill fish (EPA 1980b; DHHS 2002). Other investigators have reported a BCF of 100 for freshwater and marine plants, vertebrates, and fish (Calahan 1979; DHHS 2002).

The beryllium concentration in several foods, fruits, and fruit juices from around the world has been reviewed in (DHHS 2002). The median concentration of beryllium in the 38 foods listed was 0.0225 mg/kg fresh weight (excluding kidney beans) and the range of concentrations was <0.0001–2.2 mg/kg fresh weight. The highest concentrations (in mg/kg fresh weight) were reported for kidney beans (2.2), crisp bread (0.112), garden peas (0.109), parsley (0.077), and pears (0.065). The average concentration of beryllium in fruit and fruit juices was 0.013 mg/L, and the concentrations ranged from not detected to 0.075 mg/L. The levels for fish were located in only two studies and reported concentrations were between 0.0016–0.019 mg/kg ww. The levels of beryllium in *Sardinella aurita* from Mauritania are not higher than these levels. No regulation and guideline levels were located for beryllium in fish or foodstuffs.

Table 14. Comparison of beryllium levels from the pre- and post-PFW sampling round with levels reported in the scientific literature.

Place	Date	Species	Matrice	mg/kg ww	mg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	*Sardinella aurita*	Whole fish	<0.007	<0.02	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	*Sardinella aurita*	Whole fish	<0.005	<0.014	Post-PFW
	1966	Mullet	Whole fish	0.0016–0.019	–	(Meehan 1967)
	1966	Blackfish	Whole fish	0.0037–0.018	–	(Meehan 1967)
USA, Commencement Bay	1986	English sole	Muscle	0.006	–	(Nicola 1987)

Chromium (Cr)

Table 15 shows the levels of chromium measured in pre- and post-PFW fish samples and their comparison with the levels reported in the scientific literature and with regulation and guideline levels. Concentrations of chromium in the pre- and post-PFW samples are 0.14 and 0.038

mg/kg ww, respectively. Although the difference between the levels is rather high, the t-test classified it as not statistically significant due to the high variance in the pre-PFW data.
Chromium does not bioconcentrate in fish (Fishbein 1981; Schmidt 1984). Total chromium levels in most fresh foods are very low (vegetables (0.020–0.050 mg/kg), fruits (0.020 mg/kg), grains and cereals (0.040 mg/kg), chicken eggs (0.060–0.52 mg/kg ww), seafoods (0.12–0.47 mg/kg ww) and whole fish (0.050–0.080 mg/kg ww)) (DHHS 2000). As Table 15 shows, the levels of chromium in raw fish tissue from the Persian Gulf and Guld of Oman were in the range of <0.01 and 0. 075 mg/kg ww, while in processed (canned) fish in the range 0.00 and 0.89 mg/kg ww. The levels reported in the *Sardinella aurita* are higher compared to raw fish data from the Persian Gulf and Gulf of Oman. This could be explained by the difference in environmental conditions and species studied, but similarly to case of Ni and Al one should keep in mind that the levels could be increased by contamination during the homogenization process with the mincer. As for the comparison with the regulation and guideline levels, detected concentration of chromium in *Sardinella aurita* is well below the US EPA health criteria of 8 mg/kg ww. According to the Institute of Medicine there is no upper tolerable intake level for chromium, but the adequate intake of chromium for women and men 51-70 years old is 0.020 and 0.030 mg/day, respectively (IMNA 2003; Ikem 2005).

Table 15. Comparison of chromium levels from the pre- and post-PFW sampling round with levels reported in the scientific literature and with the regulation and guideline levels.

Place	Date	Species	Matrice	mg/kg ww	mg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	*Sardinella aurita*	Whole fish	0.14	0.48	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	*Sardinella aurita*	Whole fish	0.038	0.11	Post-PFW
Coast of Qatar	2000–2001	Demersal species	Muscle	–	<0.01–0.05	(Mora 2004)
Coast of Qatar	2000–2001	Demersal species	Liver	–	<0.01–0.08	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Muscle	–	<0.01–0.05	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Liver	–	<0.01–0.05	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Muscle	–	0.013–0.075	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Liver	–	0.019–0.028	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Muscle	–	<0.05–0.077	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Liver	–	<0.05–0.062	(Mora 2004)
Coast of California	1978–1989	Various species	Whole fish	0.2[b]	–	(Cohen 2001)
Georgia and Alabama	2003	Canned fish	–	0.00–0.30	–	(Ikem 2005)
Saudi Arabia	2004	Canned fish	–	0.02–0.89	–	(Ashraf 2006)
Russia, Krasnoyarsk	1997–1998	Crucian carp	Muscle	–	1.1[a]	(Gladyshev 2001)
Russia, Krasnoyarsk	1997–1998	Perch	Muscle	–	0.36[a]	(Gladyshev 2001)
US EPA health criteria				8	–	(Ikem 2005)

[a] average value of more measurements
[b] the value is the 85th percentile which corresponds to approximately 1.5 SD above the mean of a normally distributed data set

Cobalt (Co)

Table 16 shows levels of cobalt measured in pre- and post-PFW fish samples and their comparison with the levels reported in the scientific literature. Concentrations of cobalt in the pre- and post-PFW samples are 0.059 and 0.044 mg/kg ww, respectively. The difference between the two sampling rounds is statistically significant, but it is not very large.
The bioaccumulation factors (dry weight basis) for cobalt in marine and freshwater fish are 100–4000 and <10–1000, respectively; accumulation in the muscle of marine fish is 5–500 (Smith 1981). Cobalt largely accumulates in the viscera and on the skin, as opposed to the edible parts of the fish. In addition cobalt does not bioaccumulate within the food chain.
The levels of cobalt were determined in 50 different food items, mainly meat, fish, fruit, vegetables, pulses, and cereals on the Swedish market during the years 1983-1990 (Jorhem 1993). Beef liver and seeds were fairly high in cobalt and fish, fruit, and root and leafy vegetables were under 0.01 mg/kg ww. The cobalt levels in mg/kg fresh weight were highest in alfalfa seeds (0.86), linseed (0.56), milk chocolate (0.34), dark chocolate (0.24), white poppy seeds (0.30), blue poppy seeds (0.15), soya beans (0.084), green lentils (0.054), and beef liver (0.043). The cobalt content of 20 brands of alcoholic and nonalcoholic beer widely consumed in Spain ranged from 0.00016 to 0.00056 mg/L with a median of 0.00039 mg/L (Camean 1998).

The cobalt levels were reported in muscle and liver tissues of fish from the Persian Gulf and the Gulf of Oman (see Table 16). The levels in muscle tissue varied between <0.005 and 0.014 mg/kg dw and in liver tissue between 0.16 and 0.58 mg/kg dw. The levels measured in *Sardinella aurita* are higher than those reported for muscle tissue but lower than those in liver tissue. This is not surprising, because as was mentioned before cobalt largely accumulates in the viscera and on the skin and the levels in *Sardinella aurita* were measured in whole fish homogenate. The levels in *Sardinella aurita* are lower than in many foodstuffs. As for the regulation and guideline levels, no data were located for fish or foodstuffs.

Table 16. Comparison of cobalt levels from the pre- and post-PFW sampling round with levels reported in the scientific literature.

Place	Date	Species	Matrice	mg/kg ww	mg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	*Sardinella aurita*	Whole fish	0.059	0.17	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	*Sardinella aurita*	Whole fish	0.044	0.13	Post-PFW
Coast of Qatar	2000–2001	Demersal species	Muscle	–	<0.005–0.013	(Mora 2004)
Coast of Qatar	2000–2001	Demersal species	Liver	–	0.32–0.58	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Muscle	–	<0.005–0.014	(Mora 2004)
Coast of UAE	2000–2001	Demersal species	Liver	–	0.16–0.23	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Muscle	–	<0.01	(Mora 2004)
Coast of Bahrain	2000–2001	Demersal species	Liver	–	0.16–0.42	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Muscle	–	<0.05	(Mora 2004)
Coast of Oman	2000–2001	Demersal species	Liver	–	0.22–0.38	(Mora 2004)
Georgia and Alabama	2003	Canned fish	–	0.00–0.10	–	(Ikem 2005)
Netherlands	1986	Eel	–	2.5–25	–	(Badsha 1988)

Tin (Sn)

Table 17 shows levels of tin measured in pre- and post-PFW samples and their comparison with the levels reported in the scientific literature and with the regulation and guideline levels. Concentration of tin in the pre-PFW samples is 0.21 mg/kg ww and in the post-PFW samples below limit of detection which is 0.025 mg/kg ww.

Bioconcentration factor of inorganic tin was estimated to be 100, 1000 and 3000 for marine and freshwater plants, invertebrates and fish respectively.

Tin concentrations of vegetables, fruits and fruit juices, nuts, dairy products, meat, fish, poultry, eggs, beverages, and other foods not packaged in metal cans are generally <2 mg/kg (DHHS 2005). Tin concentrations in pastas and breads have been reported to range from <0.003 to 0.03 mg/kg. Mean tin concentrations ranging from <1 to 1000 mg/kg have been found in foods packaged in unlacquered or partially lacquered cans, while the average tin concentration in foods in lacquered cans has been reported as 0–6.9 mg/kg (WHO 2003; DHHS 2005).

Table 17. Comparison of tin levels from the pre- and post-PFW sampling round with levels reported in the scientific literature and with the regulation and guideline levels.

Place	Date	Species	Matrice	mg/kg ww	mg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	*Sardinella aurita*	Whole fish	0.21	0.61	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	*Sardinella aurita*	Whole fish	<0.025	<0.073	Post-PFW
Georgia and Alabama	2003	Canned fish	–	0.04–28.7	–	(Ikem 2005)
Permissible limits of World Health Organization (WHO)				250	–	(Ikem 2005)

Tin concentrations in various foods were determined in a dietary tin intake study for adults in France. Foods in lacquered cans generally were found to contain tin concentrations below 10 mg/kg, and tin concentrations ranged from 24 to 156 mg/kg in food from unlacquered cans. The average tin concentration in fresh foods was 0.03 mg/kg (Biego 1999). Canned vegetables and fruit products were found to have mean tin concentrations of 44 and 17 mg/kg fresh weight, respectively, in a 1994 total diet study in the United Kingdom (Ysart 1999; DHHS 2005).

Samples of fish, crustaceans, cephalopods, and bivalve molluscs were purchased from markets in Stockholm, Sweden; London, England; Marseille, France; Singapore; Ulsan, Korea; Sydney, Australia; Galveston, United States; and Halifax, Canada during August and September

1997 and analyzed for tributyltin content (DHHS 2005). Average tributyltin concentrations for bivalves, pelagic fish, pelagic invertebrates, and flatfish were 0.040, 0.016, 0.0074, and 0.0046 mg TBT/kg, respectively.
The levels detected in *Sardinella aurita* in this study are in a good agreement with the levels described above. As for the regulation and guideline levels, permissible limits from the World Health Organization are 250 mg/kg ww. The levels detected in *Sardinella aurita* samples are well below this limit.

4.2 Radium

Measured levels of ^{226}Ra and ^{228}Ra for pre- and post-PFW samples and their comparison with the levels reported in scientific literature and regulation levels are given Table 18 and 19, respectively. The levels of ^{226}Ra and ^{228}Ra found in both rounds are below the limit of detection, which are 0.001 Bq/kg ww for ^{226}Ba and 1-6 Bq/kg ww for ^{228}Ra.
The literature data shows that ^{226}Ra bioaccumulates in marine organisms. Concentration of ^{226}Ra in muscle tissue does occur (Swanson 1983; Ruttenber 1984), but at lower levels than in bones and viscera. Bioconcentration factors (BCFs) for fish living in streams or lakes receiving uranium-processing waste effluent have ranged from 1 to 60 for flesh portions, and from 40 to 1800 in bone samples (Markose 1982; Swanson 1985; Clulow 1998). Haridasan *et al.* (Haridasan 2001) when studying the fate of waste disposal from rock phosphate ore processing in India showed that the BCFs of ^{226}Ra for fish (sp. *Thalassinus*) was 2 for flesh, 20 for bone and 300 for a viscera sample. Since the concentration in *Sardinella aurita* from Mauritania was measured in the whole-fish homogenate, *i.e.* including viscera and bones, the measured concentration <0.001 Bq/kg ww is very low and can be considered to be representative for un-polluted areas.

Table 18. Comparison of ^{226}Ra levels from the pre- and post-PFW sampling round with levels reported in the scientific literature and with the maximum permitted or recommended levels.

Place	Date	Species	Matrice	Bq/kg ww	mg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	*Sardinella aurita*	Whole fish	<0.001	<0.003	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	*Sardinella aurita*	Whole fish	<0.001	<0.003	Post-PFW
Bay of Bengal, Bangladesh		fish		0.1–1.66	–	(S. Ghose 2000)
Syria	1998–2000	Syrian diet - fish	muscle	–	<3	(Al-Masri 2004)
Hong Kong	1990–1995	Grey mullet	Flesh	<0.006–<0.021	–	(Yu 1997)
Hong Kong	1990–1995	Grass carp	flesh	<0.006–<0.015	–	(Yu 1997)
Hong Kong	1990–1995	White pomfret	Flesh	<0.005	–	(Yu 1997)
Hong Kong	1990–1995	Bullseye perch	Flesh	<0.006–<0.02	–	(Yu 1997)
Hong Kong	1990–1995	Golden thread	Flesh	<0.018	–	(Yu 1997)
Hong Kong	1990–1995	Gingo	Flesh	<0.011	–	(Yu 1997)
North Australia	1984–1985	Fork-tailed catfish	Flesh	0.1–0.25	–	(Martin 1998)
North Australia	1984–1985	Bony bream	Flesh	0.53–1.0	–	(Martin 1998)
North Australia	1984–1985	Archer fish	Flesh	0.05	–	(Martin 1998)
North Australia	1984–1985	Barramundi	Flesh	0.05	–	(Martin 1998)
North Australia	1984–1985	Fresh-water mullet	Flesh	0.05	–	(Martin 1998)
North Australia	1984–1985	Long tom	Flesh	0.190	–	(Martin 1998)
North Australia	1984–1985	Saratoga	Flesh	0.1	–	(Martin 1998)
North Australia	1984–1985	Sleepy cod	Flesh	1.3	–	(Martin 1998)
North Australia	1984–1985	Tarpon	Flesh	0.02	–	(Martin 1998)
India, Chitrapuzha river, (cont.)	1998	Thalassinus	Flesh	0.042	–	(Haridasan 2001)
India, Chitrapuzha river, (cont.)	1998	Thalassinus	Viscera	6.2	–	(Haridasan 2001)
India, Chitrapuzha river, (cont.))	1998	Thalassinus	Bones	0.34	–	(Haridasan 2001)
Canada, Eliot lake (cont.)	1989	Trout	Bones	–	0.008–0.014	(Clulow 1998)
Canada, Eliot lake (cont.)	1989	Trout	Muscle	–	0.0014–0.0032	(Clulow 1998)
Canada, Eliot lake (control)	1989	Trout	Bones	–	0.011–0.015	(Clulow 1998)
Canada, Eliot lake (control)	1989	Trout	Muscle	–	0.0026–0.0064	(Clulow 1998)
Canada, Eliot lake (cont.)	1989	Whitefish	Bones	–	0.031–0.076	(Clulow 1998)
Canada, Eliot lake (cont.)	1989	Whitefish	Muscle	–	0.0017–0.0028	(Clulow 1998)
Canada, Eliot lake (control)	1989	Whitefish	Bones	–	0.0065–0.010	(Clulow 1998)
Canada, Eliot lake (control)	1989	Whitefish	Muscle	–	0.002–0.0021	(Clulow 1998)
Maximum permitted levels set by EC in foodstuffs and feedingstuffs following a nuclear accident or any other case of radiological emergency				400–1250	–	(EC 1989)

Table 19. Comparison of ^{228}Ra levels from the pre- and post-PFW sampling round with levels reported in the scientific literature and with the maximum permitted or recommended levels.

Place	Date	Species	Matrice	Bq/kg ww	mg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	*Sardinella aurita*	Whole fish	<2.3	<7.8	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	*Sardinella aurita*	Whole fish	<5	<15	Post-PFW
Bay of Bengal, Bangladesh		fish		0.39–1.35	–	(S. Ghose 2000)
Syria	1998–2000	Syrian diet - fish	muscle	–	<4	(Al-Masri 2004)
Hong Kong	1990–1995	Grey mullet	Flesh	0.1–0.15	–	(Yu 1997)
Hong Kong	1990–1995	Grass carp	flesh	<0.076	–	(Yu 1997)
Hong Kong	1990–1995	White pomfret	Flesh	<0.028	–	(Yu 1997)
Hong Kong	1990–1995	Bullseye perch	Flesh	0.064–0.072	–	(Yu 1997)
Hong Kong	1990–1995	Golden thread	Flesh	<0.07	–	(Yu 1997)
Hong Kong	1990–1995	Gingo	Flesh	<0.068	–	(Yu 1997)
Maximum permitted levels set by EC in foodstuffs and feedingstuffs following a nuclear accident or any other case of radiological emergency				400–1250	–	(EC 1989)

The literature data on levels of ^{228}Ra in fish and food stuffs are rather rare. Three studies has been located and the concentrations reported were in the range <0.028 and 1.35 Bq/kg ww. The levels found in *Sardinella aurita* from Mauritania are all below the LOD of the method used (*i.e.* <1 – <6 Bq/kg ww).

Maximum permitted levels of radioactive contamination for foodstuffs and feedingstuffs following a nuclear accident or any other case of radiological emergency are set in European Council (EURATOM) regulation No 2218/89 (EC 1989). Radium isotopes are not explicitly listed in the list, but they might be covered by category 'All other nuclides of half-life greater than 10 days'. The maximum permitted levels for this group are 400, 1000, 1250 and 1000 Bq/kg ww for baby foods, dairy produce, other foodstuffs and liquid foodstuffs, respectively. The concentrations of both isotopes in *Sardinella aurita* samples from Mauritania are well below these maximum permitted levels.

4.3 Total petroleum hydrocarbons (TPHs)

Measured levels of TPHs for pre- and post-PFW sampling rounds and their comparison with the levels reported in the scientific literature are given in Table 20.

The average level measured in the pre-PFW sample is 7.3 mg/kg ww and in the post-PFW sample is 35.8 mg/kg ww. Although the level detected in the post-PFW samples is 5 times higher than in the pre-PFW samples, the difference between the two sampling rounds is not statistically significant. This is likely to be due to the large variation among the individual measurements, especially in the measurements of post-PFW samples. The higher concentration and increased variation in the post-PFW samples can be explained by two factors. First, fish from the post-PFW sampling were older than from the pre-PFW sampling (see differences in average weights and lengths) and could therefore bioaccumulate more contaminants during their lives. Second, fish from the post-PFW sampling had higher fat content (12 % ww versus 6% ww), which resulted in higher amount of matrix artefacts in the final extract and consequently in the increased response and variation.

The majority of studies found for TPH levels in fish samples originates from the studies performed as a consequence of the massive oil spills in the Persian Gulf during 1991 war. In these studies, muscle concentrations between 0.3 and 80 mg/kg ww were reported as typical for uncontaminated sites (Burns 1973; Gupta 1993). The levels measured in *Sardinella aurita* in Mauritania are similar to these levels, especially if we take into account that the Sardinella analyses were performed in whole-fish homogenate and bioconcentration factors for livers are about 10-50 times higher than for muscle tissue (see Table 20).

As for the maximum permitted levels or recommended levels of TPHs, no regulations or guidelines applicable to fish or foodstuffs were located for these compounds.

Table 20. Comparison of TPH levels from the pre- and post-PFW sampling round with levels reported in the scientific literature.

Place	Date	Species	Matrice	mg/kg ww	mg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	*Sardinella aurita*	Whole fish	7.3	25	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	*Sardinella aurita*	Whole fish	35.8	104	Post-PFW
Coast of Qatar	2000–2001	Demersal species	Muscle	–	4–16	(Tolosa 2005)
Coast of Qatar	2000–2001	Demersal species	Liver	–	44–185	(Tolosa 2005)
Coast of UAE	2000–2001	Demersal species	Muscle	–	2–16	(Tolosa 2005)
Coast of UAE	2000–2001	Demersal species	Liver	–	56–975	(Tolosa 2005)
Coast of Bahrain	2000–2001	Demersal species	Muscle	–	12–16	(Tolosa 2005)
Coast of Bahrain	2000–2001	Demersal species	Liver	–	44–82	(Tolosa 2005)
Coast of Oman	2000–2001	Demersal species	Muscle	–	11–34	(Tolosa 2005)
Coast of Oman	2000–2001	Demersal species	Liver	–	87–177	(Tolosa 2005)
Arabian Sea (uncontaminated)	1991	Demersal species	Muscle	0.3–3.7	–	(Gupta 1993)
uncontaminated site	1970–1972	Pelagic fish	Muscle	0.3–85	–	(Burns 1973; Gupta 1993)

4.4 BTEX

Measured levels of benzene, toluene, ethylbenzene, p&m-xylens and o-xylen in pre- and post-PFW samples and their comparison with the levels reported in the scientific literature are given in Tables 21, 22, 23, 24 and 25, respectively.

As can be seen from the tables, the levels of all BTEX in both samples are below the limit of detection, 3 μg/kg ww for all BTEX compounds.

Despite the known hazard posed by BTEXs, relatively little is known about the abundance or presence of these compounds in the marine environment, especially in biota, and their behaviour in the marine ecosystem. Only two studies have examined the behaviour of BTEX compounds in the marine environment (Roose 2000; Roose 2003). One of them reported concentrations in marine organisms from the Belgium coast of the North Sea and the second one in freshwater eels from Belgium rivers. The average levels reported for marine fish were in the range 0.7 - 5.8 μg/kg ww for benzene, 0.9 – 21 μg/kg ww for toluene, 1.5 – 11 μg/kg ww for ethylbenzene, 1.5 – 11 μg/kg ww for m&p-xylene and 0.7 – 4.1 μg/kg ww for o-xylene. Although the exact levels for *Sardinella aurita* are not known, it can be concluded that they are not higher than those reported for the North Sea.

Levels of benzene were monitored in food items in a 5 year study (1996 – 2000) sponsored by the U.S. Food and Drug Administration (Fleming-Jones 2003). Benzene was found in many food items, such as in cheddar cheese, cream cheese, margarine, butter, sour cream, ground beef and many others. The levels varied between 1 and 190 μg/kg ww and the foods with the greatest maximum concentration of benzene were ground beef (maximum 190 μg/kg ww), raw bananas (maximum 132 μg/kg ww) and carbonated cola (maximum 138 μg/kg). Clearly, concentration of benzene in *Sardinella aurita* from Mauritania is lower than in many other foodstuffs.

As for the maximum permitted levels or recommended levels of BTEX, no regulations or guidelines applicable to fish or foodstuffs were located for these compounds.

Table 21. Comparison of benzene levels from the pre- and post-PFW sampling round with levels reported in the scientific literature.

Place	Date	Species	Matrice	μg/kg ww	μg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	*Sardinella aurita*	Whole fish	<3	<10	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	*Sardinella aurita*	Whole fish	<3	<8.8	Post-PFW
Belgium coast, North Sea	1998	Crangon crangon	–	0.70	–	(Roose 2000)
Belgium coast, North Sea	1998	Mactra stultorum	–	2.5	–	(Roose 2000)
Belgium coast, North Sea	1998	Mya truncate	–	0.55	–	(Roose 2000)
Belgium coast, North Sea	1998	Spisula species	–	2.0	–	(Roose 2000)
Belgium coast, North Sea	1998	Limanda limanda	Liver	14	–	(Roose 2000)
Belgium coast, North Sea	1998	Limanda lima	Muscle	0.50	–	(Roose 2000)
Belgium coast, North Sea	1998	Merlangius merlangus	Liver	5.8	–	(Roose 2000)
Belgium coast, North Sea	1998	Merlangius merlangus	Muscle	0.80	–	(Roose 2000)
Belgium rivers	2001	Freshwater eel	Muscle	1.2–11	–	(Roose 2003)

Table 22. Comparison of toluene levels from the pre- and post-PFW sampling round with levels reported in the scientific literature.

Place	Date	Species	Matrice	µg/kg ww	µg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	*Sardinella aurita*	Whole fish	<3	<10	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	*Sardinella aurita*	Whole fish	<3	<8.8	Post-PFW
Belgium coast, North Sea	1998	Crangon crangon		0.90	–	(Roose 2000)
Belgium coast, North Sea	1998	Mactra stultorum		21	–	(Roose 2000)
Belgium coast, North Sea	1998	Mya truncate		3.2	–	(Roose 2000)
Belgium coast, North Sea	1998	Spisula species		1.6	–	(Roose 2000)
Belgium coast, North Sea	1998	Limanda limanda	Liver	4.8	–	(Roose 2000)
Belgium coast, North Sea	1998	Limanda lima	Muscle	0.95	–	(Roose 2000)
Belgium coast, North Sea	1998	Merlangius merlangus	Liver	1.5	–	(Roose 2000)
Belgium coast, North Sea	1998	Merlangius merlangus	Muscle	1.0	–	(Roose 2000)
Belgium rivers	2001	Freshwater eel	Muscle	1.9-73	–	(Roose 2003)

Table 23. Comparison of ethylbenzene levels from the pre- and post-PFW sampling round with levels reported in the scientific literature.

Place	Date	Species	Matrice	µg/kg ww	µg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	*Sardinella aurita*	Whole fish	<3	<10	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	*Sardinella aurita*	Whole fish	<3	<8.8	Post-PFW
Belgium coast, North Sea	1998	Crangon crangon		9.8	–	(Roose 2000)
Belgium coast, North Sea	1998	Mactra stultorum		2.5	–	(Roose 2000)
Belgium coast, North Sea	1998	Mya truncate		2.4	–	(Roose 2000)
Belgium coast, North Sea	1998	Spisula species		2.2	–	(Roose 2000)
Belgium coast, North Sea	1998	Limanda limanda	Liver	11	–	(Roose 2000)
Belgium coast, North Sea	1998	Limanda lima	Muscle	1.5	–	(Roose 2000)
Belgium coast, North Sea	1998	Merlangius merlangus	Liver	5.2	–	(Roose 2000)
Belgium coast, North Sea	1998	Merlangius merlangus	Muscle	2.6	–	(Roose 2000)
Belgium rivers	2001	Freshwater eel	Muscle	1.2–30	–	(Roose 2003)

Table 24. Comparison of m&p-xylene levels from the pre- and post-PFW sampling round with levels reported in the scientific literature.

Place	Date	Species	Matrice	µg/kg ww	µg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	*Sardinella aurita*	Whole fish	<3	<10	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	*Sardinella aurita*	Whole fish	<3	<8.8	Post-PFW
Belgium coast, North Sea	1998	Crangon crangon		9.7	–	(Roose 2000)
Belgium coast, North Sea	1998	Mactra stultorum		3.0	–	(Roose 2000)
Belgium coast, North Sea	1998	Mya truncate		3.5	–	(Roose 2000)
Belgium coast, North Sea	1998	Spisula species		2.5	–	(Roose 2000)
Belgium coast, North Sea	1998	Limanda limanda	Liver	11	–	(Roose 2000)
Belgium coast, North Sea	1998	Limanda lima	Muscle	1.5	–	(Roose 2000)
Belgium coast, North Sea	1998	Merlangius merlangus	Liver	6.3	–	(Roose 2000)
Belgium coast, North Sea	1998	Merlangius merlangus	Muscle	3.2	–	(Roose 2000)
Belgium rivers	2001	Freshwater eel	Muscle	0.7–35	–	(Roose 2003)

Table 25. Comparison of o-xylene levels from the pre- and post-PFW sampling round with levels reported in the scientific literature.

Place	Date	Species	Matrice	µg/kg ww	µg/kg dw	Reference
Mauritania (18°23'N–16°20'W)	18.1.2006	*Sardinella aurita*	Whole fish	<3	<10	Pre-PFW
Mauritania (20°02'N–17°36'W)	1.7.2006	*Sardinella aurita*	Whole fish	<3	<8.8	Post-PFW
Belgium coast, North Sea	1998	Crangon crangon		4.1	–	(Roose 2000)
Belgium coast, North Sea	1998	Mactra stultorum		1.6	–	(Roose 2000)
Belgium coast, North Sea	1998	Mya truncate		1.3	–	(Roose 2000)
Belgium coast, North Sea	1998	Spisula species		1.6	–	(Roose 2000)
Belgium coast, North Sea	1998	Limanda limanda	Liver	6.0	–	(Roose 2000)
Belgium coast, North Sea	1998	Limanda lima	Muscle	0.70	–	(Roose 2000)
Belgium coast, North Sea	1998	Merlangius merlangus	Liver	3.6	–	(Roose 2000)
Belgium coast, North Sea	1998	Merlangius merlangus	Muscle	1.5	–	(Roose 2000)
Belgium rivers	2001	Freshwater eel	Muscle	0.6–40	–	(Roose 2003)

4.5 Polycyclic aromatic hydrocarbons (PAHs)

Sixteen EPA PAH compounds were measured in the *Sardinella aurita* samples from the pre- and post-PFW sampling rounds. In samples from the pre-PFW round three PAH compounds, naphthalene, acentaphtene and phenanthrene were detected, while in samples from the post-PFW sampling round nine PAHs, naphthalene, acentaphtene, phenanthrene, fluorene, anthracene, fluoranthene, pyrene, benzo(a)anthracene and chrysene were detected. Comparison of the levels from the two sampling rounds for the detected PAHs is shown in Figure 6. The differences between the two sampling rounds observed in the figure can be considered statistically significant for six PAHs, naphthalene, acenaphtene, phenanthrene, fluorene, fluoranthene and pyrene. For all these six compounds, higher levels were detected in the post-PFW samples than in the pre-PFW samples. For three PAHs detected in both samples (naphthalene, acentaphtene and phenanthrene), a 10-fold increase in the post-PFW samples was observed. In the following text, the literature data on PAHs in fish and foodstuffs are given and the reported levels are compared with those measured in this study.

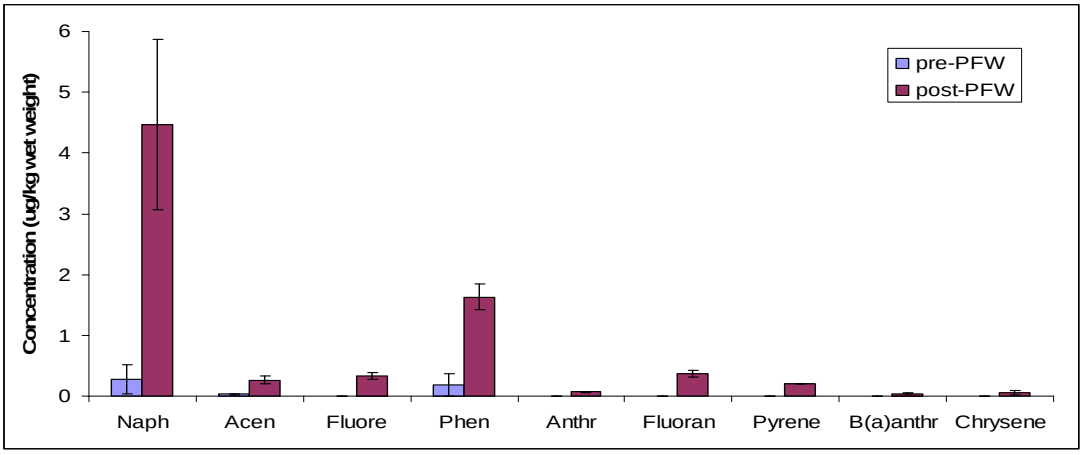

***Figure 6**. Average levels of detected PAHs in Sardinella aurita from the pre- and post-PFW sampling round performed at Mauritanian coast. When no values are shown, the level was below limit of detection.*

Literature data shows that although PAHs are accumulated in terrestrial and aquatic plants, fish, and invertebrates, many animals (including fish) are able to metabolize and eliminate these compounds. In fish and crustaceans bioconcentration factors have generally been reported in the range of 10–10000 (Eisler 1987; DHHS 1995). In general, bioconcentration was greater for the higher molecular weight compounds than for the lower molecular weight compounds. The above mentioned ability of fish to metabolize PAHs may explain why benzo[a]pyrene is not frequently detected or found only at very low levels in fish from environments heavily contaminated with PAHs (Varanasi 1980; Varanasi 1981). Because of the quick elimination of PAHs – half-lives for elimination of PAHs in fish was shown to range from <2 days to 9 days (Niimi 1987; DHHS 1995) – biomagnification has not been reported for these compounds (Eisler 1987).

PAHs have been detected in many food products including cereal, potatoes, grain, flour, bread, vegetables, fruits, oils, and smoked or broiled meat and fish. The concentrations in uncooked foods largely depend on the source of the food. The method of cooking influence the PAH content of food; the time of cooking, the distance from the heat source, and the drainage of fat during cooking all influence PAH content. Charcoal broiling and smoking is well known to significantly increase amounts of PAHs in food. In a composite sample characterized to be typical of the U.S. diet in 1979, Howard found that PAH concentrations in all food groups were less than 2 mg/kg (Howard 1979).

Few studies reporting levels of PAHs in various fish species were located. An overview of the levels reported is given in Table 26. One study in which the concentrations of PAHs in various fish and shellfish species were evaluated from Prince William Sound, Alaska, following the 1989 Exxon Valdez spill of more than 10 million gallons of crude oil were evaluated. PAHs in this

study were not detected in 18% (72/402) of the samples; trace levels were found in 78% (312/402) of the samples; and individual PAH concentrations ranging from 5 to 12 µg/kg (wet or dry weight not specified) were found in 4% (18/402) of the samples. There was no apparent difference between PAH concentrations in salmon collected from impacted areas and those collected from control areas; however, there was a suggestion that contamination may increase with time. No PAHs were detected in 14% (31/221) of samples collected in 1989, trace levels were found in 85% of these samples, and only 1% (3 samples) had individual PAH concentration >5 µg/kg; whereas in the 1990 samples, PAHs were detected in all of the 41 samples, trace levels were found in 87% of the samples, and 13% (6 samples) had individual PAH concentrations >5 µg/kg.

Table 26. Comparison of PAH levels (express both on wet and dry weight basis) from the pre- and post-PFW sampling round with levels reported in the scientific literature and with the maximum permitted levels.

Location	Year	1	2	3	4	5	6	7	8	Unit	Reference
Mauritania	2006	0.28	0.033	<0.05	0.18	<0.1	<0.1	<0.05	<0.05	µg/kg ww	Pre-PFW
Mauritania	2006	4.5	0.27	0.33	1.6	0.07	0.37	0.2	0.043	µg/kg ww	Post-PFW
Mauritania	2006	0.95	0.12	<0.17	0.62	<0.34	<0.34	<0.17	<0.17	µg/kg dw	Pre-PFW
Mauritania	2006	13	0.78	1.0	4.8	0.2	1.1	0.58	0.13	µg/kg dw	Post-PFW
Mediterranean	1988	nd–63	nd–264	nd–20	nd–20	nd–14	nd–192	nd–48	nd–473	µg/kg ww	(Cocchieri 1990)
The Gulf	1992	nd–67	nd–5.1	nd–19	nd–100	nd–78	nd–120	nd–340	nd–0.3	µg/kg dw	(Al-Yakoob 1993)
The Gulf	1992	–	–	nd–60	nd–15	–	–	nd–140	–	µg/kg dw	(Fowler 1993)
Japan	1998	12	2.5	2.4	0.62	0.25	1.9	-	–	µg/kg dw	(Deb 2000)
Kuwait	1993	2–156	1.6–22	nd–65	5.5–88	nd–5.1	nd–32	nd–68	0.14–5.3	µg/kg dw	(Saeed 1995)
The Gulf	2000	nd–12	–	–	0.3–4	nd–1.5	0.4–4	0.3–5	nd–0.3	µg/kg dw	(Tolosa 2005)
EC regulation level		–	–	–	–	–	–	–	–	µg/kg ww	(EC 2002)

Location	Year	9	10	11	12	13	14	15	16	Unit	Reference
Mauritania	2006	<0.03	<0.03	<0.03	<0.03	<0.02	<0.02	<0.02	<0.02	µg/kg ww	Pre-PFW
Mauritania	2006	0.063	<0.06	<0.31	<0.11	<0.06	<0.48	<0.21	<0.20	µg/kg ww	Post-PFW
Mauritania	2006	<0.10	<0.10	<0.10	<0.10	<0.069	<0.069	<0.069	<0.069	µg/kg dw	Pre-PFW
Mauritania	2006	0.18	<0.18	<0.91	<0.32	<0.17	<1.4	<0.62	<0.59	µg/kg dw	Post-PFW
Mediterranean	1988	nd–86	–	nd–345	nd–144	nd–44	nd–34	nd–1262	nd–185	µg/kg ww	(Cocchieri 1990)
The Gulf	1992	nd–0.05	–	–	–	nd–7.6	–	–	–	µg/kg dw	(Al-Yakoob 1993)
The Gulf	1992	–	–	–	–	–	–	–	–	µg/kg dw	(Fowler 1993)
Japan	1998	–	–	–	–	–	–	–	–	µg/kg dw	(Deb 2000)
Kuwait	1993	nd-16	–	–	–	nd–5.3	0.21–39	0.27–31	0.28–29	µg/kg dw	(Saeed 1995)
The Gulf	2000	–	–	–	–	nd–0.1	–	–	nd	µg/kg dw	(Tolosa 2005)
EC regulation level		–	–	–	–	2.0	–	–	–	µg/kg ww	(EC 2002)

[1] naphthalene, [2] acenaphthene, [3] fluorene, [4] phenanthrene, [5] anthracene, [6] fluoranthene, [7] pyrene, [8] benzo(a)anthracene, [9] chrysene, [10] benzo(e)pyrene, [11] benzo(b)fluoranthene, [12] benzo(k)fluoranthene, [13] benzo(a)pyrene, [14] dibenzo(ah)anthracene, [15] benzo(ghi)perylene, [16] indeno(123cd)pyrene

Evaluation of levels measured in *Sardinella aurita* from Mauritania shows that lower molecular weight PAHs were detected, while higher molecular weight PAHs originating from pyrolysis processes were all below the limit of detection. Comparison of the above discussed literature levels with the levels measured in this study shows that concentrations of PAHs in *Sardinella aurita* from Mauritania are in the lower part of the ranges reported for other locations.
The only European Commission regulation for PAHs is for benzo(a)pyrene and is set at 2 µg/kg ww. However, Benzo(a)pyrene was not detected in any of the *Sardinella aurita* samples.

5. Conclusions and recommendations

Two sampling rounds of *Sardinella aurita* were performed in the waters off the coast of Mauritania to evaluate levels of contamination prior to oil production (pre-PFW) and following start of oil production (post-PFW). The pre-PFW sampling round was carried out in January 18, 2006 at location 18°23'N–16°20'W and the post-PFW sampling round in July 1, 2006 at 20°02'N–17°36'W.

In total, 38 analytes were analysed in six pooled samples (3 from the pre-PFW and 3 from the post-PFW sampling round). Antimony (Sb), beryllium (Be), lead (Pb), radium (^{226}Ra and ^{228}Ra), BTEX and higher molecular weight PAHs were not detected in any of the samples, indicating that these elements and compounds were either absent or in quantities too low to detect. The levels of 11 metals (Hg, As, Cu, Cd, Zn, Be, Co, Mn, Sn, Al, Ni, and Cr), total petroleum hydrocarbons and lower molecular weight PAHs were detected in at least one of the samples. Comparison of the mean values from the pre- and post-PFW sampling round for detected analytes and consequent evaluation by the t-test showed that there is a statistically significant difference for Hg, As, Cu, Co, Al and six PAHs (naphthalene, acenaphthene, fluorene, phenanthrene, fluoranthene and pyrene). The levels of Hg, As and six PAHs were higher in the post-PFW samples, while levels of Cu, Co and Al were higher in the pre-PFW samples. Although the difference is statistically significant, the difference for metals is not very large. The difference in concentrations of six PAHs is higher - concentrations differ by a factor of 4 to 16. The observed differences could be attributed to differences in the environment in which the fish reside but also to age differences between the two sampling rounds. Compared to the pre-PFW samples, fish in post-PFW samples were older (had twice as much fat content and higher weight) and consequently more contaminants could bioaccumulate.

Comparison of the measured concentrations with the concentrations reported for fish and food in scientific literature shows that levels of contaminants in *Sardinella aurita* from Mauritania are generally low. Higher concentrations than the background levels reported from elsewhere were detected only for aluminium, nickel, chromium and cadmium. Although the levels of aluminium, nickel and chromium are higher than those reported for raw fish samples, they are in the same range as levels reported for processed fish and food (*e.g.* canning, baking). Therefore, there is a suspicion that the increased levels are a consequence of the homogenization process. The concentration of cadmium found in *Sardinella aurita* samples is higher than the maximum permitted limit set by European Commission for fish marketed in European Union countries and is a topic of regional interest that merits further investigation. However, the increased concentrations of cadmium in fish and molluscs from Mauritanian coastal waters have been reported before and have been attributed to natural processes, such as the high levels of cadmium brought to surface waters through the upwelling of deep nutrient rich waters that takes place along the Western Atlantic coast.

The survey performed provides information on levels of contaminants in *Sardinella aurita* prior to and shortly after start of oil production. Although increases in the concentration of some PAHs and metals was observed, it is not possible to attribute it to the effect of oil production. However, in order to be able to conclude that oil production activities have no effect on levels of contaminants in fish populations, a long term annual monitoring programme should be established and data compared with data from this study. In addition, benthic fish species and invertebrates such as mussels, cockles or octopus should be included in the monitoring programme. Many of these species do not migrate, they live close to the sea bottom (which might be affected by the long term discharges) and they are important for Mauritanian fisheries industry and for the local population.

6. References

Al-Masri, M. S., H. Mukallati, A. Al-Hamwi, H. Khalili, M. Hassan, H. Assaf, Y. Amin and A. Nashawati (2004). "Natural radionuclides in Syrian diet and their daily intake." *Journal of Radioanalytical and Nuclear Chemistry* **260**: 405-412.

Al-Yakoob, S., T. Saeed and H. Al-Hashash (1993). "Polycyclic aromatic hydrocarbons in edible tissue of fish from the Gulf after the 1991 oil spill." *Marine Pollution Bulletin* **27**: 297-301.

Ashraf, W., Z. Seddigi, A. Abulkibash and M. Khalid (2006). "Levels of selected metals in canned fish consumed in kingdom of saudi arabia." *Environmental Monitoring and Assessment* **117**: 271-279.

Badsha, K. S. and C. R. Goldspink (1988). "Heavy metal levels in three species of fish in Tjeukemeer, a Dutch polder lake." *Chemosphere* **17**: 459-463.

Biego, G. H., M. Joyeux and P. Hartemann (1999). "Determination of dietary tin intake in an adult French citizen." *Archive Environmental Contaminants and Toxicology* **36**: 227-232.

Birge, W. J. and J. A. Black (1980). Aquatic toxicology of nickel. Nickel in the environment. J. O. Nriagu. New York, John Wiley and Sons**:** 354-355.

Boely, T., J. Chabanne, P. Freon and B. Stequert (1982). "Cycle sexuel et migrations de Sardinella aurita sur le plateau continental ouest-africain, des Iles Bissagos a la Mauritanie." *Rapports et Proces-verbaux des Reunions, Conseil International pour l'Exploration de la Mer* **180**: 350-355.

Bruland, K. W. (1983a). Trace elements in sea water. Chemical Oceanography. J. P. Riley and R. Chester. London, Academic Press**:** 157-220.

Bruland, K. W. and R. P. Franks (1983b). Mn, Ni, Cu, Zn and Cd in the Western North Atlantic. Trace metals in sea water. C. S. Wong, E. Boyle, K.W.Bruland, J. D. Burton and E. D. Goldberg. New York, London, Plenum Press**:** 395-414.

Burns, K. A. and J. M. Teal (1973). "Hydrocarbons in the pelagic sargassum community." *Deep-Sea Research* **20**: 207-211.

Calahan, M. A., M. W. Slimak and N. W. Gabel (1979). Water[related environmental fate of 129 priority pollutants. Washington DC, U.S. Environmental Protection Agency. EPA-440/4-79-029a.

Camean, A., M. Lopez-Artiguez and I. Roca (1998). "Determination of cobalt, manganese, and alcohol content in beers." *J Food Prot* **61**: 129-131.

Cleveland, L., E. E. Little, S. J. Hamilton, D. R. Buckler and J. B. Huhn (1986). "Interactive toxicity of aluminium and acidity to early life stages of brook trout." *Trans Am Fish Soc* **115**: 610-620.

Clulow, F. V., N. K. Dave, T. P. Lim and R. Avadhanula (1998). "Radium-226 in water, sediments, and fish from lakes near the city of Elliot Lake, Ontario, canada." *Environmental Polltion* **99**: 13-28.

Cocchieri, R. A., A. Arnese and A. M. Minicucci (1990). "Polycyclic aromatic hydrocarbons in marine organisms from Italian central mediterranean coast." *Marine Pollution Bulletin* **21**: 15-18.

Cohen, T., S. S. Q. Hee and R. F. Ambrose (2001). "Trace metals in fish and invertebrates of three California coastal wetlands." *Marine Pollution Bulletin* **42**: 224-232.

Dashti, B., F. Al-Awadi, R.AlKandari, A. Ali and J. Al-Otaibi (2004). "Macro- and microelements of 32 Kuwaiti composite dishes." *Food Chemistry* **85**: 331-337.

Davis, C. D., E. A. Malecki and J. L. Greger (1992). "Interactions among dietary manganese, heme iron and non-heme iron in women." *American Journal of Clinical Nutrition* **56**: 926-932.

Deb, S. C., T. Araki and T. Fukushima (2000). "Polycyclic aromatic hydrocarbons in fish organs." *Marine Pollution Bulletin* **40**: 882-885.

DHHS (1995). Toxicological profile for polycyclic aromatic hydrocarbons. Atlanta, U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry.

DHHS (1999). Toxicological profile for mercury. Atlanta, U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry**:** 5-6.

DHHS (2000). Toxicological profile for chromium. Atlanta, U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry.

DHHS (2002). Toxicological profile for beryllium. Atlanta, U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry.

DHHS (2005). Toxicological profile for tin and tin compounds. Atlanta, U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry.

DHHS (2006). Draft Toxicological profile for aluminium. Atlanta, U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry.

EC (1989). Council Regulation (Euratom) No 2218/89, Official Journal of the European Communities L 211.

EC (2002). Commission regulation (EC) No. 221/2002 of 6 February 2002 amending regulation (EC) No. 466/2002 setting maximum levels for certain contaminants in foodstuffs., Official Journal of the European Communities. Brussels.

Eisler, R. (1987). Polycyclic aromatic hydrocarbon hazards to fish, wildlife, and invertebrates: A synoptic review. M. D. Laurel, US Fish and Wildlife Service, Patuxent Wildlife Research Center.

Elinder, C. G. (1992). "Cadmium as an environmental hazard." *IARC Scientific Publication* **1118**: 123-132.

EPA (1980a). Ambient water quality criteria for arsenic. Washington DC, U.S. Environmental Protection Agency, Office of Water Regulations and Standards.**:** EPA440580021.

EPA (1980b). Ambient water quality criteria for beryllium. Washington DC, Office of Water Regulations and Standards, Criteria and Standards Division, U.S. Environmental Protection Agency. EPA-440/5-80-024.

FAO (2006). Report of the FAO Working Group on the Assessment of Small Pelagic Fish off Northwest Africa. FAO Fisheries Report. Banjul, The Gambia**:** in prep.

Fishbein, L. (1981). "Sources, transport, and alterations of metal compounds: An overview: 1. Arsenic, beryllium, cadmium, chromium, and nickel." *Environmental Health Perspectives* **40**: 43-64.

Fleming-Jones, M. E. and R. E. Smith (2003). "Volatile organic compounds in foods: A five year study." *Journal of Agricultural and Food Chemistry* **51**: 8120-8127.

Folsom, T. R., D. R. Young and J. N. Johnson (1963). "Manganese-54 and zinc-65 in coastal organisms of California." *Nature* **200**: 327-329.

Fowler, S. W., J. W. Readman, B. Oregioni, J.-P. Villeneuve and K. McKay (1993). "Petroleum hydrocarbons and trace metals in nearshore gulf sediements and biota before and after the 1991 war: assessment of temporal and spatial trends." *Marine Pollution Bulletin* **27**: 171-182.

Garcia, S. (1982). Distribution, migration and spawing of the main fish resources in the northern CECAF area. . CECAF/ECAF Series 82/25. Rome, FAO**:** 9.

Gladyshev, M. I., I. V. Gribovskaya, A. V. Moskvicheva, E. Y. Muchkina, S. M. Chuprov and E. A. Ivanova (2001). "Content of metals in compartments of ecosystem of a Siberian pond." *Archives of Environmental Contamination and Toxicology* **41**: 157-162.

Gramiccioni, L., G. Ingrao, M. R. Milana, P. Santaroni and G. Tomassi (1996). "Aluminium levels in Italian diets and selected foods from aluminium utensils." *Food Additives and Contaminants* **13**: 767-774.

Greger, J. L., W. Goetz and D. Sullivan (1985). "Aluminium levels in foods cooked and stored in aluminium pans, trays and foil." *Journal of Food Protection* **48**: 772-777.

Gupta, R. S., S. P. Fondekar and R. Alagarsamy (1993). "State of oil pollution in the Northern Arabian Sea after the 1991 Gulf oil spill." *Marine Pollution Bulletin* **27**: 85-91.

Haridasan, P. P., A. C. Paul and M. V. M. Desai (2001). "Natural radionuclides in the aquatic environment of a phosphogypsum disposal area." *Journal of Environmental Radioactivity* **53**: 155-165.

Hellou, J., L. L. Fancey and J. F. Payne (1992a). "Concentrations of twenty-four elements in bluefin tuna, Thumus thymus from the Northwest Atlantic." *Chemosphere* **24**: 211-218.

Hellou, J., W. G. Warren and J. F. Payne (1992b). "Heavy metals and other elements in three tissues of cod, Godus morhua from the Northwest Atlantic." *Marine Pollution Bulletin* **24**: 452-458.

Howard, J. (1979). Analysis of B[a]P and other polycyclic aromatic hydrocarbons in food. Environmental carcinogens: Selected methods of anlaysis: Vol.3. Analysis of polyaromatic hydrocarbons in environmental samples. H. Egan. Lyon, France, International Agency for Research on Cancer**:** 175-191.

Ikem, A. and N. O. Egiebor (2005). "Assesment of trace elemts in canned fishes (mackerel, tuna, salmon, sardines and herrings) marketed in Georgia and Alabama (United States of America)." *Journal of Food Composition and Analysis* **18**: 771-787.

IMARES (2006). Monitoring zware metalen en organische microverontreiniging in Nederlandse visserijproducten C032/06. IJmuiden, IMARES.

IMNA (2003). Dietary reference intakes: Applications in dietary planning. Subcommittee on interpretation and uses of dietary reference intakes and the standing committee on the scientific evaluation of dietary refernce intakes. Washington, Institute of Medicine of the National Academies, The National Academic Press**:** 248.

Jenkins, D. W. (1980). Nickel accumulation in aquatic biota. Nickel in the environment. J. O. Nriagu. New York, John Wiley and Sons**:** 283-337.

Jorhem, L. and B. Sundstrom (1993). "Levels of lead, cadmium, zinc, copper, nickel, chromium, manganese, and cobalt in foods on the Swedish market, 1983-1990." *J Food Comp Anal* **6**: 223-241.

Lither, G., K. Holm and H. Borg (1995). "Bioconcentration factors for metals in humic waters at different pH in the Robbskar are (N. Sweden)." *Water, Air and Soil Pollution* **85**: 785-790.

MAFF (1999). MAFF 1999. MAFF UK - 1997 Total diet study: Aluminium, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, tin and zinc. Food Safety and Standards Group. Food Surveillance Information Sheet Number 191, Ministry of Agricultural, Fisheries and Food. Joint.

Markose, P. M., K. P. Eappen and M. Raghavaya (1982). Bioaccumulation of radium in a fresh water ecosystem. 2nd special symposium on natural radiation environment, Bombay, India.

Martin, P., G. J. Hancock, A. Johnston and A. S. Murray (1998). "Natural-series radionuclides in traditional North Australian aboriginal foods." *Journal of Environmental Radioactivity* **40**: 37-58.

McGeer, J., K. V. Brix, J. M. Skeaff, D. K. DeForest, S. I. Brigham, W. J. Adams and A. Green (2003). "Inverse relationships between bioconcentartion gactor and exposure concentration for metals: Implications for hazard assessment of metals in the aquatic environment." *Environmental Toxicology and Chemistry* **22**: 1017-1037.

Meehan, W. R. and L. E. Smythe (1967). "Occurence of beryllium as a trace element in environmental materials." *Environmental Science and Technology* **1**.

Mora, S. d., S. W. Fowler, E. Wyse and S. Azemard (2004). *Marine Pollution Bulletin* **49**: 410-424.

Mormede, S. and I. M. Davies (2001). "Trace elements in deep-water fish species from the Rockall Trough." *Fisheries Research* **51**: 197-206.

Munoz, O., V. Devesa, M. A. Suner, D. Velez, R. Montoro, I. Urieta, M. L. Macho and M. Jalon (2000). "Total and inorganic arsenic in fresh and processed fish products." *Journal of Agricultural and Food Chemistry* **48**: 4369-4376.

Nicola, R.M., R. Branchflouer, D. Pierce (1987). "Chemical contaminants in bottomfish"J. Environ. Health **49**: 342-347.

Niimi, A. J. (1987). "Biological half-lives of chemicals in fishes." *Review of Environmental Contamination and Toxicology* **99**: 1-46.

Pennington, J. A. T., B. E. Young and D. B. Wilson (1986). "Mineral content of foods and total diets: The selected minerals in foods survey, 1982 to 1984." *Journal of American Diet Association* **86**: 876-891.

Perwak, J., S. Bysshe and M. Goyer (1980). An exposure and risk assessment for copper. Washington DC, EPA.

Ranau, R., J. Oehlenschlager and H. Steinhart (2001a). "Aluminium levels of fish fillets baked and grilled in aluminium foil." *Food Chemistry* **73**: 1-6.

Ranau, R., J. Oehlenschlager and H. Steinhart (2001b). "Aluminium content in edible parts of seafood." *European Food Resources and Technology* **212**: 431-438.

Romeo, M. and M. Gnassia-Berelli (1988). "Donax trunculus and Venus verrucosa as bioindicators of trace metal concentrations in Mauritanian coastal waters." *Marine Biology* **99**: 223-227.

Romeo, M., Y. Siau, Z. Sidoumou and M. Gnassia-Barelli (1999). "Heavy metals distribution in diffrent fish species from the Mauritania coast." *The Science of the Total Environment* **232**: 169-175.

Roose, P. and U. A. T. Brinkman (2000). "Volatile organic compounds in various marine organisms from the southern north sea." *Marine Pollution Bulletin* **40**: 1167-1177.

Roose, P., G. v. Thuyne, C. Belpaire, M. Raemaekers and U. A. T. Brinkman (2003). "Determination of VOCs in yellow eel from various inland water bodies in Flanders (Belgium)." *Journal of Environmental Monitoring* **5**: 876-884.

Rosseland, B. O., T. D. Eidhuset and M. Staurnes (1990). "Environmental effects of aluminium." *Environ Geochem Health* **12**: 17-27.

Ruttenber, A. J., K. Kreiss, R. L. Douglas, T. E. Buhl and J. Millard (1984). *Health Physics* **47**: 21-35.

S. Ghose, M. N. A., M.N. Islam (2000). "Radiation dose estimation from the analysis of radionuclides in marine fish of the Bay of Bengal." *Radiation protection dosimetry* **87**: 287-291.

Saeed, T., S. Al-Yakoob, H. Al-Hashash and M. Al-Bahloul (1995). "Preliminary exposure assessment for Kuwaiti consumers to polycyclic aromatic hydrocarbons in seafood." *Environmental International* **21**: 255-263.

Scancar, J., V. Stibilj and R. Milacic (2004). "Determination of aluminium in Slovenian foodstuffs and its leachability from aluminium-cookware." *Food Chemistry* **85**: 151-157.

Schenk, R. U., J. Bjorksten and L. Yeager (1989). Composition and consequences of aluminium in water, beverages and other ingestibles. Environmental chemistry and toxicology of aluminium. T. E. Lewis. Chelsea, MI, Lewis Publishers**:** 247-269.

Schmidt, J. A. and A. W. Andren (1984). "Deposition of airborne metals into the Great Lakes: An evaluation of past and present estimates." *Adv Environ Sci Technol* **14**: 81-103.

Sidoumou, Z. (1991). Qualite des eaux du littoral mauritanien: etude des metaux traces chez deux mollusques bivalves Venus verrucosa et Donax rugosus, University of Nice Sophia-Antipolis.

Smith, I. C. and B. L. Carson (1981). Trace metals in the environment. Ann Arbor, Ann Arbor Science Publishers.

Swanson, S. M. (1983). *Health Physics* **45**: 67-80.

Swanson, S. M. (1985). "Food chain transfer of U-series radionuclides in a northern Saskatchewan aquatic system." *Health Physics* **49**: 747-770.

Tao, S. S. H. and P. M. Bolger (1999). "Dietary intakes of arsenic in the United States." *Food Additives and Contaminants* **16**: 465-472.

Thompson, S. E., C. A. Burton and D. J. Quinn (1972). Concentration factors of chemical elements in edible aquatic organisms. Livermore, CA, Lawrance Livermore Laboratory, Bio-Medical Division, University of California.

Tolosa, I., S. J. d. Mora, S. W. Fowler, J.-P. Villeneuve, J. Bartocci and C. Cattini (2005). "Aliphatic and aromatic hydrocarbons in marine biota and coastal sediments from the Gulf and the Gulf of Oman." *Marine Pollution Bulletin* **50**: 1619-1633.

Vakily, J. M. and D. Pauly (1995). Seasonal movements of sardinella off Sierra Leone. Dynamics and use of sardinella resources from upwelling off Ghana and Ivory Coast. F. X. Bard and K. A. Koranteng. Paris, OSTROM**:** 426-436.

Varanasi, U. and D. J. Gmur (1980). "Metabolic activation and covalent binding of benzo[a]pyrene to deoxyribonucleic acid catalyzed by liver enzymes of marine fish." *Biochem Pharmacol* **29**: 752-762.

Varanasi, U. and D. J. Gmur (1981). In vitro metabolism of naphthalene and benzo[a]pyrene of flatfish. Chemical analysis and biological fate: Polynuclear aromatic hydrocarbons. Fifth International Symposium. M. Cooke and A. J. Dennis. Columbus, OH, Battelle Press**:** 367-376.

WHO (1989b). Evaluation of certain food additives and contaminants. Thirty-third Report of the Joint FAO/WHO Expert Committee on Food Additives. WHO Technical Report Series 776. Geneva, WHO**:** 26-27.

WHO (2003). WHO Food Additives Series 46: TIN (addendum). Geneva, Switzerland, World Health Organization.

Ysart, G., P. Miller and H. Crew (1999). "Dietary exposure estimates of 30 elements from the UK total diet study." *Food Additives and Contaminants* **16**: 391-403.

Yu, K. N., S. Y. Mao, E. C. M. Young and M. J. Stokes (1997). "A study of radioactivities in six types of fish consumed in Hong Kong." *Applied Radiation Isotopes* **48**: 515-519.

Zaroogian, G. E. and M. Johnson (1984). "Nickel uptake and loss in the bivalves Crassostrea virginica and Mytilus edulis." *Archive Environmental Contaminants and Toxicology* **13**: 411-418.

7. Annexes 1–5

Annex 1. Weights and lengths of the individual fish in sub-pools (samples) A, B and C.

Sub-pool A (LIMS 2006/0527)		
Fish code	Weight (g)	Length (cm)
A-1	227	29.6
A-2	184	27.3
A-3	271	29.6
A-4	198	28.5
A-5	210	28.0
A-6	174	26.9
A-7	165	26.5
A-8	177	27.0
A-9	234	28.7
A-10	212	28.3
A-11	206	27.8
A-12	212	28.9
A-13	203	28.2
A-14	180	27.5
A-15	218	28.9
A-16	196	28.9
A-17	222	28.6
A-18	158	26.5
A-19	200	27.8
A-20	173	26.8
A-21	200	27.7
A-22	195	28.1
A-23	183	27.6
A-24	195	27.5
A-25	192	28.1
Average	199.4	28.0
Minimum	158	29.6
Maximum	271	26.5

Sub-pool B (LIMS 2006/0528)		
Fish code	Weight (g)	Length (cm)
B-1	211	27.8
B-2	169	26.5
B-3	206	28.4
B-4	191	27.8
B-5	165	26.0
B-6	169	26.6
B-7	218	28.7
B-8	174	27.3
B-9	226	29.0
B-10	160	27.0
B-11	195	27.8
B-12	213	29.0
B-13	167	27.0
B-14	193	27.7
B-15	212	27.8
B-16	186	27.6
B-17	230	28.8
B-18	195	28.3
B-19	168	26.5
B-20	201	28.5
B-21	199	27.7
B-22	171	26.7
B-23	191	27.7
B-24	187	27.4
B-25	206	28.6
Average	192.1	27.7
Minimum	160	26.0
Maximum	230	29.0

Sub-pool C (LIMS 2006/0529)		
Fish code	Weight (g)	Length (cm)
C-1	250	29.5
C-2	180	26.7
C-3	160	26.5
C-4	178	27.0
C-5	179	27.4
C-6	171	27.0
C-7	149	26.2
C-8	190	27.4
C-9	206	27.6
C-10	158	26.0
C-11	173	27.1
C-12	212	28.3
C-13	173	27.3
C-14	174	27.3
C-15	184	27.4
C-16	184	27.4
C-17	164	27.1
C-18	182	27.4
C-19	181	27.0
C-20	170	26.7
C-21	170	27.1
C-22	179	26.6
C-23	191	28.2
C-24	206	29.1
C-25	187	27.6
Average	182.0	27.3
Minimum	149	26.0
Maximum	250	29.5

Annex 2. Weights and lengths of the individual fish in sub-pools (samples) D, E and F.

Sub-pool D (LIMS 2006/0928)		
Fish code	Weight (g)	Length (cm)
D-1	183	26.7
D-2	169	26.0
D-3	156	26.9
D-4	165	25.7
D-5	153	26.1
D-6	183	27.9
D-7	180	26.8
D-8	141	26.5
D-9	148	25.3
D-10	162	25.5
D-11	172	26.5
D-12	166	26.1
D-13	200	27.9
D-14	164	25.7
D-15	191	27.2
D-16	179	26.7
D-17	183	27.6
D-18	165	26.6
D-19	180	27.3
D-20	163	26.4
D-21	163	26.6
D-22	165	26.2
D-23	133	25.6
D-24	161	26.8
D-25	151	25.8
Average	167.0	26.5
Minimum	133	25.3
Maximum	200	27.9

Sub-pool E (LIMS 2006/0929)		
Fish code	Weight (g)	Length (cm)
E-1	186	27.3
E-2	155	26.1
E-3	174	26.6
E-4	153	26.1
E-5	179	26.8
E-6	160	25.5
E-7	155	26.4
E-8	163	26.5
E-9	156	26.3
E-10	157	25.6
E-11	200	27.8
E-12	182	26.9
E-13	185	27.2
E-14	177	27.5
E-15	146	25.7
E-16	142	26.1
E-17	168	26.9
E-18	184	27.3
E-19	169	26.3
E-20	191	26.9
E-21	161	26.2
E-22	138	26.2
E-23	157	25.8
E-24	178	27.4
E-25	167	25.9
Average	167.3	26.5
Minimum	138	25.5
Maximum	200	27.8

Sub-pool F (LIMS 2006/0930)		
Fish code	Weight (g)	Length (cm)
F-1	196	27.5
F-2	190	27.7
F-3	194	27.2
F-4	167	27.6
F-5	159	26.6
F-6	152	26.1
F-7	171	27.1
F-8	151	25.7
F-9	191	27.7
F-10	150	25.6
F-11	154	26.5
F-12	143	26.1
F-13	151	26.3
F-14	164	26.1
F-15	175	26.9
F-16	167	26.1
F-17	173	26.9
F-18	152	26.1
F-19	168	27.1
F-20	172	26.2
F-21	159	26.4
F-22	147	26.1
F-23	162	26.8
F-24	156	26.1
F-25	170	26.4
Average	165.4	26.6
Minimum	143	25.6
Maximum	196	27.7

Annex 3. Weights and lengths of the individual fish in sub-pools (samples) G, H and I.

Sub-pool G (LIMS 2006/0893)		
Fish code	Weight (g)	Length (cm)
G-1	330	33.1
G-2	363	32.4
G-3	357	31.5
G-4	391	32.9
G-5	339	32.7
G-6	348	32.1
G-7	360	32.7
G-8	356	32.9
G-9	307	31.5
G-10	304	31.8
G-11	374	32.7
G-12	329	31.7
G-13	403	33.1
G-14	330	31.7
G-15	353	32.6
G-16	323	31.1
G-17	355	32.6
G-18	387	32.9
G-19	351	32.5
G-20	328	31.4
G-21	327	31.4
G-22	326	32.5
G-23	262	31.3
G-24	338	32.2
G-25	316	32.4
Average	342,3	32.2
Minimum	262	31.1
Maximum	403	33.1

Sub-pool H (LIMS 2006/0894)		
Fish code	Weight (g)	Length (cm)
H-1	310	31.1
H-2	287	32.3
H-3	275	31.2
H-4	321	31.8
H-5	341	33.1
H-6	371	32.2
H-7	293	31.2
H-8	344	31.7
H-9	316	31.6
H-10	321	31.4
H-11	359	32.8
H-12	378	32.7
H-13	357	32.3
H-14	333	32.2
H-15	398	32.7
H-16	298	31.6
H-17	315	31.1
H-18	326	31.6
H-19	343	31.6
H-20	333	32.1
H-21	342	31.7
H-22	317	32.4
H-23	301	31.1
H-24	362	32.6
H-25	348	32.9
Average	331,6	32.0
Minimum	275	31.1
Maximum	398	33.1

Sub-pool I (LIMS 2006/0895)		
Fish code	Weight (g)	Length (cm)
I-1	371	31.8
I-2	305	31.6
I-3	331	31.6
I-4	307	31.5
I-5	362	32.9
I-6	348	32.5
I-7	351	32.3
I-8	331	32.4
I-9	335	31.6
I-10	351	32.1
I-11	371	32.1
I-12	356	31.2
I-13	365	32.6
I-14	351	31.6
I-15	342	31.8
I-16	377	32.4
I-17	348	31.4
I-18	337	32.2
I-19	405	32.2
I-20	340	31.4
I-21	291	31.1
I-22	365	32.1
I-23	342	31.7
I-24	315	31.1
I-25	361	32.6
Average	346,3	31.9
Minimum	291	31.1
Maximum	405	32.9

Annex 4. Raw data of analysis of fish from both sampling rounds expressed on wet weight basis

		Pre-PFW sampling			Post-PFW sampling			Unit
Metals	LIMS:	2006/0527	2006/0528	2006/0529	2006/0893	2006/0894	2006/0895	
Hg		0.0045	<0.0036	0.0043	0.01	0.01	0.0096	mg/kg ww
As		1.5	1.4	1.3	1.8	1.9	1.9	mg/kg ww
Cu		1.3	1.3	1.3	1.2	1.2	1.2	mg/kg ww
Cd		0.34	0.34	0.36	0.39	0.37	0.44	mg/kg ww
Pb		<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	mg/kg ww
Zn		14	13	15	12	13	12	mg/kg ww
Sb		<0.04	<0.04	<0.04	<0.02	<0.02	<0.02	mg/kg ww
Be		<0.007	<0.007	<0.007	<0.005	<0.005	<0.005	mg/kg ww
Co		0,062	0.059	0.057	0.046	0,04	0.045	mg/kg ww
Mn		1.9	1.7	1.5	1.6	1.2	1.6	mg/kg ww
Sn		0.26	0.16	<0.1	<0.025	<0.025	<0.025	mg/kg ww
Metals	LIMS:	2006/0928	2006/0929	2006/0930	2006/0893	2006/0894	2006/0895	
Al		12	13	12	7.6	7.1	9.2	mg/kg ww
Ni		0.16	0.15	0.29	0.13	0.095	0.14	mg/kg ww
Cr		<0.06	<0.06	0.30	0.038	0.031	0.044	mg/kg ww
Radium	LIMS:	2006/0928	2006/0929	2006/0930	2006/0893	2006/0894	2006/0895	
Ra-226		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	Bq/kg ww
Ra-228		<3	<1	<3	<4	<6	<5	Bq/kg ww
TPHs	LIMS:	2006/0928	2006/0929	2006/0930	2006/0893	2006/0894	2006/0895	
		8.8	5.2	7.8	56.9	22.7	27.9	mg/kg ww
BTEX	LIMS:	2006/0928	2006/0929	2006/0930	2006/0893	2006/0894	2006/0895	
Benzene		<3	<3	<3	<3	<3	<3	µg/kg ww
Toluene		<3	<3	<3	<3	<3	<3	µg/kg ww
Ethylbenzene		<3	<3	<3	<3	<3	<3	µg/kg ww
p,m-Xylene		<3	<3	<3	<3	<3	<3	µg/kg ww
o-Xylene		<3	<3	<3	<3	<3	<3	µg/kg ww
PAHs	LIMS:	2006/0527	2006/0528	2006/0529	2006/0893	2006/0894	2006/0895	
Naphthalene		0.5	<0.03	0.3	2.9	4.9	5.6	µg/kg ww
Acenaphthane		0.04	<0.03	0.03	0.3	0.2	0.3	µg/kg ww
Fluorene		<0.05	<0.05	<0.05	0.4	0.3	0.3	µg/kg ww
Phenanthrene		0.1	<0.05	0.4	1.7	1.8	1.4	µg/kg ww
Anthracene		<0.1	<0.1	<0.1	0.06	0.08	0.07	µg/kg ww
Fluoranthene		<0.1	<0.1	<0.1	0.4	0.4	0.3	µg/kg ww
Pyrene		<0.05	<0.05	<0.05	0.2	0.2	0.2	µg/kg ww
Benzo(a)anthracene		<0.05	<0.05	<0.05	<0.04	0.05	<0.04	µg/kg ww
Chrysene		<0.03	<0.03	<0.03	0.08	0.09	<0.02	µg/kg ww
Benzo(e)pyrene		<0.03	<0.03	<0.03	<0.06	<0.06	<0.06	µg/kg ww
Benzo(b)fluoranthene		<0.03	<0.03	<0.03	<0.31	<0.31	<0.31	µg/kg ww
Benzo(k)fluoranthene		<0.03	<0.03	<0.03	<0.11	<0.11	<0.11	µg/kg ww
Benzo(a)pyrene		<0.02	<0.02	<0.02	<0.06	<0.06	<0.06	µg/kg ww
Dibenzo(ah)anthracene		<0.02	<0.02	<0.02	<0.48	<0.48	<0.48	µg/kg ww
Benzo(ghi)perylene		<0.02	<0.02	<0.02	<0.21	<0.21	<0.21	µg/kg ww
Indeno(123cd)pyrene		<0.02	<0.02	<0.02	<0.2	<0.2	<0.2	µg/kg ww
Dry weight	LIMS:	2006/0527	2006/0528	2006/0529	2006/0893	2006/0894	2006/0895	
		29.2	28.7	29.5	34.6	34.6	33.5	% ww
Lipid content	LIMS:	2006/0928	2006/0929	2006/0930	2006/0893	2006/0894	2006/0895	
(Bligh & Dyer)		5.8	6.2	5.6	12.7	13.6	12.5	% ww

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Annex 5. Raw data of analysis of fish from both sampling rounds expressed on dry weight basis

		Pre-PFW sampling			Post-PFW sampling			Unit
Metals	LIMS:	2006/0527	2006/0528	2006/0529	2006/0893	2006/0894	2006/0895	
Hg		0.015	<0.013	0.015	0.029	0.029	0.029	mg/kg dw
As		4.2	4	3.9	5.2	5.5	5.7	mg/kg dw
Cu		4.5	4.5	4.4	3.5	3.5	3.6	mg/kg dw
Cd		1.2	1.2	1.2	1.1	1.1	1.3	mg/kg dw
Pb		<0.14	<0.14	<0.14	<0.12	<0.12	<0.12	mg/kg dw
Zn		48	45	51	35	38	36	mg/kg dw
Sb		<0.1	<0.1	<0.1	<0.058	<0.058	<0.060	mg/kg dw
Be		<0.02	<0.02	<0.02	<0.014	<0.014	<0.015	mg/kg dw
Co		0.18	0,17	0.17	0.13	0.12	0.13	mg/kg dw
Mn		5.6	4.8	4.6	4.6	3.5	4.8	mg/kg dw
Sn		0.76	0.46	<0.3	<0.072	<0.072	<0.075	mg/kg dw
Metals	LIMS:	2006/0928	2006/0929	2006/0930	2006/0893	2006/0894	2006/0895	
Al		41	45	41	22	21	27	mg/kg dw
Ni		0.55	0.52	0.98	0.38	0.27	0.42	mg/kg dw
Cr		<0.21	<0.21	1.0	0.11	0.090	0.13	mg/kg dw
Radium	LIMS:	2006/0928	2006/0929	2006/0930	2006/0893	2006/0894	2006/0895	
Ra-226		<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	Bq/kg dw
Ra-228		<10	<3.5	<10	<12	<17	<15	Bq/kg dw
TPHs	LIMS:	2006/0928	2006/0929	2006/0930	2006/0893	2006/0894	2006/0895	
		30	18	26	164	66	83	mg/kg dw
BTEX	LIMS:	2006/0928	2006/0929	2006/0930	2006/0893	2006/0894	2006/0895	
Benzene		<10	<10	<10	<8.7	<8.7	<9.0	µg/kg dw
Toluene		<10	<10	<10	<8.7	<8.7	<9.0	µg/kg dw
Ethylbenzene		<10	<10	<10	<8.7	<8.7	<9.0	µg/kg dw
p,m-Xylene		<10	<10	<10	<8.7	<8.7	<9.0	µg/kg dw
o-Xylene		<10	<10	<10	<8.7	<8.7	<9.0	µg/kg dw
PAHs	LIMS:	2006/0527	2006/0528	2006/0529	2006/0893	2006/0894	2006/0895	
Naphthalene		1.7	<0.11	1.0	8.4	14	17	µg/kg dw
Acenaphthane		0.14	<0.11	0.10	0.87	0.58	0.90	µg/kg dw
Fluorene		<0.17	<0.17	<0.17	1.2	0.87	0.90	µg/kg dw
Phenanthrene		0.34	<0.17	1.4	4.9	5.2	4.2	µg/kg dw
Anthracene		<0.34	<0.35	<0.34	0.17	0.23	0.21	µg/kg dw
Fluoranthene		<0.34	<0.35	<0.34	1.2	1.2	0.90	µg/kg dw
Pyrene		<0.17	<0.17	<0.17	0.58	0.58	0.60	µg/kg dw
Benzo(a)anthracene		<0.17	<0.17	<0.17	<0.12	0.14	<0.12	µg/kg dw
Chrysene		<0.10	<0.10	<0.10	0.23	0.26	<0.060	µg/kg dw
Benzo(e)pyrene		<0.10	<0.10	<0.10	<0.17	<0.17	<0.18	µg/kg dw
Benzo(b)fluoranthene		<0.10	<0.10	<0.10	<0.90	<0.90	<0.93	µg/kg dw
Benzo(k)fluoranthene		<0.10	<0.10	<0.10	<0.32	<0.32	<0.33	µg/kg dw
Benzo(a)pyrene		<0.068	<0.070	<0.068	<0.17	<0.17	<0.18	µg/kg dw
Dibenzo(ah)anthracene		<0.068	<0.070	<0.068	<1.4	<1.4	<1.4	µg/kg dw
Benzo(ghi)perylene		<0.068	<0.070	<0.068	<0.61	<0.61	<0.63	µg/kg dw
Indeno(123cd)pyrene		<0.068	<0.070	<0.068	<0.58	<0.58	<0.60	µg/kg dw
Dry weight	LIMS:	2006/0527	2006/0528	2006/0529	2006/0893	2006/0894	2006/0895	
		29.2	28.7	29.5	34.6	34.6	33.5	% ww
Lipid content	LIMS:	2006/0928	2006/0929	2006/0930	2006/0893	2006/0894	2006/0895	
(Bligh & Dyer)		19.9	21.6	19.0	36.7	39.3	37.3	% dw

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W. van der Galiën

Signature: _____

Date: 18 January 2007