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An Assessment of the Total and Methyl Mercury Content of Zooplankton and Fish Tissue Collected from Kuwait Territorial Waters

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The results of a study of total-Hg (T-Hg) and MeHg concentrations in zooplankton and various fish species collected from Kuwait Bay and the northern area of Kuwait are reported. T-Hg concentrations in zooplankton ranged from 0.004 – 0.035 μg g^{-1} (dry weight) with MeHg representing < 25% of the T-Hg. Total and MeHg concentrations in fish differed between species and ranged from 0.073 μg g^{-1} (*Liza subviridis*) to 3.923 μg g^{-1} (*Epinephelus coiodes*). T-Hg and MeHg in fish tissue were significantly correlated at 0.01 level. They were also correlated with length and weight of the analysed species. The mean percentage of MeHg ranged from 40.1% (*Hilsha ilisha*) to 80% (*Epinephelus coiodes*) of the T-Hg. The relationships between observed concentration, habitat and feeding habits are examined. Of the fish analysed 20.6% were ⩾0.500 μg g^{-1} T-Hg, and exceeded the WHO limit. For MeHg, 20.6% were ⩾0.300 μg g^{-1}. It is estimated that ∼3.2 kg of Hg and ∼1.9 kg of MeHg are being removed yearly by fish landings from Kuwait territorial waters and introduced to the local food supply. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: mercury; methyl mercury; habitat; feeding habits; mercury intake; mercury flux.

There is a variety of significant human health and environmental-associated issues with the geographically widespread prevalence of elevated levels of both inorganic and organic Hg compounds in freshwater and marine biota. A linkage is evident between the bioaccumulation of MeHg in aquatic systems and the atmospheric mobilization and deposition of Hg, which has local, regional and global components (Mason *et al.*, 1994). Many mercury pollution problems can be linked to specific sources and there are particular concerns when such sources are adjacent to marine systems supporting significant fisheries (Ninomiya *et al.*, 1995). Such an example existed in Kuwait and, although no longer active, the legacy of its activities is still an important influence on local contamination levels. This paper examines some of the implications of this legacy on the fisheries in Kuwait.

Kuwait Bay is a semi-enclosed area approximately 70 km in length that extends from the Arabian Gulf to the west (Fig. 1). It is characterized by mudflats especially in the shallow northern part, which is less than 5 m deep. The central part of the Bay is deeper with higher wave energy whereas the shoreline that extends along the open Gulf is characterized by sandy beaches. The waters of Kuwait support a wide variety of sea plants and fishes, some of which are commercially valuable. Almost 465 species of fish have been collected from the Gulf (Kuronuma and Abe, 1986; Carpenter *et al.*, 1997).

The major point source of pollution by Hg in Kuwait was the Salt and Chlorine Plant (SCP) of the Petrochemical Industries Company (PIC) which was located in Shuwaikh as shown in Fig. 1. The factory was commissioned in 1963 to provide the Cl_2 needed for the expanding power/desalination industry and other municipal and household needs. The SCP used the mercury electrolytic cell process. The old plant contained 8 cells and it was subsequently enlarged in 1973 to contain 36 cells. Each cell used and reused 600 kg of Hg, some of which was lost with the evolved hydrogen gas, some entered the discharge and some was spilled from pumps onto the floor. Although there were considerable efforts to retrieve the Hg lost from the cell, a loss rate of 0.2 kg of Hg per tonne of chlorine manufactured was reported (Szucs and Oostdam, 1977). The total estimated loss of Hg for the period 1964–1985 based on the production of SCP (ASA, 1986) is 20780 kg (∼21 t of Hg).

Various workers have addressed measurements of Hg in the Kuwaiti marine in the past and some of these data

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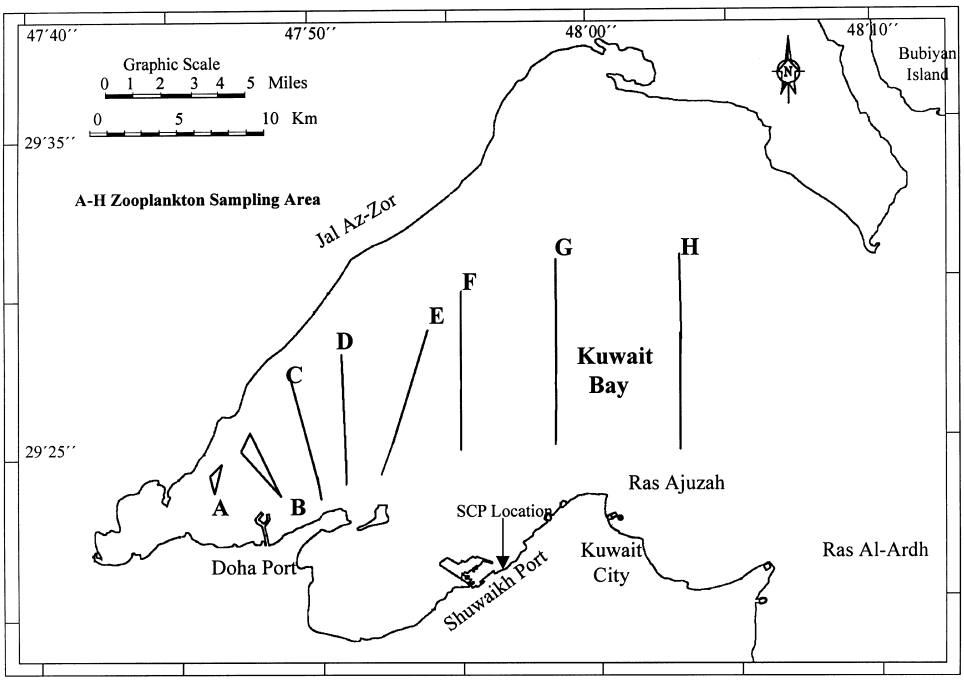

Fig. 1 The former location of the Salt and Chlorine Plant in Kuwait Bay and the zooplankton sampling stations.

TABLE 1

Previous studies of total mercury (T-Hg) and methyl mercury (MeHg) in the Arabian Gulf region.[a]

Region	Species sampled	T-Hg (μg g^{-1})	MeHg (%)	Reference
Arabian Gulf	*Epinephelus coioides* + others	0.105–0.631 (ww)	7–100	ROPME (1988)
Arabian Gulf	Various species (23)	0.35–1.320 (dw)	82–98.7	Habashi *et al.* (1993) and Al-Majed and Rajab (1998) (MeHg data)
Arabian Gulf	*Hilsha ilisha* + *circenita callipyge*	0.051–1.230 (dw)	90.3–100	ROPME (1996)
Arabian Gulf	Various species	0.25–3.201 (dw)	85.5–101.9	Al-Majed and Rajab (1998)
Kuwait	*Lutjanus coccineus*	0.5–4.0 (dw)	–	Anderlini *et al.* (1983)
Kuwait	Various species	Nd-1.57	–	Khordagui and Al-Ajmi (1991)
Kuwait	*Hilsha ilisha Scomberoides commersonianus*	0.015 (dw)	12–104	Al-Majed and Rajab (1998)

[a] dw – dry weight; ww – wet weight.

are summarized in Table 1. The present study was conducted to examine a number of fish species that are of particular importance in the local food supply and also to examine mercury levels in local zooplankton. It forms part of a comprehensive study of sources, distribution and transformation of Hg in the marine environment of Kuwait (Al-Majed, in preparation).

Materials and Methods

Zooplankton samples were collected in August 1996 from eight different areas in Kuwait Bay (Fig. 1). Oblique towing of two Kitahara's plankton nets of 334 μm was used for collecting zooplankton samples. Fish samples were purchased from the local fish market and sampling was extended over a 20-month period between August 1996 and early 1998. A total number of 330 fish representing seven species (*Liza subviridis, Acanthopagrus latus, Hilso ilisha, Arius thalassinus, Otolithes argenteus, Scoberomorus guttas* and *Epinephelus coioides*) were collected and the edible muscle tissue analysed (MOOPAM, 1989). The fishes were caught mainly from the northern area of Kuwait, between Uuha and Faylakah Islands. The selected fish species are of great commercial values in Kuwait and represent different habitat (epiplagic, mesopelagic and demersal) and feeding habits (planktivorous, omnivorous and carnivorous). The overall mean standard deviation and the mean with 95% confidence interval (CI) of fish length (cm) and weight (g) are summarized in Table 2. Dry weight/wet weight ratios were measured for each sample after freeze drying the pre-weighed samples to constant weight. The dry weight/wet weight ratios for all seven species (330 samples) had a mean of 0.25 ± 0.02.

TABLE 2
The overall mean, standard deviation and 95% CI of the mean of length and weight for fish species.

Fish code	Species name *Latin* (Local)	Variables	Mean	S.D.	95% CI for mean boundary		Classification of fish according to	
					Lower	Upper	Habitat	Feeding habits
L.su	*Liza subviridis*	Length (cm)	18.1	2.2	17.5	18.7	mezopelagic	planktivorous
	(Biyah) $n = 51$	Weight (g)	86.4	28.1	78.5	94.3		
A.la	*Acanthopagrus latus*	Length (cm)	26.9	3.6	25.8	28	demersal	carnivorous
	(Sheim) $n = 48$	Weight (g)	488.4	193.9	432.1	544.7		
H.il	*Hilsha ilisha*	Length (cm)	33.8	2.4	33	34.5	mezopelagic	planktivorous
	(Suboor) $n = 47$	Weight (g)	583.7	147.8	540.3	627.1		
A.th	*Arius thalassinus*	Length (cm)	32.7	147.8	31.7	33.6	demersal	carnivorous
	(Chim) $n = 62$	Weight (g)	605.7	147.8	544.7	666.8		
O.ar	*Otolithes argenteus*	Length (cm)	39.4	147.8	37	41.8	demersal	carnivorous
	(Newaiby) $n = 50$	Weight (g)	653.6	147.8	557.2	750		
S.gu	*Scoberomorus guttas*	Length (cm)	46	147.8	44.2	47.9	epipelagic	omnivorous
	(Khubbat) $n = 47$	Weight (g)	918.3	147.8	814.8	1021.8		
E.co	*Epinephelus coioides*	Length (cm)	60.6	147.8	55.6	65.6	demersal	carnivorous
	(Hamoor) $n = 25$	Weight (g)	3839.4	147.8	2762.8	4916		

Analysis of total mercury in zooplankton and fish

In order to release Hg from zooplankton or fish tissue, the IAEA (1996) method was applied. The procedure is based on oxidative digestion of dry samples using a mixture of concentrated nitric acid (HNO_3) concentrated sulphuric acid (H_2SO_4) and bromine chloride (BrCl) in a semi-closed Teflon vial. The mercury content of the extract was determined using a PSA Mercury Analyser. This machine utilizes a hydride reduction stage followed by gold trap pre-concentration and atomic fluorescence detection.

Determination of methyl mercury in zooplankton and fish tissue

Measurement of MeHg was conducted using the UNEP (1992) method. This method is based on liberating the organic form of mercury (R–Hg) from the dried biological matrices by homogenization of the sample in an acid medium. Copper ions are added to promote release of any R–Hg bond to sulphur. Bromine is added to form the organo–mercury complex compound. Final measurement of the methyl mercury content was made using an HP5890 Series II GC fitted with an ECD and a 1.6 m glass column packed with 5% DEGS-PS on 100–120 mesh Supleco support.

Quality control and quality assurance (T-Hg)

The reliability and consistency, of T-Hg in zooplankton analysis was confirmed by using standard reference materials (SRMs) of different Hg levels which were analysed in parallel with the samples. These included CRM-414, LUTS-1, GBW-08571 and CRM-422. Four SRMs were analysed with the samples. CRM 414 was analysed in triplicate. Six blank samples were also analysed with the batch. The recovery values of SRMs were in the range 95.5–98.0%. To check the reproducibility of analysis, 50% of the samples were analysed in triplicate. The RSD varied between 0.00% and 6.93%.

For T-Hg in fish analysis the following SRMs were used: CRM 4, LUTS-1, GBW 08571, DORM-2, DOLT-2, CRM 422, IAEA-350 and MA-A-2. Five SRMs were analysed with each batch of samples (each batch containing 30 samples). Five blank samples were also analysed with each batch. The recovery values for SRMs were in the range 94–98%. To check the reproducibility of analysis, 10% of the samples were analysed in triplicate and one SRM out of five was treated in the same manner. The RSD varied between 0.00% and 5.44%.

Quality control and quality assurance (MeHg)

Zooplankton samples were analysed in parallel with SRMs of different MeHg levels to ensure the reliability and consistency. For this purpose LUTS-1, DOLT-2 and IAEA-350 were used. The three SRMs were analysed with the batch of zooplankton samples. The recovery values of SRMs ranged between 95.7% and 98.1%. LUTS-1, DOLT-2 and 50% of zooplankton samples were analysed in triplicate to check the reproducibility of the analysis (one sample per batch of IAEA-350 was also analysed). The batch also included five blank samples. The RSD varied between 0.00% and 0.38%.

For fish samples two SRMs were used. IAEA-350 and another secondary SRM (EPD Ref. No.1) which had previously been calibrated with IAEA-350 in a preliminary stage of this work. The mean recovery was 94.1%. The RSD values ranged from 0.98% to 7.87%.

Results and Discussion

Levels of mercury in zooplankton

There is some uncertainty about the dominant zooplankton species in Kuwait Bay. Michel *et al.* (1986) have reported that the species composition is dominated by copepods (83.1%) with larvaceans (7.1%), cladeocerans (4.7%) and chaetognaths (12%) making up the remainder. However, results reported a decade later by

EPD (1996), indicate a different species balance with copepods ranging from 44.9 to 69.1%, and the remaining population being distributed between planktonic larvae 18.1–47.1% other crustacea 3.1–23.7% and non crustacea 0.3–11.6%.

The overall mean of T-Hg in zooplankton was 0.011 (S.D. = 0.010) μg g^{-1} dry weight and ranged from 0.004 to 0.035 μg g^{-1}. The lowest level (0.004 μg g^{-1}) was found in samples taken from area C and area E (Fig. 1). The highest concentration (0.035 μg g^{-1}) was detected in samples from site A. This relatively high level could be attributed to the shallowness of the area that has high levels of suspended particulate matter. Nishimura and Kumagai (1983) and Plourde *et al.* (1997) have suggested zooplankton may acquire mercury through a pathway, which involves uptake of contaminated sediment. However, no statistically significant differences (one-way ANOVA–Post Hoc Tests (ANOVA–PHT)) between the zooplankton from the different areas were observed.

Methyl Hg was also measured in zooplankton but the results were found to be <0.001 μg g^{-1} (detection limit) in all the analysed samples. Previous results (Back and Watras, 1995) suggest that MeHg does not normally exceed 30% of T-Hg in zooplankton and in our samples it was $<25\%$ based on a minimum T-Hg value in the sample (0.004 μg g^{-1}) and a detection limit of 0.001 μg g^{-1}.

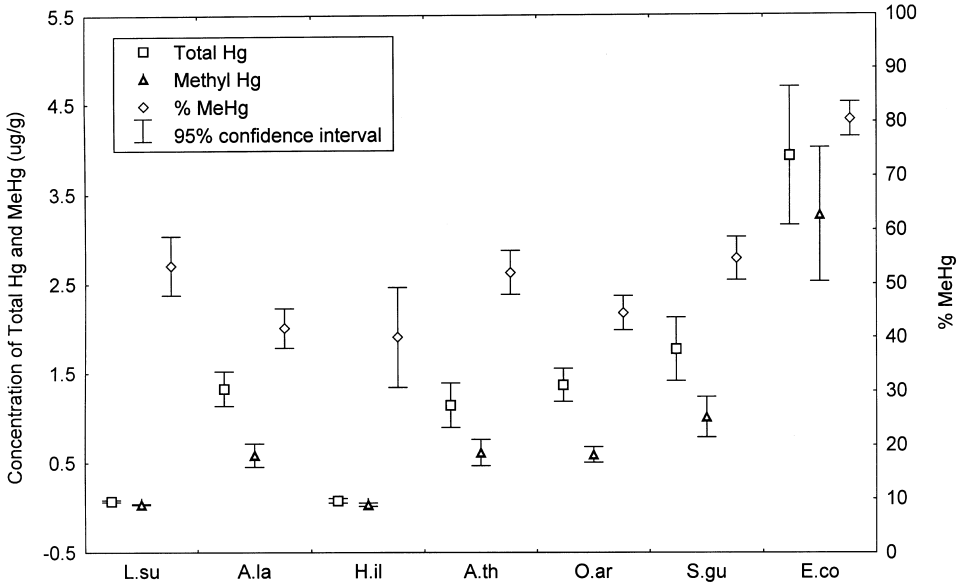

Fig. 2 The overall mean concentrations of T-Hg, MeHg and MeHg% (with 95% CI) for the seven fish species.

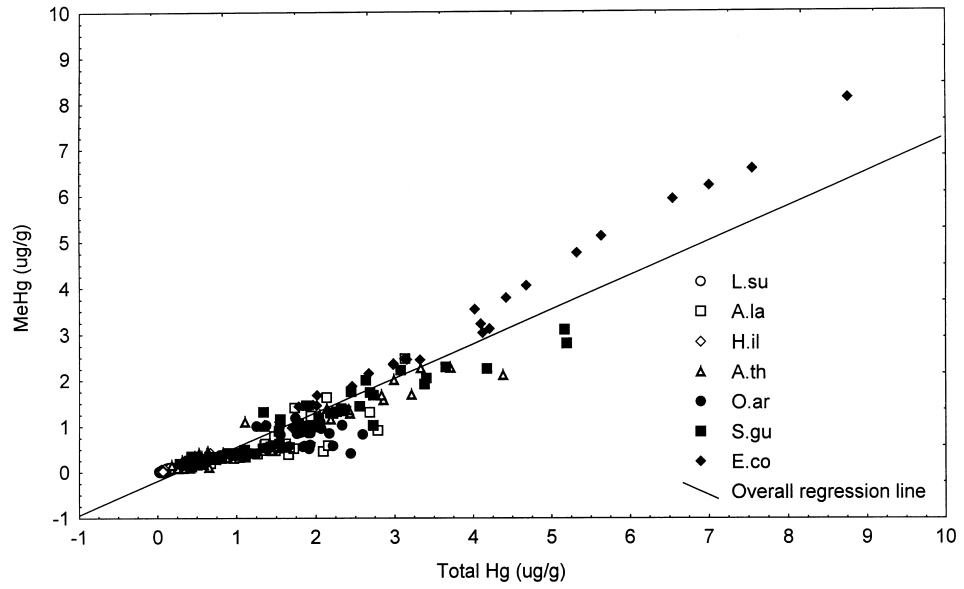

Fig. 3 The relationship between T-Hg and MeHg concentrations for the seven fish species.

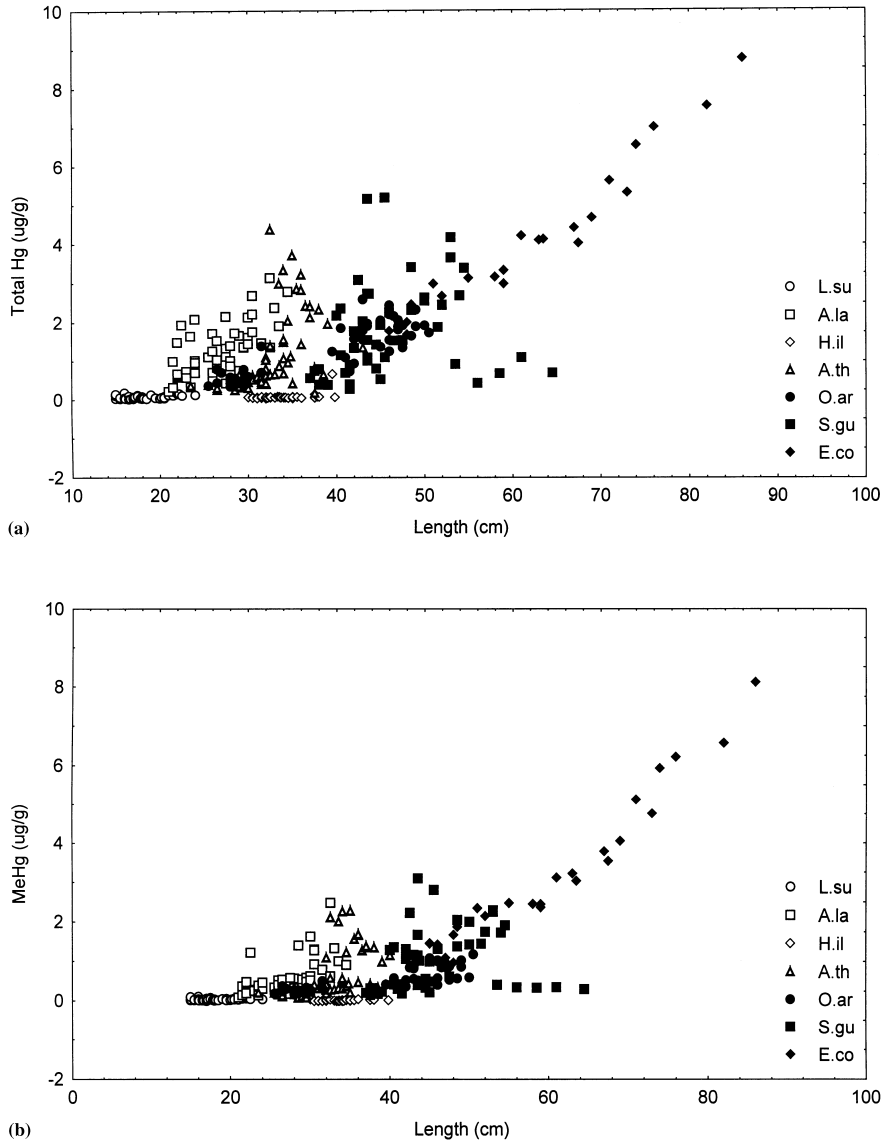

Fig. 4 The relationship between total mercury: (a) and methyl mercury; (b) as a function of fish length.

In general, the concentrations of T-Hg in zooplankton were found to be lower than those reported for freshwater bodies of mid-northern Quebec (Canada) and South-Central Ontario (Canada), Wisconsin USA lakes (Back and Watras, 1995; Plourde *et al*., 1997). The T-Hg concentrations obtained in this study could not be compared to other coastal areas because of lack of data.

Distribution of mercury in fish samples

Total and MeHg concentrations were determined in all the fish muscle samples listed in Table 2. The concentrations are expressed as μg g^{-1} dry weight. In this section, results are discussed according to fish type, habitat and feeding habits. Other variables including, ratio of MeHg to T-Hg (MeHg %), length (cm) and weight (g) are also considered.

Distribution of mercury according to the fish type

The overall mean values of T-Hg, MeHg and MeHg% with 95% confidence intervals (CI) for the seven analysed fish species are shown in Fig. 2. There is a considerable variation in both T-Hg and MeHg concentrations between the different species with *H. ilisha* and *L. subviridis* exhibiting the lowest concentrations and *E. coioides* the highest with a range across all species of 0.01–3.92 μg g^{-1} for T-Hg and <0.001–3.27 μg g^{-1} for MeHg. The concentration range between species was, however, fairly well constrained, probably as a result of the restricted size ranges available in the market. The values for T-Hg and MeHg correspond reasonably well with those obtained previously (ROPME, 1988) when allowance is made for the fact that the earlier values were reported on a wet weight basis.

The distributions of T-Hg concentrations were shown to be log-normal (Kolmogrov–Smirnov test) for five of

the analysed species (*L. subviridis, A. latus, A. thalassinus, S. guttas* and *E. coioides*). In the other two remaining species (*H. ilisha* and *O. argenteus*) the distribution was not statistically resolvable. MeHg concentrations were all log-normally distributed.

There was a very strong and statistically significant ($p < 0.01$) correlation between T-Hg and MeHg concentrations as shown in Fig. 3. A similar correlation has recently been described by Kannan *et al.* (1998). Closer inspection of the data does however reveal that, although there is a clear general trend the points may be resolved by species with the slopes of the lines being slightly less for species exhibiting the lower contaminant concentrations. This has important implications for the distribution of contaminants between representatives of different habitats that are discussed below.

There were significant correlations between both T-Hg and MeHg concentrations and length for all species except *S. guttas* (T-Hg) and *L. subviridis* and *S. guttas* (MeHg) (Fig. 4a and b). It may be that the lack of correlation for the latter species reflects different populations of fish being present in the market over the collection period. There were also significant correlations ($p < 0.0005$–0.013) between T-Hg and MeHg concentrations and weight for all species except *L. subviridis*. This result represents the fact that weight is in effect a proxy for age and hence exposure. The same

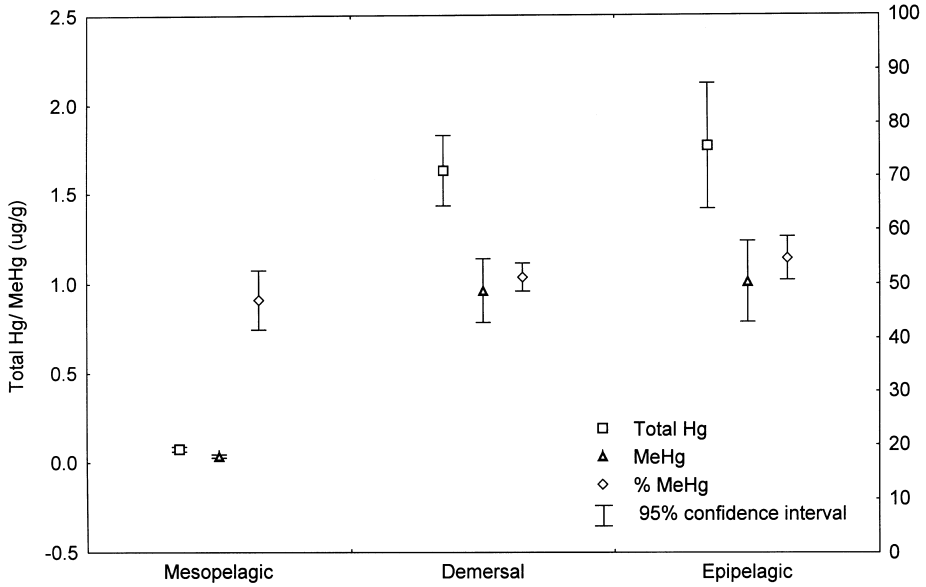

Fig. 5 The overall mean concentrations of T-Hg, MeHg and MeHg (with 95%CI) with fishes grouped according to their habitat/feeding habits.

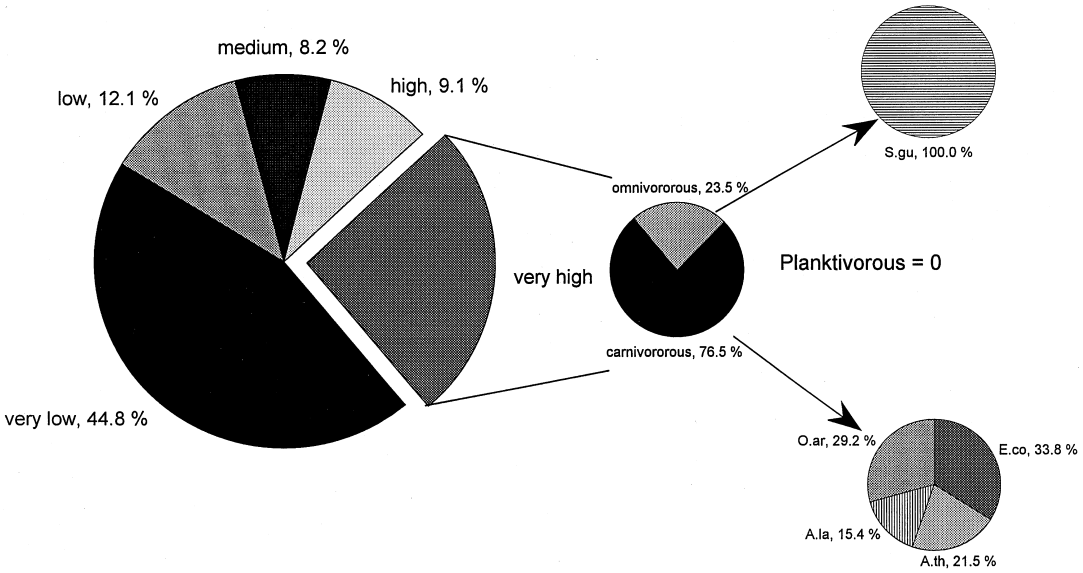

Fig. 6 The distribution of T-Hg in fishes according to concentration categories (Chvojka *et al.*, 1990).

positive correlation was found earlier by several authors (Phillips *et al.*, 1997; Stafford, 1997).

Analysis of the variance of the mean concentrations between species (ANOVA–PHT) reveals significant differences between most species pairs. Generally, the differences in contaminant burdens between the different species are related to the physiological differences between different species (Nishimura and Kumagai, 1983; Goldstein *et al.*, 1996) or the quantity and type of food taken by different populations of the same species (Kim, 1995). Variations in concentration within species may come about through the migration of fish species from unpolluted areas to relatively more polluted areas. It seems that a combination of several of these factors is responsible for the observed differences.

The distribution of Hg according to habitat/feeding habits

The results may be categorized according to the habitats occupied by the sampled species and their feeding habits that are identified in Table 2 and the results are shown in Fig. 5. There is a very obvious difference between the contaminant distributions in mesopelagic fish and the other two groups (epipelagic and demersal) as has previously been reported by Andersen and Depledge (1997). The suggested reason for this large difference relates to differences in feeding

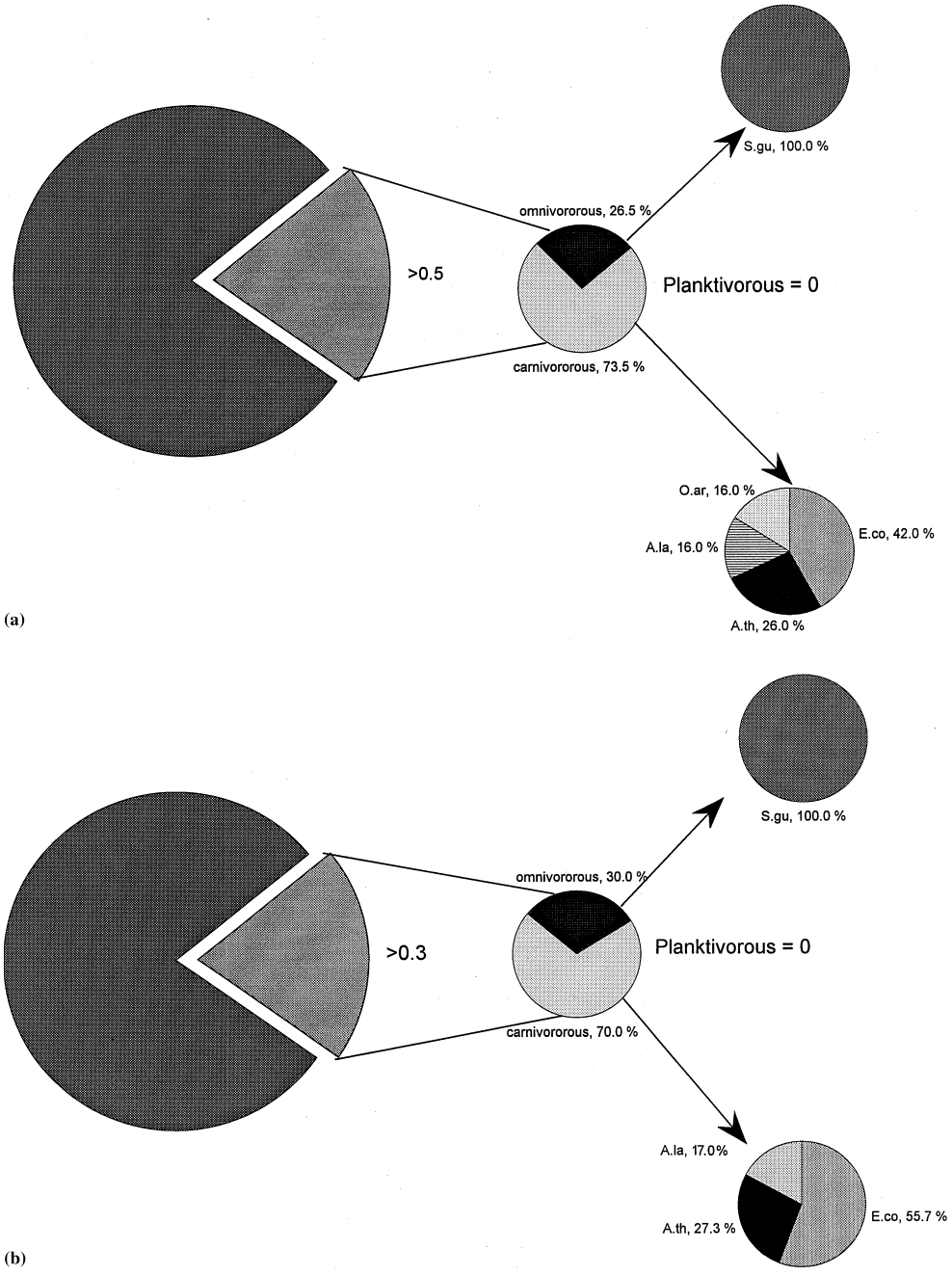

Fig. 7 The distribution of (a) T-Hg and (b) MeHg in fishes according to WHO limits.

habits (the mesopelagic fish are planktivorous) and also differences in exposure with epipelagic fish being more exposed to atmospheric inputs and photochemical production of MeHg and demersal fish being more influenced by sediment conditions.

The findings of this study are similar to other studies especially for the difference of the mean Hg content between planktivorous and carnivorous (Nakagawa *et al.*, 1997; Joiris *et al.*, 1997). Carnivorous fish can be used as a good indicator for monitoring of mercury pollution (Vigh *et al.*, 1996) while other species with other feeding habits should also be monitored for human health aspects.

Mercury concentrations and international limits

It is important to have an overall picture of the obtained T-Hg in the analysed species from a public health perspective. So as to achieve this it was first necessary to convert concentrations to a wet weight values using dry weight/wet weight ratio (0.25 ± 0.02). It is then possible to apply the categorization of Chvojka *et al.* (1990) who described T-Hg in the wet weight of fish from 0.05 to 0.15 μg g^{-1} as very low, from 0.15 to 0.25 μg g^{-1} as low, from 0.25 to 0.35 μg g^{-1} as medium, from 0.35 to 0.45 μg g^{-1} as high and total Hg (T-Hg) above 0.45 μg g^{-1} as very high. The results are shown in Fig. 6. It is clear that the fish in the 'very high' category (e.g. *E. coioides* and *O. argentus*) are drawn exclusively from the omnivores and carnivores and that planktivorous fish represent significantly lower health threats. A simpler grouping utilizing the WHO permissible limits (WHO, 1990) can also be used (Fig. 7a and b) where 0.5 μg g^{-1} is the limit for T-Hg and 0.3 μg g^{-1} for MeHg. The results for T-Hg indicate that 79.4% of the samples

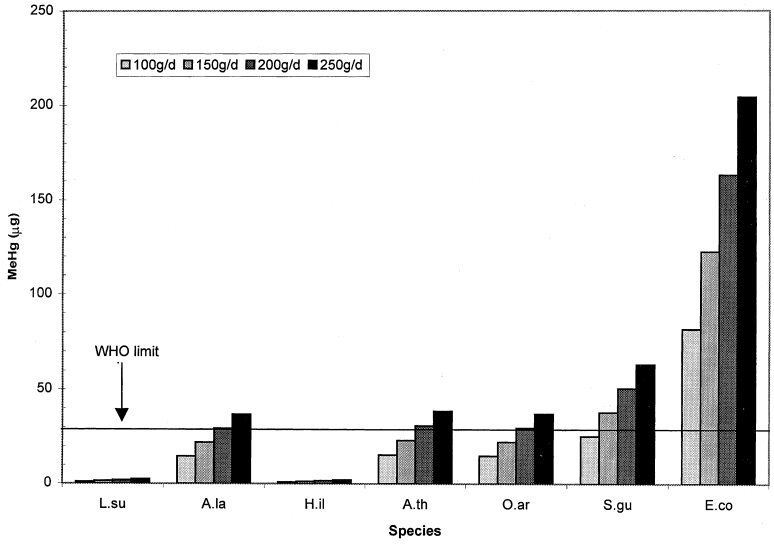

Fig. 8 The estimated human intake of MeHg (μg) from different fish species according to quantities of fish consumed.

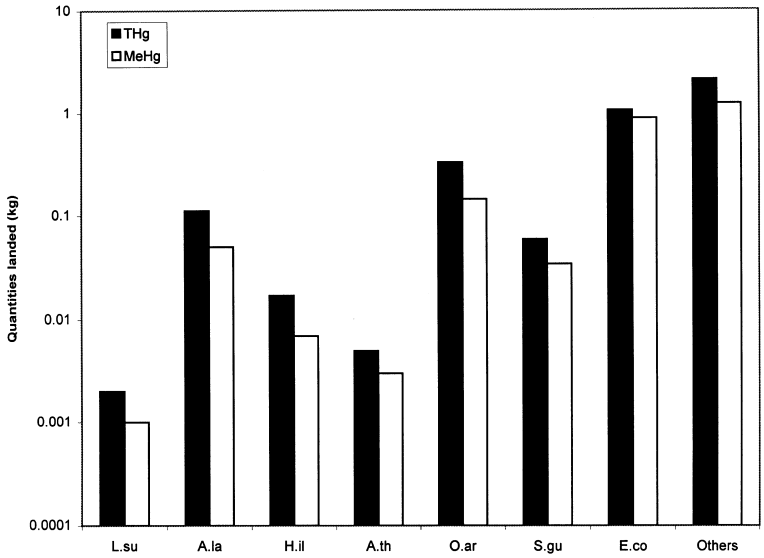

Fig. 9 The estimated quantities (kg) of T-Hg and MeHg reaching the Kuwait food supply based on fish landings (1994–1996).

were <0.500 μg g^{-1} and 20.6% were $\geqslant 0.500$ μg g^{-1} and exceeded the WHO limit. For MeHg the results indicate that 79.4% of the analysed samples are <0.300 μg g^{-1} and 20.6% are $\geqslant 0.300$ μg g^{-1} and exceeded the WHO limit.

The results of this study were found to be similar to other findings (Minganti *et al*., 1995; Nakagawa *et al*., 1997).

Public health implications

To assess the potential health impact, the 30 μg day^{-1} maximum intake limit for MeHg of a 70 kg person was used as a guideline (US-EPA, 1984). Using the observed concentrations in the fish and a range of fish consumption (100, 150, 200 and 250 g d^{-1}) the results shown in Fig. 8 were obtained. From this it can be seen that at a consumption rate of 200 g d^{-1} or more the EPA limit was approached or exceeded for all species except *L. subviridis* and *H. ilisha*. Particularly high exposure is associated with consumption of *E. coioides*. This level of consumption is common amongst some consumer groups in Kuwait (Al-Majed and Preston, 1999). Of course these calculations relate only to the fish consumption route of mercury exposure and other sources must also be taken into account to reliably estimate the total exposures.

Mercury removal by fish from Kuwait

The quantity of fish caught by artisans and which reaching the local market in the years 1994–1996 ranges between 10 000 and 11 000 tonnes annually (ASA, 1986). The species sampled in this study represent 33.1% of the total landings. Accordingly a total of ~3.2 kg of Hg and ~1.9 kg of MeHg are being removed yearly by fish landings. The results are summarized in Fig. 9. It should be noted that this is the minimum estimation of the Hg removed from Kuwait Bay by fish uptake since only edible tissues were analysed. Levels of other organs (liver, kidney, brain, skin, others) in the species are expected to contain more Hg than the tissues (Goldstein *et al*., 1996). Nevertheless, in terms of the estimates of the total mercury contamination in Kuwait Bay, this removal mechanism is clearly not very significant.

Al-Majed, N. (1999) Ph.D. Thesis University of Liverpool (in preparation).

Al-Majed, N. and Preston, M. (1999) Factors influencing the total mercury and methyl mercury in the hair of the fishermen of Kuwait. *Environmental Pollution* (in press).

Al-Majed, N. and Rajab, W. (1998) Levels of mercury in the marine environment of ROPME sea aera. In *Offshore Environment of the ROPME Sea Area after the war related oil spill*. Results of the 1993-94, Umitaka-Maru Cruises, 125–147. eds. A. Otsuki, M. Abdulraheem, R. Reynolds, 321 pp. Terra Scientific Publishing Company, Tokyo, ISBN No. 4-88704-123-3.

Anderlini, V., Samhan, O. and Awayes, R. (1983) *Detection and assessment of trace metal pollution in Kuwait's marine environment*. Kuwait Institute for Scientific Research, State of Kuwait, Vol. 1, KISR 605.

Andersen, L. and Depledge, H. (1997) A survey of total mercury and methylmercury in edible fish and invertebrates from Azorean waters. *Marine Environment Research* **44**, 331–350.

ASA (1986) Annual Statistical Abstract. Central Statistical Office, Ministry of Planning. Edition **23**, State of Kuwait.

Back, C. and Watras, J. (1995) Mercury in zooplankton of northern Wisconsin lakes: Taxonomic and site-specific trends. *Water Air and Soil-Pollution* **80**, 931–938.

Carpenter, E., Krupp, F., Jones, A. and Zajonz, U. (1997) *The Living Marine Resources of Kuwait, Eastern Saudi Arabia, Bahrain, Qatar, and the United Arab Emirates*, FAO species identification field guide for fishery purposes, Food and Agriculture Organisation of the United Nations, Rome. ISBN 92-5-103741-8, 293 pp.

Chvojka, R., Williams, J. and Fredrickson, S. (1990) Methyl mercury, total mercury, and selenium in snapper from two areas of the New South Wales coast, Australia. *Marine Pollution Bulletin* **21**, 570–573.

EPD (1996) *Environment Protection Department*, Annual Report. Ministry of Health, Kuwait.

Goldstein, M., Brigham, E. and Stauffer, C. (1996) Comparison of mercury concentrations in liver, muscle, whole bodies, and composites of fish from the Red River of the North. *Canadian Journal of Fisheries and Aquatic Sciences* **53**, 244–252.

Habashi, B., Al-Majed, N. and Borhama, A. (1993) Levels of trace metals in ROPME sea area. Final Report of to the Scientific Workshop on Results of the R/V Mt. Mitchell Cruise in ROPME Sea Area, Vol. 1, 73-86. Kuwait, 24-28 January 1993 ROPME/IOC(UNESCO)/UNEP/NOAA/EPC (Kuwait).

IAEA (1996) International Atomic Energy Agency, Training Manual of Sampling and Analysis of Trace Metals in Environmental Samples.

Joiris, R., Laroussi Moatemri, N. and Holsbeek, L. (1997) Mercury and polychlorinated biphenyls in zooplankton and shrimp from the Barents Sea and the Spitsbergen area. *Bulletin of Environmental Contamination and Toxicology* **59**, 472–478.

Kannan, K., Smith, G., Lee, F., Windom, L., Heitmuller, T., Macauley, M. and Summers, K. (1998) Distribution of total mercury and methyl mercury in water, sediment, and fish from south Florida estuaries. *Archives of Environmental Contamination and Toxicology* **34**, 109–118.

Khordagui, H. and Al-Ajmi, D. (1991) Mercury in seafood: A preliminary risk assessment for Kuwaiti consumers. *Environment International* **17**, 429–435.

Kim, P. (1995) Methylmercury in rainbow trout (*Oncorhynchus mykiss*) from lakes Okareka, Okaro, Rotomahana, Rotorua and Tarawera, North Island, New Zealand. *Science of the Total Environment* **164**, 209–219.

Kuronuma, K. and Abe, Y. (1986) *Fishes of the Arabian Gulf*. Kuwait Institute for Scientific Research, State of Kuwait.

Mason, P., Fitzgerald, F. and Morel, M. (1994) The biogeochemical cycling of elemental mercury-anthropogenic influences. *Geochimica et Cosmochimica Acta* **58**, 3191–3198.

Michel, H., Behbehani, M., Herring, D., Arar, M. and Shoushani, M. (1986) Zooplankton diversity, distribution and abundance in Kuwait waters. In *Proceedings of the First Arabian Gulf Conference on Environment and Pollution*. Kuwait University.

Minganti, V., Capelli, R., Fiorentino, F., De-Pellegrini, R. and Vacchi, M. (1995) Variations of mercury and selenium concentrations in *Adamussium colbecki* and *Pagothenia bernacchii* from Terra Nova Bay (Antarctica) during a five year period. *International Journal of Environmental Analytical Chemistry* **61**, 239–248.

MOOPAM (1989) *Manual of oceanographic observations and pollutants analysis methods* (Second Edition). The Regional Organisation for the Protection of the Marine Environment (ROPME), Kuwait.

Nakagawa, R., Yumita, Y. and Hiromoto, M. (1997) Total mercury intake from fish and shellfish by Japanese people. *Chemosphere* **35**, 2909–2913.

Ninomiya, T., Ohmori, H., Hashimoto, K., Tsuruta, K. and Ekino, S. (1995) Expansion of methylmercury poisoning outside of Minamata: An epidemiological study on chronic methylmercury poisoning outside of Minamata. *Environmental Research* **70**, 47–50.

Nishimura, H. and Kumagai, M. (1983) Mercury pollution of fishes in Minamata Bay and surrounding water: Analysis of pathway of mercury. *Water Air and Soil Pollution* **20**, 401–411.

Phillips, R., Heilprin, J. and Hart, A. (1997) Mercury accumulation in barred sand bass (*Paralabrax nebulifer*) near a large wastewater outfall in the Southern California Bight. *Marine Pollution Bulletin* **34**, 96–102.

Plourde, Y., Lucotte, M. and Pichet, P. (1997). Contribution of suspended particulate matter and zooplankton to MeHg contam-

ination of the food chain in midnorthern Quebec (Canada) reservoirs. *Canadian Journal of Fisheries and Aquatic Sciences* **54**, 821–831.

ROPME (1988) Regional Organization for the Protection of the Marine Environment, Results of project number: KA/5102 82 10(2363) rev.4. Survey of mercury in fish and sediments from the ROPME Sea Area. (unpublished report) prepared by IAEA-MESL, 64 pp.

ROPME (1996) Regional Organization for the Protection of the Marine Environment, Results of Contaminant Screening in the ROPME Sea Area. Mid term progress Report. (unpublished report) prepared by IAEA-MESL, Contract (94–96), 50 pp.

Stafford, P. (1997) Mercury concentrations in Maine sport fishes. *Transactions of the American Fisheries Society* **126**, 144–152.

Szucs, F. and Oostdam, B. (1977). Salt and Chlorine Plant effluents and the effect of mercury on the nearby aqueous and sedimentary marine environment of Kuwait. Kuwait Institute for Scientific Research, Kuwait. KISR PPI010EESRRT7701.

UNEP (1992) Determination of methylmercury in selected marine organisms by gas chromatography. Reference Methods for Marine Pollution Studies No. 13, Rev. 1.

US-EPA (1984) Environmental Protection Agency. Mercury Health Effects update: Health Issue Assessment: final Report, EPA 600/8 84 019F, Office of Health and Environmental Assessment, Washington DC.

Vigh, P., Mastala, Z. and Balogh, V. (1996) Comparison of heavy metal concentration of grass carp in a shallow eutrophic lake and a fish pond (possible effects of food contamination). *Chemosphere* **32**, 691–701.

WHO (1990) World Health Organization. Environmental Health Criteria No. 101: Methylmercury. Geneva.