Helgol Mar Res (1999) 53:154–162

ORIGINAL ARTICLE

Barak Herut · Nurit Kress · Edna Shefer
Hava Hornung

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

Received: 25 February 1999 / Received in revised form: 22 April 1999 / Accepted: 30 April 1999

Abstract The trace element contamination levels in mollusks were evaluated for different marine coastal sites in the Mediterranean (Israeli coast), Red (Israeli coast) and North (German coast) Seas. Three bivalve species (*Mactra corallina*, *Donax sp*, and *Mytilus edulis*) and two gastropod species (*Patella* sp. and *Cellana rota*) were sampled at polluted and relatively clean sites, and their soft tissue analyzed for Hg, Cd, Zn, Cu, Mn and Fe concentrations. Representative samples were screened for organic contaminants [(DDE), polychlorinated biphenyls PCBs and polycyclic aromatic hydrocarbons (PAHs)] which exhibited very low concentrations at all sites. In the Red Sea, the gastropod *C. rota* showed low levels of Hg (below detection limit) and similar Cd concentrations at all the examined sites, while other trace elements (Cu, Zn, Mn, Fe) were slightly enriched at the northern beach stations. Along the Mediterranean coast of Israel, Hg and Zn were enriched in two bivalves (*M. corallina* and *Donax* sp.) from Haifa Bay, both species undergoing a long-term decrease in Hg based on previous studies. Significant Cd and Zn enrichment was detected in *Patella* sp. from the Kishon River estuary at the southern part of Haifa Bay. In general, *Patella* sp. and *Donax* sp. specimens from Haifa Bay exhibited higher levels of Cd compared to other sites along the Israeli Mediterranean coast, attributed to the enrichment of Cd in suspended particulate matter. Along the German coast (North Sea) *M. edulis* exhibited higher concentrations of Hg and Cd at the Elbe and Eider estuaries, but with levels below those found in polluted sites elsewhere.

Key words Trace elements · Mollusks · Contamination levels · Coastal marine sites

B. Herut (✉) · N. Kress · E. Shefer · H. Hornung
Israel Oceanographic and Limnological Research,
National Institute of Oceanography,
P.O.Box 8030, Tel Shikmona, Haifa, Israel 31080
Tel: +972-4-8515202; Fax: +972-4-8511911
e-mail: barak@ocean.org.il

Introduction

The coastline is a complex region comprising bays, estuaries and large semi enclosed areas where human population and industrial development are concentrated and therefore subject to contamination. Knowledge of the environmental status of the ecosystem with regard to various types of pollutants is an important factor in coastal zone management in general and in decision-making of marine waste disposal in particular. Among several marine and coastal pollution-monitoring programs (in national and international frameworks), the monitoring of mollusks was formerly implemented in many coastal areas especially in “status and trends”-type heavy metal monitoring. The specific goals of such programs are to assess the status of the coastal zone with regard to pollutant levels, to identify their sources, and to detect early signs of potential health and ecological risks.

Several studies examined the distribution of heavy metals in mollusks at Haifa Bay, located in the northern part of the Israeli Mediterranean coast (Navrot et al. 1974; Hornung and Oren 1980; Hornung et al. 1981 1984 1989; Krom et al. 1990; Herut et al. 1996) and along the German North Sea coast (Borchardt et al. 1988 1989; Zauke et al. 1995). No related observations are known for the northern part of the Gulf of Aqaba, the Red Sea. The aim of this study was to assess the state of trace element contamination in mollusks at different marine coastal sites as part of the German-Israeli MARS 1 Program: “Biological indicators of nature and man-made changes in marine and coastal waters”. Three bivalve species (*Mactra corallina*, *Donax* sp. and *Mytilus edulis*) and two gastropod species (*Patella* sp. and *Cellana rota*) were sampled at polluted and clean coastal sites in the Mediterranean, Red and North Seas.

Study sites

The sampling sites were chosen to include stations known to be polluted and stations known to be relatively clean. This was based on published data (as given below)

Table 1 Sampling sites, mollusk species and codes

Sampling site	Area	Species
Red Sea (RS)	Gulf of Aqaba	
Observatory[a] (OBS)	South beach of Eilat	*Cellana rota (CR)*
North Beach (NB)	North beach of Eilat	*Cellana rota (CR)*
Ardag	North beach of Eilat	*Cellana rota (CR)*
Mediterranean Sea (MED)	Eastern MED Basin	
Ma'agan Michael (MM)	Center MED Israeli coast	*Patella* sp., *Mactra corallina (MC), Donax* sp. *(DT)*
Tel Shikmona (TS)	Southern Haifa beach	*Patella* sp.
Hof shemen (HS)	Haifa Bay–Kishon estuary	*Patella* sp.
Q. Haim (QH)	Southern Haifa Bay	*Mactra corallina (MC), Donax* sp. *(DT)*
Q. Yam (QY)	Southern Haifa Bay	*Mactra corallina (MC), Donax* sp. *(DT), Patella* sp.
Frutarom (FR)	Northern Haifa Bay	*Mactra corallina (MC), Donax* sp. *(DT),*
Akko	Northern Haifa Bay	*Mactra corallina (MC)*
Achziv (ACH)	North MED Israeli coast	*Patella* sp.
North Sea (NS)	German coast	
Elbe, Cuxhaven, Leitdamm (CUX)	Elbe River estuary	*Mytilus edulis (ME)*
Eidersperrwerk (Eider)	Eider River estuary	*Mytilus edulis (ME)*
Helgoland Dune (HD)	Helgoland Harbor	*Mytilus edulis (ME)*
Spiekeroog (SP)	Southern NS German coast	*Mytilus edulis (ME)*

[a] Marine Biological Laboratory, Inter-University Institute, Migdalor sites as given in other papers of this issue

and on additional measurements conducted in this study. Among the sites sampled in the eastern Mediterranean Sea (MED) (Table 1) the stations in Haifa Bay (HB) were considered here as polluted (mainly by heavy metals and nutrients), although at different degrees of pollution, while the other stations along the MED coast were considered as relatively clean (Hornung et al. 1989; Cohen et al. 1993; Herut et al. 1993 1994 1996, in press Herut and Kress 1997; Kress and Herut 1998).

The sampling in the Gulf of Aqaba, the Red Sea (RS), was conducted at three sites: at OBS situated near coral reefs with oligotrophic waters (Reiss and Hottinger 1984; Genin et al. 1995), and at NB and Ardag sites at the north beach of Eilat, considered as slightly contaminated; both are near the Ardag fish farm, but the quality of their water and sediments is beyond the farm's influence (Angel et al. 1995).

The Elbe estuary in the North Sea is known to be polluted by heavy metals, chlorinated hydrocarbons and nutrients (Buther 1990; Kausch et al. 1990). The pollution gradient decreases in the order Elbe>Eider>Helgoland. The additional site Spiekeroog was added in 1997 as a reference to the Elbe estuary station but showed high chemical burden in specimens collected at this site was found (Diamant and Westernhagen 1998).

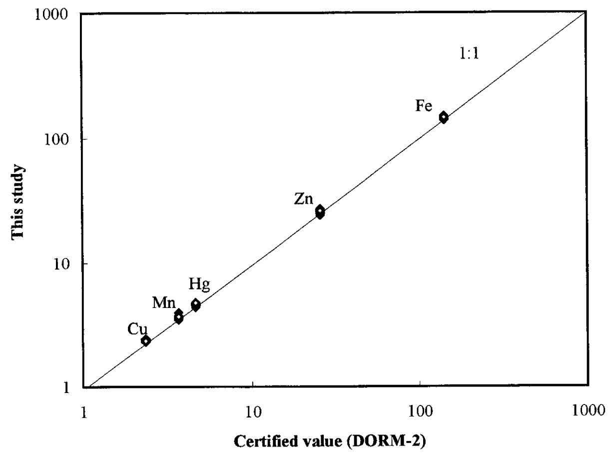

Fig. 1 Quality control chart for determination of metals in mollusks in DORM-2 (NRCC). Points represent results (μg g^{-1} dry wt.) of analyses of standard reference materials vs. their certified values. Cd was measured in DOLT-1 (NRCC). The results were within 5% of the certified value (4.18±0.28 μg g^{-1}dry wt.)

Materials and Methods

Sampling

Three bivalves (*M. corralina, Donax* sp. and *M. edulis*) and two gastropods (*Patella* sp. and *C.rota*) were sampled at several coastal sites in the Mediterranean, Red and North Seas (Table 1) between October 1995 and July 1998. Specimens were collected and kept in deep freeze at –20°C until analysis. The whole soft tissue of mollusks was taken for analysis. Prior to the analysis, the specimens were thawed, rinsed, measured, and weighed. Special care was taken to eliminate sediment particles adhering to the animals. Low-weight mollusks were pooled into composite samples, while large specimens were analyzed individually. The samples were lyophilized for 48 h and then digested with concentrated nitric acid in Uniseal, Teflon-lined, high-pressure decomposition vessels as described by Hornung et al. (1989).

Analytical methods

The solutions were analyzed for Cd, Cu, Zn, Fe, and Mn by flame or graphite furnace atomic absorption spectrophotometer on a

Table 2 Statistical summary of length (mm), weight (g) and percent dry weight of mollusks (*n* = number of analyses)

Species	Parameter	Station	OBS	NB	Ardag		
C. rota	*n* (composite)		14	12	4		
	Length	Range	25.5–41.0	26.0–41.0	17.0–29.5		
		Mean±SD	35.6±4.1	35.8±4.7	23.8±4.7		
	Weight	Range	0.65–3.77	0.75–2.84	0.15–1.05		
		Mean±SD	2.33±1.0	2.05±0.60	0.63±0.35		
	Dry weight	Range	14.5–24.1	13.1–19.5	13.3–21.7		
		Mean±SD	18.4±2.3	15.3±2.0	18.1±3.0		
		Station	ACH	QY	HS	TS	MM
Patella sp.	*n* (composite)		7	14	32	6	10
	Length	Range	20–35	27–39	20–41	22–35	24–40
		Mean±SD	27±5	33±3	29±5	29±4	32±5
	Weight	Range	0.46–2.05	1.5–4.1	0.62–3.15	0.60–2.78	0.81–2.53
		Mean±SD	1.24±0.55	2.8±0.77	1.56±0.65	1.59±0.76	1.53±0.56
	Dry weight	Range	11.6–23.1	14.1–18.1	12.7–22.4	15.2–18.1	12.8–17.1
		Mean±SD	17.9±3.5	16.1±1.3	16.6±2.0	16.9±1.0	15.7±1.2
		Station	Akko	FR	QY	QH	
M. corallina	*n* (composite)		13	63	40	6	
	Length	Range	23–42	15–54	15–42	16–29	
		Mean±SD	36.1±5.2	28.7±6.7	29.2±6.8	22.2±4.2	
	Weight	Range	0.69–3.95	0.13–3.94	0.19–4.15	0.18–1.08	
		Mean±SD	2.09±0.73	1.12±0.77	1.56±1.01	0.61±0.29	
	Dry weight	Range	5.0–9.3	3.9–15.4	5.4–13.4	7.8–14.1	
		Mean±SD	7.2±1.0	7.3±2.6	8.1±2.3	10.1±2.2	
		Station	FR	QY	QH	MM	
Donax sp.	*n* (composite)		37	25	19	39	
	Length	Range	12–38	15–30	18–29	15–35	
		Mean±SD	23.7±6.0	21.8±4.1	22.8±3.2	26.1±4.9	
	Weight	Range	0.08–1.27	0.09–1.26	0.26–1.12	0.10–1.48	
		Mean±SD	0.49±0.32	0.45±0.30	0.59±0.26	0.70±0.35	
	Dry weight	Range	7.9–24.4	7.6–22.3	9.2–13.2	6.5–16.7	
		Mean±SD	14.7±5.0	14.1±5.3	11.1±1.0	10.8±2.5	
		Station	CUX	Eider	HD	SP	
M. edulis	*n* (composite)		16	14	18	12	
	Length	Range	27–47	21–62	13.5–67	27.5–37.0	
		Mean±SD	37.9±5.5	39.2±13.0	44.2±14.3	32.2±2.6	
	Weight	Range	0.53–4.28	0.31–8.81	0.06–10.67	0.61–1.67	
		Mean±SD	2.03±1.11	2.99±2.71	4.28±3.29	1.04±0.29	
	Dry weight	Range	9.3–17.5	9.2–18.1	8.8–17.4	9.3–14.1	
		Mean±SD	12.4±2.7	11.8±2.9	13.4±2.4	12.0±1.2	

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-50 B. 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^{-1} wet wt., respectively.

Organic analysis of chlorinated hydrocarbons (dioxins), hydrocarbons (aliphatic, aromatic, polar), pesticides, and PCBs was performed on selected sediment and biota samples by the Global Geochemistry Corporation (GGC), USA (an EPA certified laboratory). Quality control and quality assurance of trace metal determinations in the biota were performed on certified standard reference materials (DORM-2 and DOLT1) from the National Research Council of Canada (NRCC) and bovine liver from the National Institute of Standards and Technology (NIST). The standards were digested and analyzed in the same manner as the samples, with each analytical run, and the results were within 5% of the certified mean values (or within the certified range) (Fig. 1). Moreover, a long-term quality control and international intercomparison exercises were performed by the Israel Oceanographic and Limnological Research (IOLR) chemical laboratory and are reported in annual reports on monitoring of heavy metals along the Mediterranean coast of Israel (for example, see Herut et al. 1998).

Statistical analyses were performed using the statistical package SAS/STAT. The procedures used were the general linear mod-

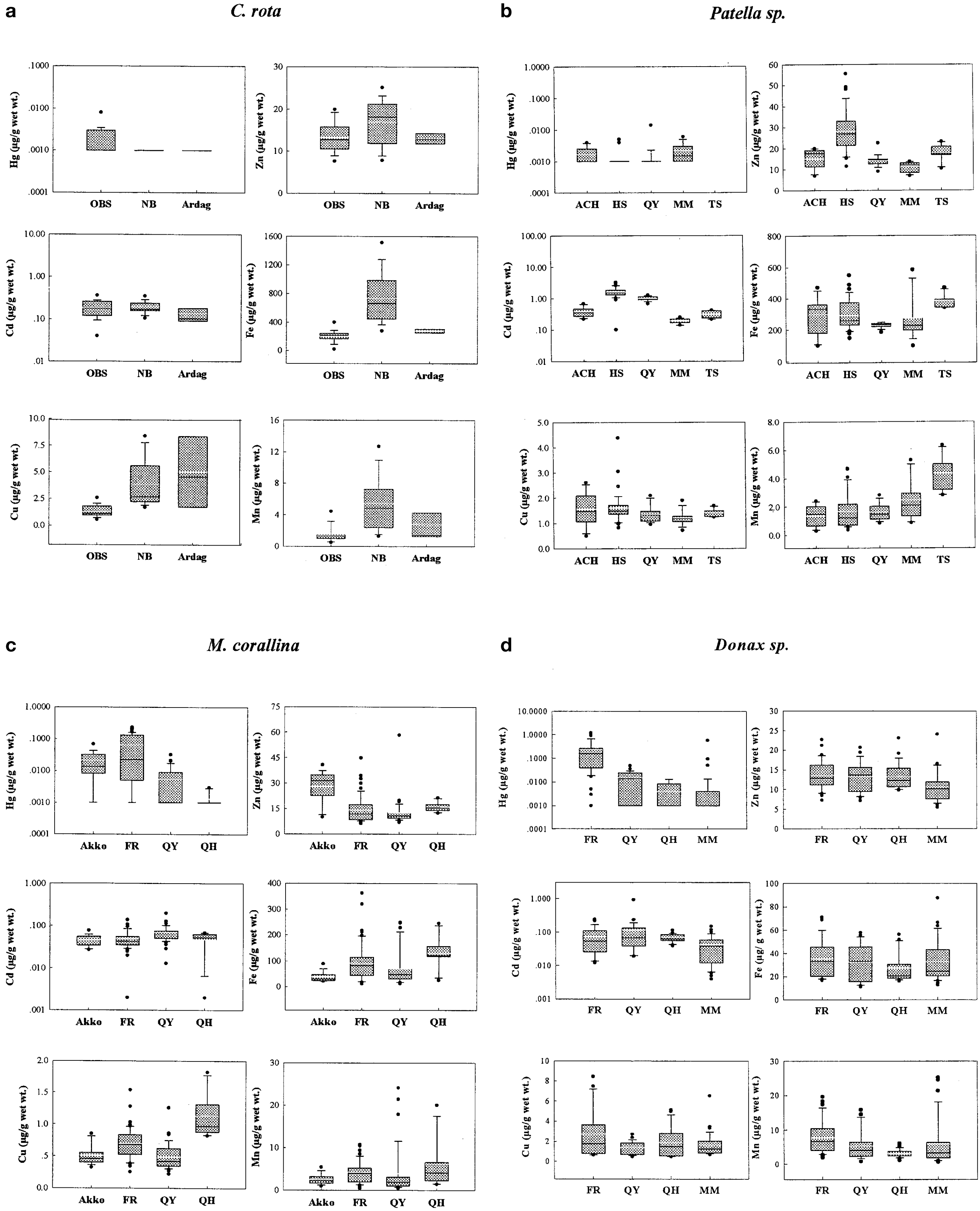

Fig. 2 Box plots of Hg, Cd, Cu, Zn, Mn and Fe concentrations (µg g^{-1} wet wt.) in two gastropod species (**a** *Cellana rota* and **b** *Patella* sp.) and three bivalve species (**c** *Mactra corallina*, **d** *Donax* sp., and **e** *Mytilus edulis*) at different sites (see Table 1). *Bottom* and *top edges* 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*). Note that Hg and Cd concentration axis is in logarithmic scale

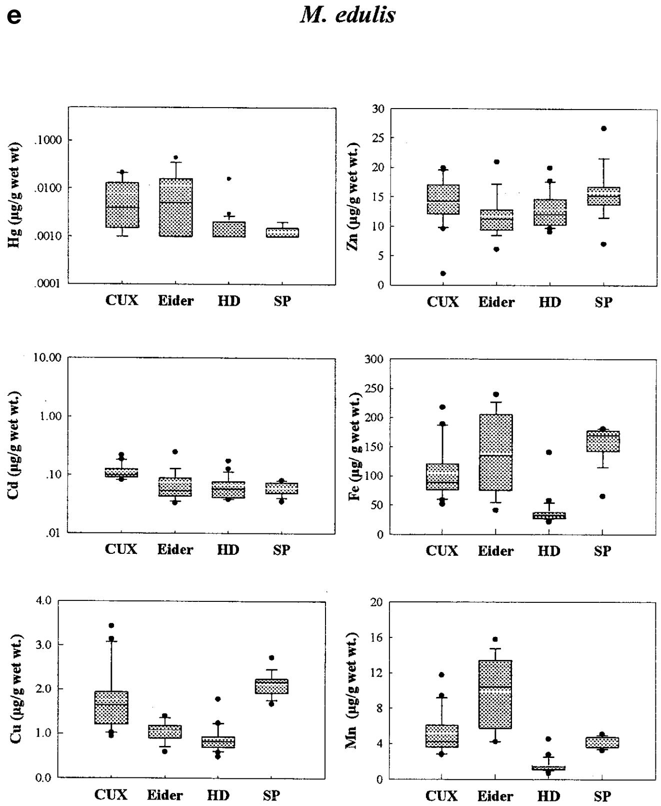

Fig. 2e legend see page 157

el (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.

Results and discussion

A total of 1626 specimens of bivalves and gastropods were collected and analyzed for their trace element concentrations. Organic contaminant screening was performed on representative samples. The species contamination level and the spatial distribution pattern of contamination with regard to some trace elements and in brief with regard to organic pollutants are discussed hereafter.

Trace elements

As documented in many studies, some trace elements accumulate in the soft tissue of mollusks, increasing with weight or body size, i.e., bioaccumulation (Boyden 1974; Fisher et al. 1996; Wang et al. 1996; Wang and Fisher 1997). In order to compare data from different sites and years it is necessary to remove the body size effect if such exists. Therefore, prior to the spatial analysis we checked for the dependence of each element concentration on animal size, for each of the species at each of the sampling locations. When dependence was found in some of the sites, we divided the specimens into size groups and then performed the statistical analysis on the absolute concentrations. Usually, the statistical tests were performed on the larger size subgroup, which was not size dependent and contained the vast majority of the total specimens sampled. When no size dependence was found, the values were compared as such.

Red Sea

The main species found in the Red Sea at all sampling locations was *C. rota*. A statistical summary of the length, weight, percent dry weight, and number of composite sample analyses is presented in Table 2. A statistical summary of Hg, Cd, Cu, Zn, Mn, and Fe concentrations (as box plots) is given in Fig. 2a. The specimens collected at the Ardag site were significantly smaller than those collected at the other two stations (NB and OBS). There was a significant positive power correlation between weight and length that was similar at all the stations (Fig. 3). No correlation was found between trace metal concentrations and the body size, therefore the absolute concentrations were compared between the sites.

Hg concentrations were below detection limit, except for three samples from OBS (Fig. 2a). No differences in Cd levels were found between the sites. Cu concentrations were significantly lower at OBS compared to the other two stations, while Zn concentrations were higher at NB. Higher Fe and Mn concentrations were found in NB and Ardag as compared to OBS. In general, the two northern stations (NB and Ardag) exhibited higher metal concentrations (Cu, Zn, Mn and Fe) except for Hg and Cd. It is presumed that the above differences are attributed to natural variations in the uptake of these essential metals (such as Fe and Mn) as shown by the significant linear correlation between Fe and Mn (Fig. 4).

Mediterranean Sea

Two bivalves (*Donax* sp. and *M. corallina*) and one gastropod (*Patella* sp.) were sampled in the Mediterranean Sea, as presented in Table 1. A statistical summary of the length, weight, percent dry weight, and number of composite samples in each species is given in Table 2. The distribution of the trace metal concentrations in the different species is presented in Fig. 2b–d. Hereafter, the spatial differences will be examined for each species.

Patella sp. There was a significant positive power correlation between weight and length of *Patella* sp. that was similar at all the stations (Fig. 3). Cd concentrations in specimens from HS increased with size; no correlation was found between the other trace metal concentrations and the body size. Hg concentrations were below detection limit in most of the samples, and low in the rest (Fig. 2b) compared to previous measurements along the coast

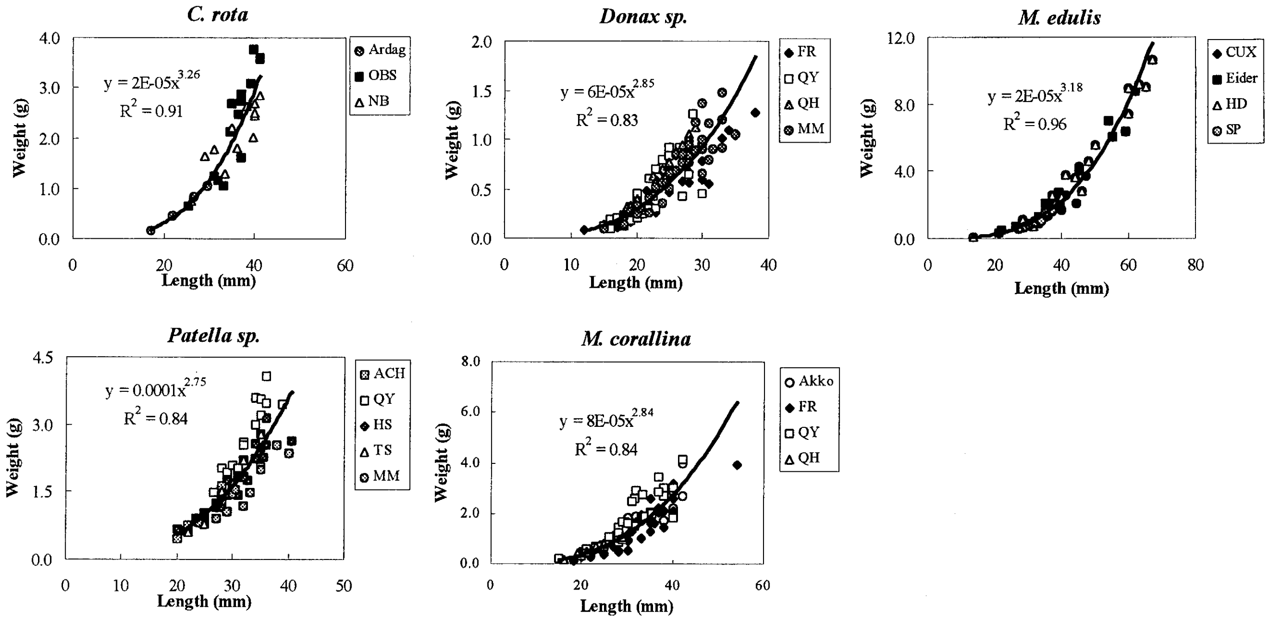

Fig 3 Soft body weight vs. shell length in three bivalve species (*M. corallina*, *Donax* sp. and *M. edulis*) and two gastropod species (*Patella* sp. and *C. rota*). The power fits had r>0.87 in all species

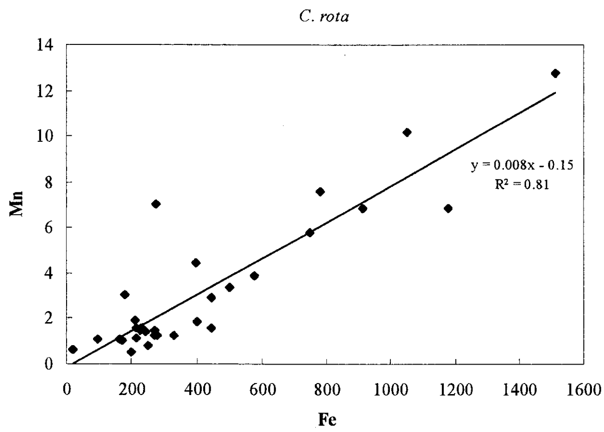

Fig. 4 Relationship between Mn and Fe concentrations (µg g^{-1} wet wt.) in the gastropod *C. rota* collected from different stations on Eilat beach, the Red Sea (see Table 1). The linear regression fit is included

(Navrot et al. 1974; Hornung et al. 1981; Manelis 1992). Cd was significantly higher in Haifa Bay (HS and QY) compared to the other sites along the coast which had the following sequence: ACH = TS >MM (Fig. 2b). Zn was higher in HS, while no significant differences were found among the other stations. Fe and Mn concentrations in specimens collected at TS were higher than at the other stations, where the levels were not significantly different between them (Fig. 2b). The metal concentrations in *Patella* sp. at all stations decreased in the following order: Fe>Zn>Mn>Cu>Cd>Hg, except for HS where Cd>Cu.

HS exhibited Cd concentrations higher by approximately an order of magnitude and significantly higher Zn concentrations (Fig. 2b) due to the high pollution of these metals in the Kishon River estuary. The latter is the source of particulate Cd enrichment in HB and may explain also the higher concentrations in QY as compared to the other coastal stations (Herut and Kress 1997).

The concentrations of Cd in samples from the coastal stations outside HB were similar to those reported previously from stations along the Israeli MED coast (Manelis 1992) or other MED relatively clean areas (Shiber and Shatila 1978; Catsiki et al. 1991). High levels of Cd as in HS were reported for sites along the Turkish MED coast (Ramelow 1985) and levels higher even by an order of magnitude were reported along the UK Atlantic Ocean coast (Nickless et al. 1972; Peden et al. 1973).

Mactra corallina. Significant power correlation was calculated between the wet weight of the soft tissue and the shell length in specimens of *M corallina* from all the stations (Fig. 3). Specimens from QY showed higher weight/length ratios than FR and QH, probably attributed to the lower contamination level in QY. No specimens were found at the other stations along the coast (besides two at MM).

No correlation with size was found for Cd and Hg while a negative power correlation was found for Cu, Zn, Fe, and Mn concentrations (Fig. 5). For comparison of the metals that were size dependent, the dataset was divided into two subsamples: smaller and larger than 1.5 g. The comparison between stations was performed by the >1.5 g subsample group which was not size dependent (trace element concentrations revealed no correlation with body size).

Hg concentrations were highest at FR, and decreased in the following sequence: FR>Akko>QY>QH (Fig. 2c). The enrichment sequence of Hg follows the distribution of Hg concentrations in the sediments (Fig. 6) and in suspended particulate matter (Hornung et al. 1989; Herut et al. 1996, 1997). These significant differences in Hg levels

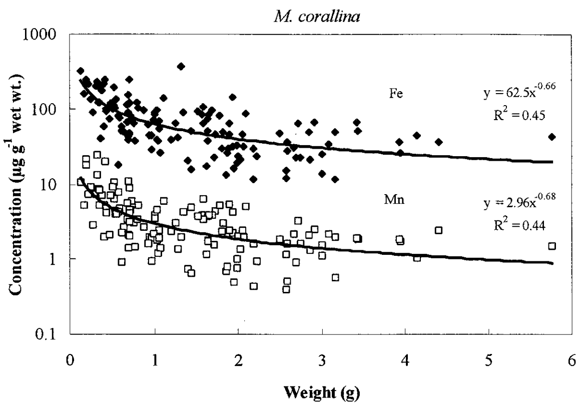

Fig. 5 Relationship between Fe and Mn concentrations (µg g^{-1} wet wt.) vs. body weight (g wet wt.) in the bivalve *M. corallina* collected at stations in Haifa Bay (see Table 1) in the northern part of the Mediterranean coast of Israel. Power fits are included

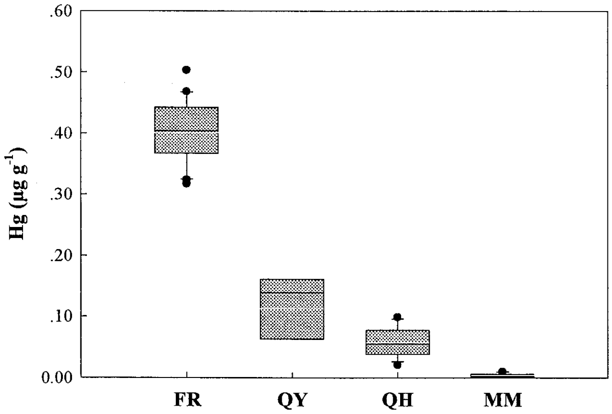

Fig. 6 Box plots of Hg concentrations (µg g^{-1} dry wt.) in sediments from FR, QY, QH and MM stations (see Table 1). *Bottom* and *top edges* of each box are located at the sample 25 and 75 percentiles. *Central horizontal lines* are drawn at the sample median (*black*) and sample mean (*white*)

were found despite the long-term decrease in Hg concentrations in *M. corallina* with a half time of approximately 2 years (Herut et al. 1996). Cd concentrations were similar between the stations, with somewhat higher concentrations in QY and FR. No differences were found for Fe and Mn between the stations. Zn was higher in Akko and Cu higher in FR than in QY but not significantly different from Akko. The certain enrichment of Cu at the stations in northern HB may be attributed to its higher concentrations in SPM in that area as compared to the southward stations (Herut et al. in press).

Donax sp. A significant power correlation was found between the wet weight of the soft tissue and the shell length in specimens of *Donax* sp. from all the stations (Fig. 3). No correlation to size was found for Cd and Mn. The concentration of Hg was found to be size dependent in FR and QY, Cu was size dependent in all the stations and Zn and Fe in all the stations except QH. All cases exhibit a negative power correlation. For the statistical comparison of Hg, Cu, Zn and Fe levels, the database was divided into two subsample: smaller and larger than 0.5 g soft body weight. The comparison between stations was performed in the two subsample groups.

Hg in FR is significantly higher than at all other sites (Fig. 2d) similar to the Hg distribution in *M. corallina* specimens. The long-term decrease in Hg levels in *M. corallina* is observed also in the *Donax* sp. specimens from northern HB, where higher levels of Hg in *Donax* sp. have been reported in the past (Hornung et al. 1984; Fishelson et al. 1996). No significant differences in Hg levels were found among the other sites. Cd was significantly enriched at all stations in HB compared to MM, similar to the observed trend in *Patella* sp. This Cd enrichment is probably attributed to the enrichment of Cd in SPM from HB (Herut and Kress 1997). Cu concentrations were significantly higher in FR compared to QY in both size groups and also higher than MM in the small size group. Between the stations no differences were found in Zn concentrations in the smaller size group, while FR and QH were significantly higher than QY and MM in the larger group. Mn in FR was higher than in QH but not significantly different from QY and MM. Between the sites no differences were found for Fe.

North Sea

One bivalve, *Mytilus edulis*, was sampled in the North Sea, as presented in Table 1. A statistical summary of the length, weight, percent dry weight and number of composite samples at each site is given in Table 2. The distribution of the trace metal concentrations is presented in Fig. 2e. A significant similar power correlation was found between the wet weight of the soft tissue and the shell length in specimens from all the stations (Fig. 3). No correlation was found between Zn and Cd concentrations and the size of the specimens at all the stations. Hg was below detection limit in most of the samples in HD and SP, while in CUX and Eider the small specimens exhibited somewhat higher Hg concentrations. Fe and Mn showed a negative power correlation with weight in CUX and Eider (Fig. 7), while Cu only in Eider. Since Hg, Cu, Fe, and Mn concentrations depended on size, the dataset was divided into two subgroups for statistical analysis, smaller and larger than 2 g. Because all the samples from SP fell in the smaller size subsample, the statistical tests were conducted on both groups.

Cd concentrations were higher in CUX and not significantly different between the other stations (CUX>Eider=HD=SP). No significant differences were found in Zn concentrations, except for SP>Eider. In both subgroups, Hg was higher in CUX and Eider than in HD and SP (Eider=CUX>HD=SP). Cu comparison gave the same results for the two subgroups, with highest concentrations found in CUX and SP (SP=CUX>Eider=HD). In the <2 g subgroup, Fe concentrations decreased in the following order: Eider>Cux>HD with SP not significantly different

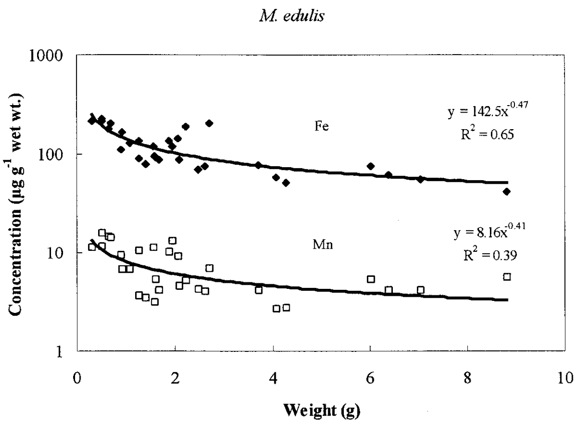

Fig. 7 Relationship between Fe and Mn concentrations (µg g^{-1} wet wt.) vs. body weight (g wet wt.) in the bivalve *M. edulis* collected at CUX and Eider stations in the North Sea (see Table 1). Power fits are included

from Eider and CUX, but higher than HD. In the larger subgroup, the order was CUX=Eider>HD. The Mn sequence in both groups was the same, Eider>Cux>HD, while SP was not significantly different from CUX and HD in the smaller size group, but lower than Eider.

In general, the trace element concentrations in *M. edulis* measured in this study were similar to concentrations reported for other coastal sites of the North Sea (e.g., Lande 1977; Borchardt et al. 1989).

Organic contaminants screening

Seventeen composite samples of mollusks representing the various sampling sites were screened for a suite of organic compounds. From the total 26 chlorinated insecticides and PCBs analyzed, only DDE and one congener of PCB were found in the biota. Traces of DDE, at least an order of magnitude lower than the National Oceanic and Atmospheric Administration's (NOAA's) "action limit" criteria (0.05 and 0.5 µg g^{-1} wet wt. for DDE and PCBs, respectively; National Oceanic and Atmospheric Administration NOAA 1988), were found in all the specimens. The lowest values were found in the RS *C. rota* species and the highest in the MD species (6.3–22.5 ng g^{-1} dry wt.). PCB concentrations in mollusks from the RS and from MM were the lowest. The highest PCB values were in the North and MED Seas (86–643 and 269–920 ng g^{-1} dry wt., respectively), with concentrations of an order of magnitude lower than NOAA's criteria. Inspection of the PAH compounds showed very low concentrations (18–693 ng g^{-1} dry wt.) with a wide distribution range, indicating oil pollution as their main source. In general, the concentrations of the organic compounds found were very low and indicated traces of oil pollution in HB and SP station at the NS.

Summary

1. The bivalve *C. rota* exhibited similar low concentrations of the toxic metals (Hg and Cd) at all sites of the Red Sea. The other elements (Cu, Zn, Mn, and Fe), probably present in essential concentration levels, were higher at the northern beach of Eilat (NB and Ardag) as compared to the southern beach (OBS).
2. The bivalves (*Mactra corallina* and *Donax* sp.) in the Mediterranean Sea exhibited higher Hg levels at stations in Haifa Bay compared to the rest of the coast, following a similar trend in the sediments and SPM. Similar behavior was observed for Zn levels in *Donax* sp. The contamination of Hg in HB is from two sources, a chlor-alkali plant in the north and the Kishon River in the south. The latter is the main source of anthropogenic Zn.
3. Significant Cd and Zn enrichment of approximately an order of magnitude was detected in *Patella* sp. specimens from HS attributed to the nearby highly polluted Kishon River estuary.
4. *Patella* sp. and *Donax* sp. specimens from Haifa bay exhibited higher levels of Cd compared to other sites along the Israeli Mediterranean coast, attributed to the enrichment of Cd in SPM in Haifa Bay. The main source of anthropogenic Cd is the Kishon River.
5. Among the stations examined along the German coast in the North Sea, Hg and Cd levels were highest at the Elbe River estuary (CUX), and the former enriched also in the Eider River estuary. Overall, the levels were low compared to other polluted sites in the North Sea.
6. There is no significant organic contamination in the examined bivalves and gastropods. Very low concentrations of DDE, PCBs, and PAHs were observed. The latter derived mainly from oil pollution as indicated by its wide-range distribution in samples from Haifa Bay and SP station in the North Sea.

Acknowledgments The authors would like to express their gratitude to Y. Gertner, G. Fainstein, L. Izraelov, and E. Shoham-Frider for their technical assistance in the trace metal analyses and sample collection. This study was supported by the BMBF MARS 1D project GR 01478, and partly by the Israeli Ministry of Infrastructure and the Israeli Ministry of Environment.

References

Angel DL, Krost P, Gordin H (1995) Benthic implications of net cage aquaculture in the oligotrophic Gulf of Aqaba. Eur Aquacult Soc (Spec Publ) 25:129–173

Borchardt T, Burchert S, Hablizel H, Karbe L, Zeitner R (1988) Trace metal concentrations in mussels: comparison between estuarine, coastal and offshore regions in the southeastern North sea from 1983 to 1986. Mar Ecol Prog Ser 42:17–31

Borchardt T, Burchert S, Karbe L, Zeitner R (1989) Enhanced heavy metal concentrations in *Mytilus edulis* from the central North Sea. Sci Mar 53:725–728

Boyden CR (1974) Trace element content and body size in molluscs. Nature 254:311–314

Buther H (1990) Spatial and temporal trends in organochlorine contamination of dab (*Limanda limanda*) and flounder (*Platichthys flesus*) in the North Sea. ArchFisch Wiss 40:133–152

Catsiki VA, Papathanassiou E, Bei F (1991) Heavy metals levels in characteristic benthic flora and fauna in the central Aegean Sea. Mar Pollut Bull 22:566–569

Cohen Y, Kress N, Hornung H (1993) Organic and trace metal pollution in the sediments of the Kishon river (Israel) and possible influence on the marine environment. Water Sci Tech 27: 439–447

Diamant A, Westernhagen HV (1998) Report of the German-Israeli co-operation in marine science. MARS 1 Report to the Israeli Minostry of Science, Jerusalem

Fishelson L, Manelis R, Zuk-Rimon Z, Dotan A, Hornung H, Yawetz A (1996) Ecology, enzymology and population dynamics of some littoral molluscs. MAP technical Report 103:57–73, UNEP. Athens

Fisher NS, Teyssie JL, Fowler SW, Wang WX (1996) Accumulation and retention of metals in mussels from food and water: a comparison under field and laboratory conditions. Environ Sci Technol 30:3232–3242

Genin A, Lazar B, Brenner S (1995) Vertical mixing and coral reef death in the Red Sea following eruption of Mt. Pinatubo. Nature 377:507–510

Herut B, Kress N (1997) Particulate metals contamination in the Kishon river estuary, Israel. Mar Pollut Bull 34:706–711

Herut B, Hornung H, Krom MD, Kress N, Cohen Y (1993) Trace metals in shallow sediments from the Mediterranean coastal region of Israel. Mar Pollut Bull 26:675–682

Herut B, Hornung H, Kress N (1994) Mercury, lead, copper, zinc and iron in shallow sediments of Haifa Bay, Israel. Fresenius Environ Bull 3:147–151

Herut B, Hornung H, Kress N, Cohen Y (1996) Environmental relaxation in response to reduced contaminant input: the case study of mercury pollution in Haifa Bay, Israel. Mar Pollut Bull 32:366–373

Herut B, Hornung H, Kress N (1997) Long-term record mercury decline in Haifa Bay (Israel) shallow sediments. Fresenius Environ Bull, 6:48–53

Herut B, Hornung H, Kress N, Cohen Y (1998) Monitoring of heavy metals along the Mediterranean coast of Israel in 1997. IOLR Rep. H/18/98, 27 pp.

Herut B, Tibor G, Yacobi YZ, Kress N (in press) Synoptic measurements of chlorophyll-a and suspended particulate matter in a transitional zone from polluted to clean seawater utilizing airborne remote sensing and ground measurements, Haifa Bay (SE Mediterranean). Mar Pollut Bull

Hornung H, Oren OH (1980) Heavy metals in *Donax trunculus* L. (bivalvia) in Haifa Bay, Mediterranaen (Israel). Mar Environ-Res 4:195–201

Hornung H, Raviv D, Krumgalz BS (1981) The occurrence of mercury in marine algae and some gastropod molluscs of the Mediterranean shoreline of Israel. Mar Poll Bull 12:387–390

Hornung H, Krumgalz B, Cohen Y (1984) Mercury pollution in sediments, benthic organisms and inshore fishes of Haifa Bay, Israel. Mar Environ Res 12:191–208

Hornung H, Krom MD, Cohen Y (1989) Trace metal distribution in sediments and benthic fauna of Haifa Bay, Israel. Estuar Coastal Shelf Sci 29:43–56

Kausch H, Wilson WG, Barth H (eds) (1990) Biogeochemical cycle in two major European estuaries: the Shanelbe project. Water Pollut Res Rep 15

Kress N, Herut B (1998) Hypernutriphication in the oligotrophic eastern Mediterranean. A study in Haifa Bay, Israel. Estuar Coastal Shelf Sci 46:645–656

Krom MD, Hornung H, Cohen Y (1990) Determination of the environmental capacity of Haifa Bay with respect to the input of mercury. Mar Poll Bull 21:349–354

Lande E (1977) Heavy metals pollution in Trondheimsfjorden, Norway, and the recorded effects on the fauna and flora. Environ Pollut 12:187–198

Manelis R (1992) The patella caerulea and Monodonta turbinata as bioindicators of contamination along the Israeli coast of the Mediterranean Sea: The thermal affects and content of metal ions. M.Sc Thesis, Tel-Aviv University, 94 pp.

Navrot J, Amiel AJ, Kronfeld J (1974) *Patella vulgata*: a biological monitor of coastal metal pollution. A preliminary study. Environ Pollut 7:303–308

Nickless G, Stenner R, Terrille N (1972) Distribution of cadmium, lead and zinc in the Bristol Channel. Mar Pollut Bull 3: 188–190

National oceanic and Atmosperic Administration (1988) PCB and chlorinated pesticide contamination in US fish and shellfish: a historical assessment report. NOAA Technical Memorandum NOS OMA 39

Peden JD, Crothers JH, Waterfall CE, Beasley J (1973) Heavy metals in Somerset marine organisms. Mar Poll Bull 4:7–9

Ramelow GJA (1985) Study of heavy metals in limpets (*Patella* sp.) collected along a section of southeastern Turkish Mediterranean coast. Mar Environ Res 16:243–253

Reiss Z, Hottinger L (1984) The Gulf of Aqaba. Ecological micropaleontology. Springer, Berlin Heidelberg New York

Shiber JG, Shatila TA (1978) Lead, cadmium, copper, nickel and iron in limpets, mussels and snails from the coast of Ras Beirut, Lebanon. Mar Environ Res 1:125–134

Wang WX, Fisher NS, Luoma SN (1996) Kinetic determination of trace elements bioaccumulation in the mussel *Mytilus edulis*. MarEcol Prog Res 140:91–113

Wang WX, Fisher NS (1997) Modeling metal bioavailability for marine mussels. Rev Environ ContamToxicol 151:39–65

Zauke GP, Bernds D, Janßen HJ, Clason B, Meurs HG (1995) Schwermetalle in organismen des niedersachsischen Wattenmeeres bei Norderney (1991–1994): Pb, Cd, Cu, Zn und Hg in ausgewahlten Muscheln (Bivalvia) und Borstenwurmern (Polychatea). Ber Forschungsstelle Küste 40:23–37

Communicated by A. Diamant