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Trace element levels in fish from clean and polluted coastal marine sites in the Mediterranean Sea, Red Sea and North Sea

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Abstract The bioaccumulation of Hg, Cd, Zn, Cu, Mn and Fe was evaluated in the muscle and liver tissue of four fish species (*Siganus rivulatus*, *Diplodus sargus*, *Lithognatus mormyrus and Plathychtis flesus*) from clean and polluted marine coastal sites in the Red Sea, Mediterranean Sea and North Sea within the framework of the MARS 1 program. Representative liver samples were screened for organic contaminants (DDE, PCBs and PAHs) which exhibited very low concentrations. The levels of Cd, Cu, Zn, Fe and Mn found in the muscle tissue in this study were similar among the four species and within the naturally occurring metal ranges. However, differences were found among the sites. In the Red Sea, Cu was higher in the muscle of *S. rivulatus* at Ardag and Zn at the Observatory (OBS). Cu, Zn and Mn were higher in the Red Sea than in the specimens from the Mediterranean. The differences were attributed to different diets derived from distinctively different natural environments. *D. sargus* from Haifa Bay (HB) had higher Cd, Cu and Mn values than specimens from Jaffa (JFA), and *L. mormyrus* higher Cd, Fe and Mn in HB, corresponding to the polluted environmental status of the Bay. No differences in metal levels were found among the North Sea sites, except for Fe that was lower at the Eider station. Hg was low in all the specimens, but the values varied with species and sites. The lowest Hg values were found in *S. rivulatus*, the herbivorous species, as expected from its trophic level. Hg in *P. flesus* was higher than in *S. rivulatus* but still low. Higher Hg values were found in the muscle tissue of *L. mormyrus*, with the highest values in *D. sargus*, both carnivorous species from the same family. Hg in *D. sargus* was higher in HB than in JFA, as expected, but in the larger specimens of *L. mormyrus* from JFA values were higher, while in the small specimens there were no differences in Hg values. The levels of all metals were higher in the liver than in the muscle, with enrichment factors ranging from 3 to 104, depending on species and sites. The lowest enrichment values were found for Hg. Based on liver values, the specimens of *S. rivulatus* from the OBS had the highest levels, as well as *D. sargus* and *L. mormyrus* from JFA, contrary to the known relative environmental status of the sites.

Key words Trace elements · Bioaccumulation · Organic contaminants · Fish

Introduction

Marine organisms, among them fish, accumulate contaminants from the environment and therefore have been extensively used in marine pollution monitoring programs (e.g., ICES (Uthe et al. (1991); UNEP (1993); the National Oceanic and Atmospheric Administrations National Status and Trends Program). These programs aim, among other things, to define the environmental status of coastal regions (spatial monitoring), to establish temporal trends in the concentration of pollutants in selected areas (trend monitoring) and to assure the quality of marine food (compliance monitoring) (Jensen and Cheng 1987; Hornung and Kress 1991; Jorgensen and Pedersen 1994; Herut et al. 1996; and many others). Among the various parameters measured, trace metal concentrations and their accumulation in fish are some of the most widespread used in environmental monitoring, resulting in a wealth of data compiled by various authors (Eisler 1981; Thompson 1990; Hornung and Kress 1993; Kennish 1997, and others).

This research was carried out within the framework of the joint German-Israel MARS-1 co-operation in the marine sciences program: “Biological indicators of natural and man-made changes in marine and coastal waters”. In contrast to spatial and trend monitoring programs that utilize mostly the chemical data, the aim of this research was to provide an additional tool to complement and aid

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in the interpretation of the biological results of the three groups participating in MARS-1. With this purpose in mind, we worked in conjunction with the other groups on four fish species: *Siganus rivulatus* (Red and Mediterranean Seas), *Diplodus sargus* and *Lithognatus mormyrus* (Mediterranean Sea) and *Plathychtis flesus* (North Sea), collected in contaminated and relatively clean sites. The objective of this study was to determine the differences in concentrations of mercury and cadmium (nonessential metals) and copper, zinc, iron and manganese (essential metals) in the muscle and liver tissue of the fish, with respect to site and species. In addition, we performed a screening of organic pollutants on selected samples of fish liver to achieve a preliminary assessment of the levels in the biota.

Materials and methods

Sampling

Siganus rivulatus (rabbitfish) specimens (56) were caught in traps at two sites in the Red Sea: Ardag, considered contaminated due to the proximity to mariculture fish farms, and at the marine observatory (OBS) situated near coral reefs with oligothrophic waters (Genin et al. 1995; see sampling sites map in the introduction of this issue). Sampling was performed in January–June 1996 and January 1997. In the Mediterranean Sea, *S. rivulatus* specimens (33) were caught with gill nets in Haifa Bay (HB), known to be a polluted area (Hornung et al. 1989; Cohen et al. 1993; Herut et al. 1993 1996; Herut and Kress 1997; Kress and Herut 1998), in September 1997 and January 1998. *Diplodus sargus* (white bream) specimens (49) and *Lithognatus mormyrus* (striped bream) specimens (44) were collected in Haifa Bay and in Jaffa (JFA) in February 1997, June–July 1997 and January 1998. Jaffa is considered a relatively clean area (Herut et al. 1993 1998). *Platichthys flesus* (flounder) specimens (30) were collected in July and October 1996 by bottom trawl at three stations in the North Sea: the Elbe estuary, Eider estuary and Tiefe Rinne (TR) near Helgoland island. The Elbe estuary is considered most polluted by heavy metals, chlorinated hydrocarbons and nutrients (Büther 1990; Kausch et al. 1990), followed by the Eider. TR is considered to be a relatively clean site.

Sample preparation and analysis

Fish specimens were measured, weighed and dissected, and the muscle tissue and liver taken for analysis. Only the muscle tissue was analyzed in *P. flesus*. The samples were kept in deep freeze at –20°C until lyophilization for 48 h. After drying, the samples were digested with concentrated nitric acid in Teflon-lined, high-pressure decomposition vessels as described by Hornung et al. (1989). The solutions were analyzed specifically for Cd, Cu, Zn, Fe and Mn by flame or graphite furnace atomic absorption spectrophotometry on a Perkin-Elmer 1100B spectrophotometer equipped with a deuterium-arc background corrector. Mercury was analyzed by cold vapor atomic absorption spectrometry on a Coleman Mercury Analyzer MAS-50B. Detection limits for Cd, Hg, Cu, Zn, Fe and Mn were 0.03, 0.005, 0.03, 0.07, 0.04 and 0.01 µg/g wet wt., respectively.

Screening of organic pollutants [chlorinated hydrocarbons (dioxins), hydrocarbons (aliphatic, aromatic, polar), pesticides, PCBs] was performed by the Global Geochemistry Corporation (GGC), USA, an EPA-certified laboratory, on eight composite liver samples: *S. rivulatus* (HB, Ardag and two samples from OBS), *D. sargus* and *L. mormyrus* (HB and JFA).

Quality control and quality assurance of trace metal determinations were performed on certified standard reference materials from the National Institute of Standards and Technology (NIST, bovine liver) and from the National Research Council of Canada (NRCC, DORM 2 and DOLT 1). The standards were digested and analyzed in the same manner as the samples, with each analytical run. All standard reference materials gave results within 5% of the certified values.

Statistical analysis

Statistical analyses were performed using the statistical package SAS/STAT. The procedures used were the general linear model (GLM) using the method of least squares, the *t*- test, ANOVA and the Duncan *a*-parametric test. All tests were conducted under the assumption of 95% confidence level.

One of the purposes of this work was to check for differences in metal levels at different sampling sites. It is known that metal contents may depend on the body size of an organism (Boyden 1974; Phillips 1980; Ridout et al. 1989; Hornung and Kress 1991; Evan et al. 1993; Kress et al. 1998). Therefore, to prevent bias due to body size effects, analyses can be performed on a selected size group or the results may be normalized to body size. In this study, prior to the spatial analysis, we checked for each species the dependence of each element on size at each of the sampling locations. If the trace metal concentrations were found to be size dependent at all sites, the values were normalized (metal concentration/weight, or metal concentration × weight, if concentration decreased with size) and the normalized values compared. When no size dependence was found, the values were compared as such. When size dependence was found only at some of the sites, we divided the specimens into similar size groups and then performed the statistical analysis on the non normalized values for each of the groups.

Results

Siganus rivulatus

The relationships between fish weight and length and between liver weight and fish length of *S. rivulatus* are shown in Fig. 1. Statistical summaries of Hg, Cd, Cu, Zn, Fe and Mn concentrations in muscle and liver tissue are given in Table 1. Specimens analyzed in the OBS were larger than the specimens from HB. In Ardag, the size range included small (11 specimens less than 160 mm long) and large (15 specimens longer than 200 mm) specimens.

No size dependence was found for trace metal concentrations in muscle and liver of *S. rivulatus* from the Red Sea, except for Cu and Zn in the muscle tissue at the Ardag station. Therefore, statistical comparison was performed on the nonnormalized concentration values. For Cu and Zn in the muscle, a subsample of 14 fishes from Ardag with an average weight of 190.2±30 g and 22 fishes from OBS with an average weight of 200±31 g were compared. The statistical comparison showed the following results:

Muscle: Cu: OBS < Ardag; Hg, Zn: OBS > Ardag;
Cd, Fe, Mn: OBS=Ardag
Liver : Hg, Cd, Cu, Zn: OBS>Ardag; Fe, Mn:
OBS=Ardag

Mercury in muscle and liver tissue was significantly higher in the OBS due to two specimens with relatively high values both in the muscle (>0.05 µg/g wet wt.) and liver tissue (>0.9 µg/g wet wt.).

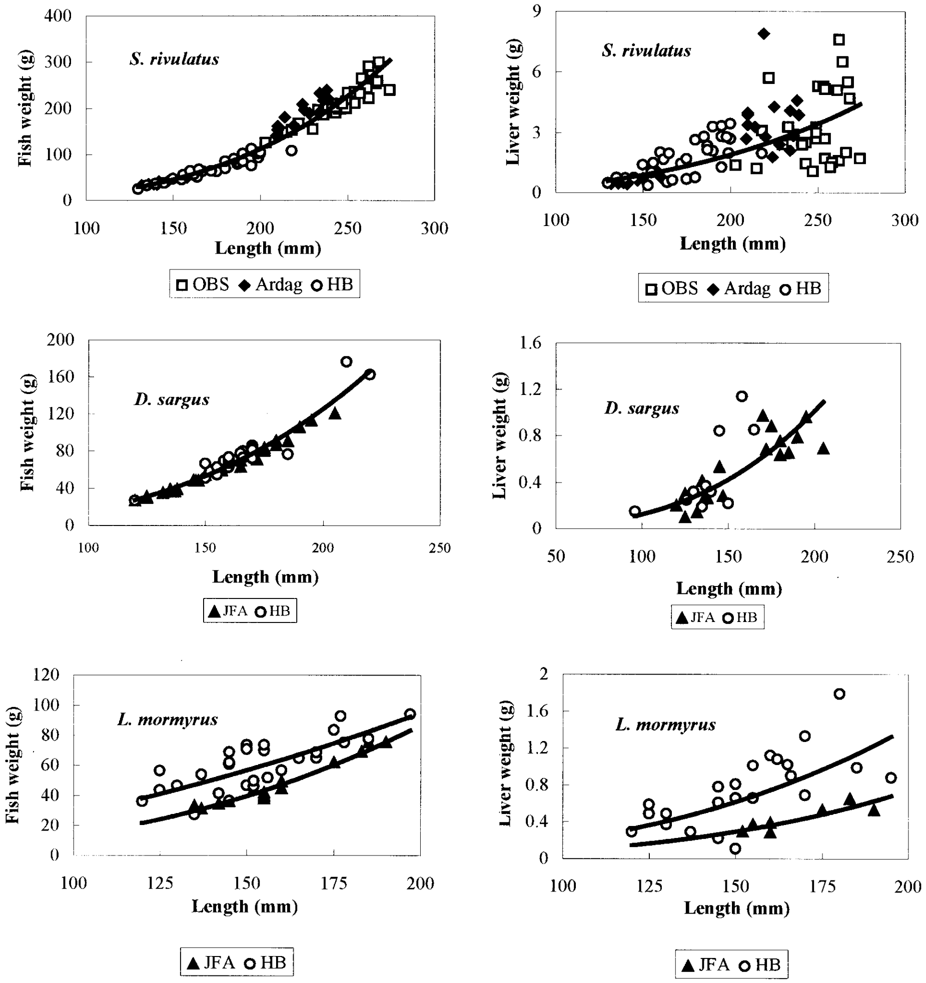


Fig 1 Fish weight vs. length and liver weight vs length in *Siganus rivulatus*, *Diplodus sargus* and *Lithognatus mormyrus* from the different sampling sites. Sampling sites in the Red Sea are Ardag and Observatory (*OBS*) and in the Mediterranean Sea, Jaffa (*JFA*) and Haifa Bay (*HB*)

The concentrations found in specimens from the Mediterranean were similar to the concentrations found in the Red Sea. A parametric statistical comparison among the three sites showed that, in general, the highest concentrations in liver were found at the OBS, except for Fe and Mn, which were higher in HB. In the muscle tissue, Cu was highest at Ardag, Zn in the Observatory and Mn in both Red Sea stations. Hg, Cd and Fe were not significantly different.

Diplodus sargus

The relationships between total fish weight and length and between liver weight and fish length of *D. sargus* are shown in Fig. 1. Statistical summaries of Hg, Cd, Cu, Zn, Mn and Fe concentrations in muscle and liver tissue are given in Table 1. There were no differences in the fish weight and liver weight of *D. sargus* collected at Haifa Bay and Jaffa, except for two large specimens collected in HB (Fig. 1).

The concentrations of Hg and Fe in the muscle tissue at both sampling sites increased with size; therefore the normalized values were used in the statistical comparison. In the liver, Hg and Fe increased with size in JFA while Mn increased in HB. Most Hg values in liver tissue from HB were below or close to the detection limit, while higher values were found in JFA. No size dependence was found in the other cases and the nonnormalized values were compared. The results were as follows:

Muscle: Hg, Cd, Cu, Mn: HB>JFA; Zn, Fe: HB=JFA
Liver: Cd: HB>JFA; Hg: JFA>HB; Cu, Zn,
Fe: HB=JFA

Due to the different size distribution at the sites, it was not feasible to divide the data into subsamples for Fe and Mn comparison in the liver. Therefore, we performed the statistical analysis on both the nonnormalized values and the normalized values. The results were the same for Fe, with no significant differences between the sites, but for Mn the nonnormalized values did not indicate differences while the normalized values showed JFA >HB.

Lithognatus mormyrus

The relationships between fish weight and length and between liver weight and fish length of *L. mormyrus* are shown in Fig. 1. It can be seen that the relationship was different, with slightly higher weights in HB for the

Table 1 Number of specimens (*n*), ranges, means (± standard deviation) and medians of length, total fish weight (under muscle) or liver weight, % dry weight and metal concentration (µg/g wet wt.) in the species studied from each sampling site. bdl – Below detection limit (Hg <0.001; Cd <0.01 µg/g wet wt.)

	Length (mm)	Weight (g)	Dry wt (%)	Element (µg/g wet wt.)					
				Hg	Cd	Cu	Zn	Fe	Mn
Siganus rivulatus – Muscle									
Haifa Bay									
Range	130–218	25–113	20–26	bdl-0.045	bdl-0.10	0.15–0.59	2.53–8.32	3.65–28.2	0.08–0.50
Median				0.001	0.002	0.24	5.51	6.88	0.14
Mean (SD)				0.012 (0.016)	0.02 (0.03)	0.29 (0.11)	5.41 (1.29)	7.76 (4.09)	0.15 (0.07)
n	30	30	30	29	30	30	30	30	30
Ardag									
Range	132–239	33–240	23–34	bdl-0.003	bdl-0.05	0.22–0.74	2.99–11.5	4.33–10.5	0.12–0.71
Median				0.001	0.03	0.39	6.19	7.49	0.19
Mean (SD)				0.001 (0.001)	0.03 (0.01)	0.43 (0.15)	6.38 (2.12)	7.40 (1.88)	0.24 (0.13)
n	25	26	26	26	26	26	26	26	25
Observatory									
Range	203–274	126–300	22–30	bdl-0.334[a]	0.01–0.05	0.16–0.69	4.35–23.3	4.03–16.3	0.10–0.42
Median				0.001	0.03	0.35	7.88	7.07	0.23
Mean (SD)				0.019 (0.062)	0.03 (0.01)	0.35 (0.12)	8.37 (3.62)	7.31 (2.63)	0.23 (0.07)
n	30	30	30	30	30	30	30	30	30
Siganus rivulatus – liver									
Haifa Bay									
Range		0.36–3.45	21–50	bdl-0.325	0.11–2.09	1.51–77.3	51.6–403	139–1232	0.32–2.80
Median				0.002	0.38	5.93	90.7	720	0.86
Mean (SD)				0.021 (0.060)	0.52 (0.44)	14.4 (18.5)	125 (77.4)	695 (305)	0.92 (0.45)
n		33	33	33	33	33	33	33	33
Ardag									
Range		0.43–7.9	24–63	bdl-0.083	0.13–1.00	4.98–52.0	73.4–541	222–2729	0.52–1.95
Median				0.001	0.36	14.4	192	317	0.92
Mean (SD)				0.011 (0.020)	0.39 (0.19)	19.0 (11.9)	218 (110)	423 (461)	1.00 (0.31)
n		27	27	26	27	27	27	27	27
Observatory									
Range		1.1–7.6	27–44	bdl-1.724	0.28–1.48	14.0–144	87.6–732	140–929	0.73–2.26
Median				0.011	0.64	38.9	416	425	0.99
Mean (SD)				0.166 (0.388)	0.72 (0.34)	45.3 (25.0)	404 (161)	468 (165)	1.06 (0.33)
n		29	29	28	29	29	29	29	29
Diplodus sargus – muscle									
Haifa Bay									
Range	120–220	26.8–176	19–28	0.016–0.334	bdl-0.11	0.23–0.38	3.92–5.36	3.37–6.61	0.10–0.23
Median				0.094	0.02	0.30	4.52	5.12	0.15
Mean (SD)				0.114 (0.083)	0.03 (0.02)	0.30 (0.04)	4.63 (0.41)	5.02 (0.91)	0.16 (0.03)
n	23	23	23	23	23	23	23	23	23
Jaffa									
Range	120–205	26.5–120	17–25	bdl-0.161	bdl-0.03	0.20–0.37	3.84–5.84	2.17–6.13	0.10–0.20
Median				0.018	0.02	0.23	4.62	4.09	0.14
Mean (SD)				0.044 (0.051)	0.02 (0.01)	0.25 (0.04)	4.65 (0.53)	4.14 (0.89)	0.14 (0.02)
n	26	26	26	26	26	26	26	26	26
Diplodus sargus – liver									
Haifa Bay									
Range		0.15–1.14	20–29	bdl-0.082	0.23–2.65	4.66–11.0	40.2–55.4	130–524	0.66–3.61
Median				0.001	0.42	8.31	47.6	212	1.62
Mean (SD)				0.019 (0.027)	0.65 (0.68)	7.82 (2.01)	47.3 (4.7)	251 (130)	1.81 (0.79)
n		10	10	9	10	10	10	10	10
Jaffa									
Range		0.10–0.97	19–36	0.040–0.311	0.15–0.46	2.09–9.30	34.3–67.7	107–398	0.63–2.51
Median				0.100	0.31	7.92	51.5	161	1.76
Mean (SD)				0.134 (0.089)	0.29 (0.08)	7.08 (2.05)	51.5 (8.7)	183 (71)	1.76 (0.45)
n		19	21	21	21	21	21	21	21

Table 1 continued

	Length (mm)	Weight (g)	Dry wt (%)	Element (µg/g wet wt.)					
				Hg	Cd	Cu	Zn	Fe	Mn
Lithognatus mormyrus – muscle									
Haifa Bay									
Range	120–270	27.3–315	21–28	bdl-0.169	bdl-0.04	0.20–0.72	3.73–11.4	3.32–12.8	0.09–0.39
Median				0.033	0.03	0.32	6.12	5.67	0.21
Mean (SD)				0.043 (0.041)	0.03 (0.01)	0.35 (0.11)	6.44 (1.49)	6.27 (2.22)	0.21 (0.07)
n	29	29	29	29	29	29	29	29	29
Jaffa									
Range	135–190	31.0–75.5	20–26	bdl-0.143	bdl-0.03	0.25–0.36	5.08–6.71	2.67–6.68	0.15–0.23
Median				0.034	0.02	0.30	6.01	4.41	0.17
Mean (SD)				0.044 (0.038)	0.02 (0.01)	0.30 (0.03)	6.00 (0.44)	4.48 (1.01)	0.18 (0.03)
n	15	15	15	15	15	15	15	15	15
Lithognatus mormyrus – liver									
Haifa Bay									
Range		0.11–1.79	25–38	bdl-0.187	0.13–0.73	1.31–5.96	27.9–72.1	62.6–735	0.48–2.44
Median				0.063	0.38	3.27	34.6	177	1.54
Mean (SD)				0.072 (0.064)	0.35 (0.15)	3.38 (0.95)	36.6 (8.9)	206 (147)	1.51 (0.42)
n		23	24	24	24	24	24	24	24
Jaffa									
Range		0.28–0.65	19–36	0.106–0.233	0.09–0.48	2.92–5.59	27.7–64.1	19.5–179	1.48–2.55
Median				0.137	0.19	4.63	43.2	150	2.01
Mean (SD)				0.160 (0.053)	0.26 (0.14)	4.37 (0.82)	45.1 (11.3)	136 (50)	2.03 (0.31)
n		7	7	7	7	7	7	7	7

[a] Without highest value the mean (± SD) is 0.008 (0.022) µg/g wet wt

same fish length. Statistical summaries of Hg, Cd, Cu, Zn, Mn and Fe concentrations in muscle and liver tissue are given in Table 1.

The concentrations of Hg and Fe in the muscle tissue in JFA increased with size, while Mn in Haifa Bay decreased with increasing size. In the liver, Cd in JFA increased with size while Zn decreased. No correlation with size was found for the other cases.

The statistical comparison of the muscle tissue was performed in two groups: smaller and larger than 60 g. For the liver tissue, specimens smaller than 75 g were considered as one subsample. The statistical results were as follows:

Muscle: Cd, $Fe_{<60}$, $Mn_{<60}$: HB>JFA; $Hg_{<60}$, Cu, Zn, $Fe_{>60}$, $Mn_{>60}$: HB=JFA; $Hg_{>60}$:JFA>HB
Liver: Hg, Cu, Mn, $Zn_{<75}$: JFA>HB ; Fe: JFA=HB; $Cd_{<75}$: HB>JFA

Platichthys flesus

The statistical summary of Hg, Cd, Cu, Zn, Mn and Fe concentrations (as box plots) in muscle tissue of *P. flesus* is given in Fig. 2. No correlation between metal levels and length of the specimen was found. No differences were found in trace metal concentrations among the stations, except for Fe that was significantly lower in the Eider.

Organic screening

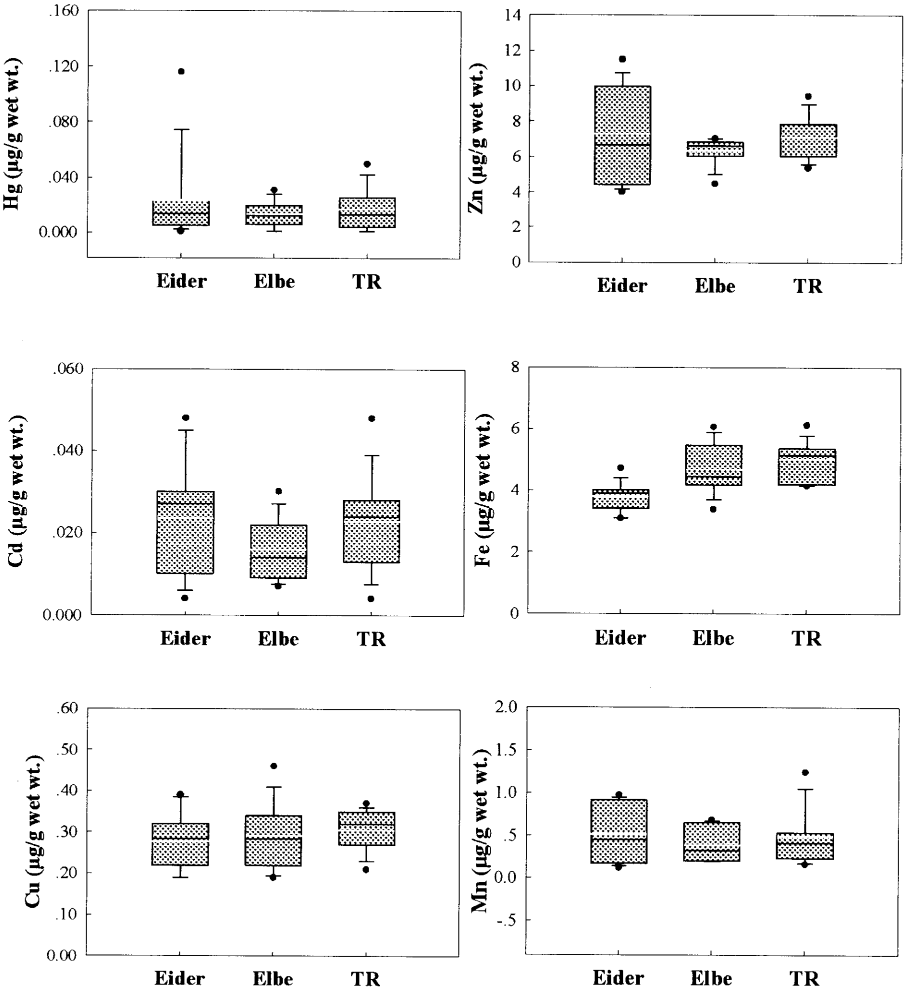
Eight composite samples of fish liver representing the various sampling sites were screened for a suite of organic compounds. The dry weight percentage of the livers ranged between 21 and 63% in *S. rivulatus*, and 19 and 38% in *D. sargus* and *L. mormyrus* (Table 1). Of the total 26 chlorinated insecticides and PCBs analyzed, only low concentrations of DDE (1.4–22.7 ng/g dry wt.) and of one congener of PCB (5.5–775 ng/g dry wt.) were found in the biota. (See "action limit" criteria for protecting humans and or wildlife from effects of pesticides and PCBs, NOAA 1988). The lowest values were found in the Red Sea.

PAHs were detected in all the samples (55.4–987 ng/g dry wt.). The single most dominant PAH was pyrene followed by phenanthrene (4 and 3 rings, respectively). Inspection of the PAH speciation showed mainly the alkylated compounds. Aromatic steranes (4-ring cycloalkanes) that serve as biomarkers for oil pollution were found in the liver of *S. rivulatus* from Haifa Bay.

Discussion

The levels of Cd, Cu, Zn, Fe and Mn found in the muscle tissue in this study were similar among the four species (Table 1) and in agreement with the metal ranges considered natural and cited in the literature. Thompson (1990) and Kennish (1997) found low Cd levels in the fish muscle, with values rarely exceeding 0.2 µg/g wet wt. Cu

Fig. 2 Box plots of Hg, Cd, Cu, Zn, Mn and Fe concentrations (µg g^{-1} wet wt.) in the muscle tissue of *Plathychtis flesus* at the different sites. Ten specimens were analyzed at each site. *Bottom* and *top edge* of each *box* are located at the sample 25 and 75 percentiles. *Central horizontal lines* are drawn at the sample median (*black*) and sample mean (*white*)



and Zn tend to be uniform, regardless of species and location, indicating close physiological regulation. Mean Cu values are around 0.3–0.8 µg/g wet wt. and Zn concentrations are generally less than 10 µg/g wet wt. Fe mean values range between 1 and 14 and Mn is usually less than 1 µg/g wet wt. The Cd, Cu, Zn, Fe and Mn levels found in the muscle tissue of *S. rivulatus* in this study were similar to the levels found in specimens collected at HB in 1991 and 1993 (Hornung and Kress,1993). The same is true for the levels found in *D. sargus* and *L. mormyrus* (Hornung and Kress 1991, 1993).

However, even though the Cd, Cu, Zn, Fe and Mn levels in the muscle tissue found in this study were within natural ranges, there were some differences among the sites in the Red and Mediterranean Seas. Cu was higher in *S. rivulatus* at Ardag and Zn at the OBS. Cu, Zn and Mn were higher in the Red Sea than in the specimens from the Mediterranean. Trace metals can be transferred to biota from the sediments (by ingestion and adsorption), from seawater, and through the food web (Phillips 1980). There were almost no differences in trace metal contents in the sediments from Ardag and OBS (Herut and Kress 1998). On the other hand, higher metal levels were found in the sediments and particulate matter of HB compared to the Red Sea sites, contrary to the lower metal levels found in HB specimens. Therefore, it is assumed that the differences found among the sites originate from different diets. *S. rivulatus* is a herbivorous species, but at the Ardag site it may feed also on excess food supplied to the mariculture cages (see contribution by Diamant et al., this Volume). The area is sandy and close to *Halophila sp.* seagrass . The OBS is located at a natural reef, while the flora in HB is different from the Red Sea. It was shown (Hornung et al. 1992) that there are differences in metal contents in green, brown and red algae. Cd and Fe are higher in the red algae, decreasing in the brown and lowest in the green algae. Zn is similar in the green and red algal species and highest in the brown algae. Therefore, the natural diet may influence the metal contents in specimens collected at different sites. *D. sargus* from HB had higher Cd, Cu and Mn values than specimens from JFA, in agreement with the known environmental status of Haifa Bay, i.e., higher trace metal contamination in sediments and suspended particulate matter (Herut and Kress 1997; Herut et al. 1998). Also in *L. mormyrus* from HB, the concentrations of Cd, Fe and Mn were higher than in JFA. Contrary to findings in the Red and Mediterranean Seas, the concentration of metals in the muscle tissue of *P. flesus* from the North Sea stations was not site specific.

In contrast to the other measured metals, Hg levels in the muscle have been shown to vary widely (Thompson 1990; Kennish 1997) and to have a well-defined age/size accumulation trend, depending on species and location. It is the only metal that shows biomagnification, i.e., higher accumulation in species of higher trophic levels (Eisler 1981). In this study, Hg was low in all the specimens, with values below 1 µg/g wet wt. (considered the maximum permissible level for human consumption). However, there were differences related to species and sites. The lowest Hg values were found in *S. rivulatus*, the herbivorous species, as expected based on its trophic level. Hg levels found in the specimens from HB in this study were similar to the levels found since 1979 (Hornung and Kress 1993). *S. rivulatus* does not seem to accumulate Hg even in HB known to be polluted by Hg (Herut et al. 1996, 1998), in contrast to *D. sargus* and *L. mormyrus*, as will be explained below. Hg in *P. flesus* was higher than in *S. rivulatus* but still low.

Higher Hg values were found in the muscle tissue of *L. mormyrus*, with the highest values in *D. sargus*, probably due to their diet. Both species, from the Sparidae family, feed on hard-shell mollusks, with polychaetes second in abundance. Both species prey occasionally upon fish. From the identification of the mollusks in the stomach contents it may be concluded that *D. sargus* preys at depths of 1–50 m mainly in rocky habitats with occasional visits to sandy habitats while *L. mormyrus* exhibits a contrasting trophic pattern, generally preying in sandy habitats but at the same depths. (D. Golani, personal communication). A temporal decrease in the concentration of Hg in *D. sargus* and *L. mormyrus* collected in HB has been observed since 1980 (Herut et al. 1996, 1998), but the levels in the Bay remain higher than in other areas along the Israeli Mediterranean coast. In this study, Hg in *D. sargus* was higher in HB than in JFA, as expected, but in the larger specimens of *L. mormyrus* from JFA values were higher, while in the small specimens there were no differences in Hg values.

The levels of all metals were higher in the liver than in the muscle, with enrichment factors ranging from 3 to 104, depending on species and sites. The lowest enrichment values were found for Hg, in agreement with the literature (Thompson 1990). Based on liver values, the specimens of *S. rivulatus* from the OBS had the highest levels, as well as *D. sargus* and *L. mormyrus* from JFA, all contrary to the known relative environmental status of the sites. OBS and JFA were considered the clean reference sites for the Red and Mediterranean Seas, respectively. The organic contaminants, although in low levels, were higher in Mediterranean than in the Red Sea specimens.

In conclusion, although the metal levels found were low, there were differences among the sites, not always in accordance with the environmental data available. Some of the differences could be explained by differences in diets and trophic level of the species, while others could not be explained based on the available data. The trace metal concentration data in fish could not be used to classify the sites as polluted or not polluted but was able to indicate site-specific contamination, in particular with respect to Hg levels. A new approach to the use of bioaccumulation data is the development of tissue residue threshold values, which connects between the tissue concentrations of a pollutant and measured biological effect in order to predict toxicity to organisms in the environment (Jarvinen et al. 1998). The data presented here was collected jointly with the MARS-1 groups and could, in conjunction with the biological results, provide a tool to predict the environmental status of an organism.

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