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Metal accumulation in benthic invertebrates and sediments at the Kaohsiung Ocean Disposal Site, Taiwan

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ABSTRACT

The distribution of metals (Hg, Pb, Cd, Cr, Cu, Zn, and Ni) in the sediments and in benthic invertebrates (arthropod, echinoderm, and mollusc) from the Kaohsiung Ocean Disposal Site (KODS) during 2014 was studied in terms of biota-sediment accumulation factor (BSAF). The mean concentration of metals in the sediments varied in the following order: Zn >> Cr > Cu > Ni > Pb > Hg > Cd. Results showed that the metal concentration in the sediments from the KODS was in agreement with that of other Asia harbors; there was no drastically high metal level in the Kaohsiung area. Results also showed that arthropod *Acanthephyra* species had accumulated high metal concentrations (e.g. 0.53, 3.02, 6.80, 53.24, 162.2, and 1.42 μg g^{-1} of Hg, Pb, Cd, Cu, Zn, and Ni, respectively), whereas mollusc *Fusinus hyphalus* had the lowest metal concentration. A positive correlation ($p < 0.01$) was observed between the concentration of Cr in the sediments and in arthropods. For all benthic invertebrates investigated, the BSAF of Cd and Hg were higher than 1.0. Especially the BSAF of Cd was remarkably high, e.g. for arthropods (30.0), echinoderms (38.7), and molluscs (42.2); whereas the BSAF of Pb, Cr, and Ni were low (BSAF << 1.0). According to the above results, benthic invertebrate of arthropods had a large metal accumulation capacity and thus could be suggested as the bioindicator of metal contamination of marine systems in further studies.

Keywords: Bioaccumulation; Metals; Sediments; Benthic invertebrates

1. Introduction

Metals in the marine environment have natural and anthropogenic sources. However, in recent decades, the release of metals into the marine environment is increasing via atmosphere, rivers, landfill leachates, and direct discharges [1]. The increase in the discharge of wastes into marine systems has resulted in a significant increase in metal contamination. Metals in ecosystems are non-degradable and persistent, which brings about metal accumulation in organisms and metal toxicity [2].

Metals tend to adsorb on the surface of suspended particulate matter in water, and affect marine organisms [3]. Furthermore, suspended particulate matters

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can settle and become incorporated into sediments. Sediments are the ultimate reservoir or sink for pollutants and play a critical role in the remobilization of pollutants in the aquatic environment [4]. Disturbance to the sediment during dredging operations can resuspend metals in the water, which impacts organisms and other species in the food chain.

Bioaccumulation is related to the assimilation of pollutants by organisms at a rate greater than that of physiological metabolisms. Once the pollutant enters the environment and organisms, toxic effects do not directly express immediately. Organisms accumulate metals in the tissue at the beginning and toxic effects appear after a few years. Bioaccumulation of metals in marine organisms has been used as an indirect measurement of the level and availability of metals in the marine ecosystem [5–8]. Consequently, bioaccumulation of metals will be a suitable preliminary assessment for ecological risk. It is therefore necessary to establish the bioaccumulation pattern of metals in marine organisms.

In the aquatic environment, the selection of suitable species that could be a bioindicator of metal accumulation in organisms at different trophic levels is of the utmost importance [2]. Aquatic benthic invertebrates are known to accumulate metals at level several orders of magnitude higher than that of the bulk water or sediments [9,10]. There are many routes for benthic invertebrate exposure to metals, such as solution and particulate phases. The patterns of uptake and bioaccumulation depend on metals, species, organs, life stage, diet type, and environmental factors. As our knowledge, it is hard to jump to conclusions for which route is the major and more toxic for benthic invertebrate. However, sediments were identified as the major source of metals to deposit feeding invertebrates due to high assimilation efficiencies of ingested metal and sediment ingestion rates [11]. Most of benthic invertebrates are living and even consume sediments. Based on the feeding mechanisms, the benthic invertebrates consist of deposit and plankton feeder. Therefore, metal concentration in sediments can be accumulated by benthic invertebrates following ingestion and digestion of food [12]. Benthic invertebrates are one of the major foods of aquatic predators such as fish, making them an important link in the food chain at higher trophic levels, which implicates that metals in benthic invertebrates may bring about metal bioaccumulation in the food web [13].

It has been suspected that at Kaohsiung Ocean Disposal Site (KODS), Taiwan the disposal of dredged materials from the Kaohsiung Harbor is the major source of metal contamination [14]. However, there is strong evidence of metal pollution in sediments of Kaohsiung Harbor originated from locally commercial activities and the four feeding tributaries, i.e. Love River, Canon River, Jen-Gen River, and Salt River [14,15]. Chen et al. [14] has studied the distribution of metals in the sediment of KODS. But no data are available on the distribution of metals in benthic organisms and the ecological impacts of metal contaminants. This study was to assess the distribution of metals in sediments and benthic invertebrates at the KODS, to investigate the ecological effects of dredged material dispersal and to understand the metal accumulation capacity of benthic invertebrates by estimating the biota-sediment accumulation factor (BSAF) and identifying possible metal bioindicators.

2. Materials and methods

2.1. Sample collection

KODS is located in southwestern Taiwan with its center located at E 120° 03.59′ N 22°27.57′. It has a square area of 36 km^2 (6 × 6 km^2) and water depths of 500–700 m (Fig. 1). More than 290 million m^3 of dredging mud has been discharged to the site since 2004 [16]. The present study was conducted at three different sampling lines across the KODS, marked L1, L2, and L3 (Table 1).

This study used the Ocean Researcher III to collect the sediments and benthic invertebrate samples four times from sampling lines during March and October in 2014. Each sampling, sediments and benthic invertebrate were collected in three different sampling lines, a total of 12 samplings were conducted eventually in this study. The benthic invertebrate samples were obtained using bottom trawl, with 8 m in length and 6 m in width, trawling at a vessel speed of 2.0 knots for 20 min. The mesh sizes of the trawl range from 25 cm at the opening to 1.5 cm in front of the codend. Firstly, the water depths is over 500 m leading to difficulties in sampling operation. Secondly, the biological density is quite low under such water depth. Therefore, it is uncontrollable for the species and numbers of benthic invertebrates every sampling. For these reasons, the selected invertebrates were the most frequently sampled and had the relative large sampling number. The sediments were collected by a SIHPEK grab sampler. The sediments and benthic invertebrates were wrapped into polyethylene plastic bags, placed in an ice box, and brought to the laboratory for further analysis. Before metal content analysis, collected benthic invertebrates were classified into three types, namely arthropod, echinoderm, and mollusc, and weighed.

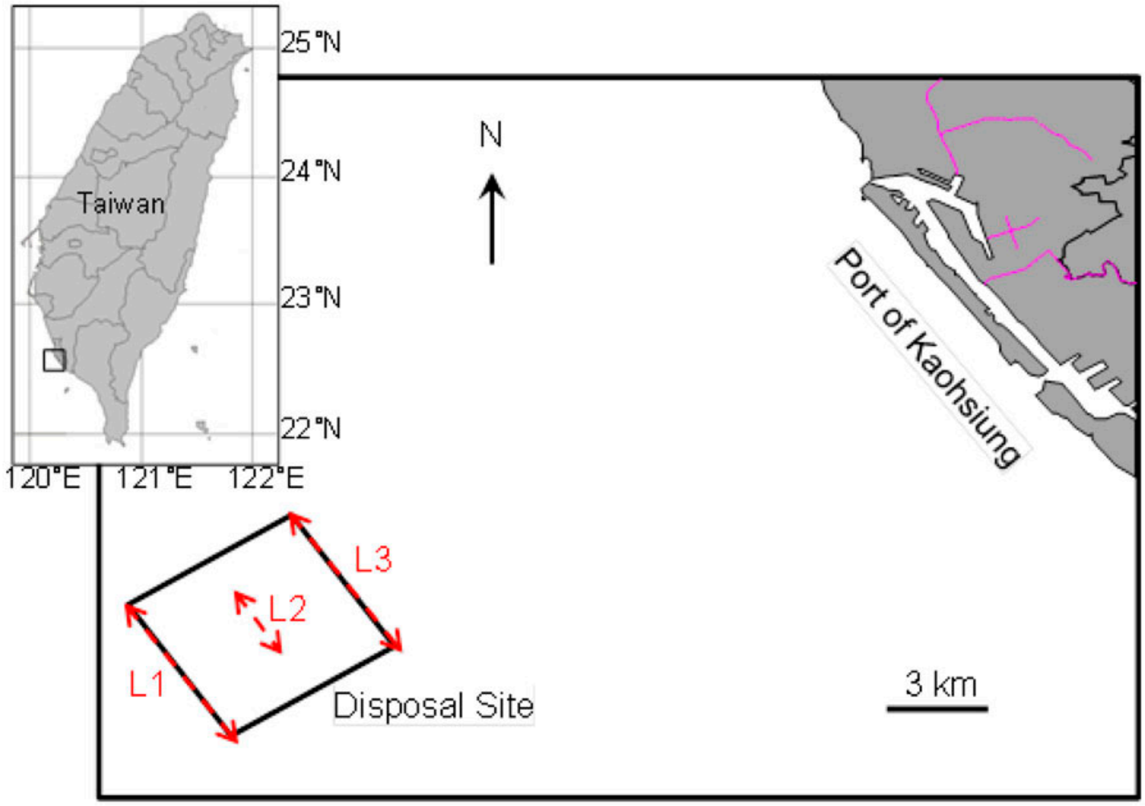

Fig. 1. Map of the KODS showing the location of the sampling lines (L1, L2, and L3).

Table 1
Water depth and geographical coordinate of the sampling lines at KODS, Taiwan

Sampling line	Water depth (m)	Geographical coordinate
L1	626	22˚28,18´ N 120˚01,42´ E ↔ 22˚25,42´ N 120˚03,36´ E
L2	578	22˚27,57´ N 120˚03,59´ E
L3	548	22˚30,06´ N 120˚04.30´ E ↔ 22˚27,31´ N 120˚06,36´ E

2.2. Chemical analysis

The sediment samples were first sieved and particles with diameter >63 μm were discarded. The sieved sediment samples were dried naturally at room temperature and gently homogenized into fine powder with mortar and pestle (Retsch RM 100 Motor Grinder). The combination of ultra-pure acids (HNO_3 : HCl = 1:3 by volume) was added to the sediment sample (1.0 g dry weight) and then heated at 100˚C to digest. Once the digestion process was completed and after cooling the samples were filtered through 0.45 μm filter paper into a pre-selected final volume.

The benthic invertebrate samples were freeze-dried for one day until constant weight. Each dried sample was ground by using porcelain mortar and a pestle. Each sample was weighted (0.5–1.0 dry weight), and digested with nitric acid (67–70% HNO_3, Fisher Scientific) and hydrogen peroxide (>35% H_2O_2, SHOWA) in glass beaker at 95˚C until the solution becomes clear. At the end of the digestion and after cooling, the samples were diluted to 25 mL with deionized distilled water and then analyzed for metal content.

All samples were analyzed for the following elements: Hg, Pb, Cd, Cr, Cu, Zn, and Ni. The metal content was determined using a flame atomic absorption spectrophotometry (Hitachi Z-6100). Hydride generator coupled with an atomic absorption spectrophotometry was used to analyze total mercury (cold vapor mode). Blank was carried out for instrument calibration. The quality of the analytical procedure was verified by analyzing the certified standard reference material for sediments and benthic invertebrates by HISS-1 (marine sediments, National Research Council of Canada) and DORM-2 (dogfish muscle tissue, National Research Council of Canada), respectively. Replicate analysis of these reference materials showed good accuracy, with mean recovery rate nearly of 90%.

2.3. Data analyses

The Pearson correlation coefficient was utilized to describe the correlation between metal content in sediments and in benthic invertebrates. Results were considered significant at $p < 0.05$. All statistical analyses were carried out with SPSS 12.0 software for Windows. BSAF was calculated according to the following equation:

$$\mathrm{BSAF} = \frac{C_b}{C_s}$$

where C_b and C_s are the mean metal concentration in the biota (μg g^{-1} dry weight) and sediments (mg kg^{-1} dry weight), respectively. BSAF measures the level of metal accumulation in an organism that lives in the sediment.

3. Results and discussion

3.1. Metal concentration in sediments

Results of metal concentration (mg kg^{-1} dry weight) in sediments of the three sampling lines are shown in Table 2. The mean metal level decreased from Zn to Cd for the sediments in the following order: Zn >> Cr > Cu > Ni > Pb > Hg > Cd. Results indicated that Zn was most accumulated in the sediments and Cd the lowest. In the sampling line of L3, the mean concentration of Hg (0.42 mg kg^{-1}), Pb (22.89 mg kg^{-1}), Cr (31.85 mg kg^{-1}), Cu (29.06 mg kg^{-1}), and Ni (24.52 mg kg^{-1}), was higher than that of other two sampling lines, whereas the highest concentrations of Cd (0.10 mg kg^{-1}) and Zn (121.05 mg kg^{-1}) were observed in L2. The sampling line of L3 is located at the most shoreward side than other sampling line, suggesting the elevated metal concentration could be partly attributed to localized anthropogenic inputs. The spatial decrease of metal level was most notable for Cd, Cr, Cu, and Zn.

According to the Sediment Quality Guidelines and the Marine Sediment Screening Benchmarks of US Environmental Protection Agency [17,18], only Hg exceeded the Sediment Quality Guideline ERL (Effect Range Low) of 0.15 mg kg^{-1}, adopted from [17], whereas other metals were lower than the values of ERL. Meanwhile, with the exception of Cu, Zn, and Ni, the metals mean concentration was lower than the screening concentration (30.2 mg kg^{-1} for Pb, 0.68 mg kg^{-1} for Cd, 52.3 mg kg^{-1} for Cr, 18.7 mg kg^{-1} for Cu, 124 mg kg^{-1} for Zn, and 15.9 mg kg^{-1} for Ni). The screening benchmark is chosen based on direct chronic exposure and non-lethal endpoint experiment to protect the sensitive species in the aquatic environment.

According to Table 3, the metal concentration of sediments from the KODS was at the same order of magnitude as other Asia areas. It must be mentioned that there was no exception at the KODS, where the dredged materials have been disposed for 10 years. However, results showed no elevated metal concentration in the sediments, which can be attributed to the rapid dispersion of the dumped sediments over a large surface by strong marine currents in these shallow coastal waters.

Table 2
Mean, maximum, and minimum concentration (mg kg^{-1} dry weight) of metals in sediment and sediment quality guidelines at KODS, Taiwan

Sampling line		Hg	Pb	Cd	Cr	Cu	Zn	Ni
L1	Mean	0.41	17.38	0.03	17.67	17.33	72.29	23.55
	Min–max	0.28–0.66	14.81–20.48	0.01–0.07	15.90–21.65	14.15–19.45	65.81–78.32	21.10–25.74
L2	Mean	0.31	21.15	0.10	24.42	25.86	121.05	22.06
	Min–max	0.06–0.46	17.18–27.63	0.01–0.22	22.85–26.82	20.77–32.87	83.10–210.45	15.37–26.78
L3	Mean	0.42	22.89	0.09	31.85	29.06	113.73	24.52
	Min–max	0.33–0.51	17.88–26.45	0.02–0.14	26.67–36.35	19.16–34.68	77.74–128.67	20.77–30.30
ERL[a]		0.15	46.7	1.2	81	34	150	20.9
ERM[a]		0.71	218	9.6	370	270	410	51.6
Benchmark[b]		–	30.2	0.68	52.3	18.7	124	15.9

[a]ERL and ERM present the effect range low and median [17].

[b]Marine Sediment Screening Benchmarks, USEPA, http://www.epa.gov/reg3hscd/risk/eco/btag/sbv/marsed/screenbench.htm.

Table 3
Metal concentration (mg kg^{-1}) of marine sediments in different regions at KODS, Taiwan

Area	Hg	Pb	Cd	Cr	Cu	Zn	Ni	References
KODS, Taiwan	0.06–0.66	14.81–27.63	0.01–0.22	15.90–36.35	14.15–34.68	65.81–210.5	15.37–30.30	Present study
Kaohsiung Coast, Taiwan	–	2.5–23.8	0.05–0.42	12.5–95.0	1.3–23.8	45.0–127.5	3.8–42.5	[27]
Quanzhou Bay, China	0.17–0.74	34.3–100.9	0.28–0.89	51.1–121.7	24.8–119.7	105.5–241.9	16.1–45.7	[28]
Xiamen Bay, China	–	44.9–59.8	0.11–1.01	36.7–134.3	18.5–97.2	65–223	24.8–64.8	[29]
Victoria Harbor, Hong Kong	–	21–85	–	–	16–280	52–221	–	[30]
Hong Kong coast	–	9–260	0.1–5.3	5–560	1–4,000	17–790	5–220	[31]
East China Sea	–	10.0–44.8	–	–	4.29–41.5	18.2–114.2	8.17–48.6	[32]
Tianjin Bohai Bay, China	0.02–0.85	17.5–34.9	0.14–1.82	18–191	11.4–27.3	68.7–392.8	–	[33]
Eastern Coast of the Gulf of Tailand	0.005–0.121	1.69–66.3	<0.006–0.19	–	14.4–103	7.48–131	<0.64–80	[34]
Youngil Bay, Korea	–	22.0–53.2	0.3–4.0	15.0–39.2	10.9–133.7	86.6–377.0	–	[35]
Masan Bay, Korea	–	13.0–82.2	0.1–7.5	30.54–99.82	13.45–90.69	79.98–378.7	10.15–40.39	[36]
Ise-Tokai region, Japan	–	6.26–82.7	0.06–1.48	43.0–168	13.5–81.6	66.7–210	21.0–124	[37]

3.2. Metal concentration in benthic invertebrates

Table 4 shows the distribution of benthic invertebrates and heavy metal concentration, expressed on a dry weight basis. The collected benthic invertebrates included arthropods of *Lophogaster* spp., *Pasiphaea* spp., *Heterocarpus gibbosus*, *Aristeus virilis*, *Systellaspis pellucida*, *Plesionika* spp., *Acanthephyra* sp., *Cyrtomaia* sp. (crab), and *Sympagurus* spp. (hermit crab), echinoderm of Crinoidea, and mollusc of *Fusinus hyphalus*. All collected arthropod species belonged to the decapoda except *Lophogaster* spp.

Results showed that arthropod *Acanthephyra* sp. accumulated the higher metal concentration (0.53 μg g^{-1} for Hg, 3.02 μg g^{-1} for Pb, 6.80 μg g^{-1} for Cd, 53.24 μg g^{-1} for Cu, 162.2 μg g^{-1} for Zn, and 1.42 μg g^{-1} for Ni) with the exception of Cr level. On the other hand, most of the species having the lowest metal concentrations were found in mollusc *F. hyphalus* (0.10 μg g^{-1} for Hg, 0.30 μg g^{-1} for Pb, 0.38 μg g^{-1} for Cd, and 6.23 μg g^{-1} for Zn). It also found that the highest metal concentration of Cr and Cu were observed in arthropod *H. gibbosus* with 2.48 and 57.60 μg g^{-1}, respectively. Crinoidea has accumulated the relatively high concentration in Hg with 0.29 μg g^{-1} and Pb with 3.23 μg g^{-1}.

Data indicated that arthropods had the high Cd accumulation (mean organism concentration in the range of 0.48–6.80 μg g^{-1}) even if they lived in the low Cd level (mean concentration in the range of 0.03–0.10 mg kg^{-1}). Results for Cd accumulation in arthropods were similar with the Cd deficiency reported by Prowe et al. [19]. The high bioaccumulation of Cd in benthic invertebrates might be the consequence of Cu deficiency. Prowe et al. [19] raised a potential reason to hypothesize the insufficiency in the uptake process for essential Cu leading to increase in the uptake of Cd [7,19]. For arthropods, it needs about 7–15 mg Cu kg^{-1} dw of whole body to satisfy the hemocyanin component demand [20]. Hence, Cd could be easily accumulated in the bottom organisms of the food chain and passed along the trophic ladder, and finally bioconcentrated to high levels in the top predators [5].

Table 5 gives the metal concentration in marine organisms from different regions**.** Results on the concentration trend of Cd and Cu were in agreement that of the Iberian deep sea plain [19]. The Hg concentration in arthropods and molluscs was within the range reported for crustaceans and molluscs in the Bay of Biscay, Atlantic [8]. Results revealed that molluscs expressed the low metal accumulation, which was inconsistent with the previous studies in the other regions [21–23]. It is expected that benthic organisms of high metal bioaccumulation were found at the KODS because nearly 30 million cubic meter sediment which dredged from Kaohsiung Harbor dumped into the disposal annually. However, the present studied seems to cannot support this hypothesis.

Table 4
Sample size (N), body weight (g), and metal concentration (μg g^{-1} dry weight) of different benthic invertebrates at KODS, Taiwan

Species	Common name	N	Weight	Hg	Pb	Cd	Cr	Cu	Zn	Ni
Arthropod										
Lophogaster spp.	Mysid	4	4.03 ± 3.16	0.20 ± 0.11	1.58 ± 0.81	0.65 ± 0.64	2.37 ± 3.49	5.35 ± 1.32	10.6 ± 6.0	0.53 ± 0.40
Pasiphaea spp.	Glass shrimp	3	1.50 ± 0.69	0.18 ± 0.06	0.41 ± 0.39	0.51 ± 0.54	0.40 ± 0.14	5.10 ± 3.24	16.4 ± 21.3	2.00 ± 2.31
Heterocarpus gibbosus	Humpback nylon shrimp	4	4.13 ± 1.06	0.19 ± 0.11	2.80 ± 2.33	5.64 ± 4.65	2.48 ± 2.85	57.6 ± 61.3	82.0 ± 82.6	1.63 ± 1.45
Aristeus virilis	Stout red shrimp	3	16.4 ± 11.7	0.27 ± 0.21	0.40 ± 0.26	0.48 ± 0.13	0.25 ± 0.21	14.3 ± 3.4	15.7 ± 10.5	0.53 ± 0.32
Systellaspis pellucida	Shrimp	3	2.27 ± 0.61	0.11 ± 0.15	0.73 ± 0.25	0.78 ± 0.55	1.90 ± 2.77	14.4 ± 11.5	12.8 ± 3.7	0.75 ± 0.21
Plesionika spp.	Shrimp	6	5.17 ± 1.58	0.36 ± 0.24	1.78 ± 1.65	1.46 ± 1.83	0.43 ± 0.17	22.1 ± 23.9	35.6 ± 37.4	1.07 ± 1.23
Acanthephyra sp.	Subantarctic ruby prawn	5	6.76 ± 2.02	0.53 ± 0.74	3.02 ± 2.29	6.80 ± 7.21	1.38 ± 1.41	53.2 ± 66.3	162.2 ± 172.3	1.42 ± 1.29
Cyrtomaia sp.	Spider crab	4	11.9 ± 9.2	0.11 ± 0.10	1.80 ± 1.41	1.01 ± 0.69	0.67 ± 0.25	25.4 ± 16.4	24.4 ± 4.1	1.00 ± 0.08
Sympagurus spp.	Hermit crab	5	5.42 ± 4.38	0.14 ± 0.10	0.80 ± 0.37	0.66 ± 0.56	0.48 ± 0.16	17.6 ± 18.7	22.2 ± 9.1	0.62 ± 0.40
Echinoderm										
Crinoidea	Sea lily	9	5.60 ± 2.64	0.29 ± 0.21	3.23 ± 1.96	0.56 ± 0.47	1.23 ± 0.93	3.70 ± 3.64	25.4 ± 16.3	0.78 ± 0.16
Mollusc										
Fusinus hyphalus	–	3	7.50 ± 1.25	0.10 ± 0.09	0.30 ± 0.00	0.38 ± 0.07	0.35 ± 0.21	5.10 ± 3.34	6.23 ± 1.63	0.63 ± 0.61

Note: Values are mean ± SD.

3.3. Relation between sediments and invertebrates

The relation between metals accumulated in the sediments and organisms were shown in Table 6. With the exception of Cr, there was no significant correlation between metal concentration in the sediments and in arthropods for all six metals studied. There was a significant correlation between Cr level in the sediment and in arthropods ($r = 0.410$, $p < 0.01$), which indicated that Cr content in the sediment was probably one of the major contributors of Cr accumulation in arthropods. For echinoderms, Cr concentration in the tissue was positively correlated to Cr level in sediments ($r = 0.451$, $p < 0.05$), whereas there were negative correlation for Cu and Zn. For molluscs, there was only significant correlation between the sediments and tissues for Cd ($r = 0.456$, $p < 0.05$).

3.4. Biota sediment accumulation factor

The distribution of BSAF in different benthic invertebrates was estimated and shown in Fig. 2. The results indicated that the BSAF of metals in the three groups of benthic invertebrates were as the following, for arthropods: Cd > Cu > Hg > Zn > Pb > Cr ≈ Ni, for echinoderms: Cd > Hg > Zn > Cu > Pb > Ni > Cr, and for molluscs: Cd > Hg > Cu > Zn > Pb > Cr > Ni.

In all benthic invertebrates studied, while the BSAF value of Cd and Hg was high than 1.0, showing the tendency to bioaccumulate Cd and Hg from sediments. Especially, the BSAF of Cd were remarkably high with a value of 30.0 for arthropods, 38.7 for echinoderms, and 42.2 for molluscs, while the mean BSAF of Hg were nearly 1.0 among all three benthic invertebrates. Furthermore, the BSAF of Pb, Cr, and Ni was also low. However, the bioaccumulation level of metal in the organisms may not lead to any toxic effect, but may danger the predators [2].

Results implicated that the bioaccumulation factor of Cd and Hg were high in benthic invertebrates. Cadmium tends to accumulate in the organism tissue. The high bioaccumulation of Cd was in good agreement with that of crustaceans from the Iberian deep sea plain, which was in the range of 0.8 and 16.3 μg g^{-1} [19]. Copper plays an important role in the metabolism of crustaceans, because it is an important constituent of hemocyanin in crustaceans. Therefore, the level of Cu was higher in arthropods than other benthic invertebrates [24].

3.5. Discussion

In the present study, BSAF values were calculated to estimate the distribution of metals in the benthic

Table 5
Metal concentration (μg g^{-1} dry weight) of marine organisms in different regions at KODS, Taiwan

Areas	Hg	Pb	Cd	Cr	Cu	Zn	Ni	References
KODS, Taiwan								Present study
Arthropods	ND–0.46	0.1–5.8	ND–16.3	ND–6.6	0.1–150	ND–326	ND–3.5	
Echinoderms	0.11–0.69	0.2–5.6	0.05–1.36	ND–2.3	0.8–10	7.1–47.1	ND–0.9	
Molluscs	0.04–0.21	0.3	0.32–0.46	ND–0.5	2.3–8.8	5.1–8.1	0.1–1.3	
Coastal area of Lukang, Taiwan								[21]
Molluscs				2.43–309				
Belgian coast[a]								[22]
Arthropods	0.01–0.1	0.032–0.88	0.008–0.15	0.02–0.65	3.7–43	13–49		
Echinoderms	0.02–0.1	0.073–0.86	0.038–0.21	0.06–0.30	0.80–5.2	20–72		
Molluscs	0.01–0.04	0.1–1.6	0.005–0.20	0.07–1.4	0.76–7.9	9.2–22		
Bay of Biscay, Atlantic								[8]
Crustaceans	0.15–2.99							
Molluscs	0.04–0.78							
Iberian								[19]
Arthropods		0.3–0.6	0.8–16.3		17–56	52–79		
Barents Sea								[7]
Crustaceans			0.2–10.5		9–68	59–110		
Kuwait Bay								[23]
Crustaceas		2.05			5.21	22.93	2.48	
Molluscs		1.21			51.01	68.01	1.27	

[a]Unit based on wet weight.

Table 6
Pearson correlation coefficient between metal concentration in sediments and in benthic invertebrates at KODS, Taiwan

	Correlation coefficient						
Organism types	Hg	Pb	Cd	Cr	Cu	Zn	Ni
Arthropods	−0.205	−0.104	0.202	0.410[b]	−0.154	−0.100	0.172
Echinoderms	−0.064	−0.174	0.056	0.451[a]	−0.382[a]	−0.353[a]	0.141
Molluscs	0.007	−0.144	0.456[a]	0.441	−0.047	0.073	−0.139

[a]Correlations significant at $p < 0.05$.
[b]Correlations significant at $p < 0.01$.

invertebrates and in the surrounding sediments and to understand metal bioaccumulation in various benthic invertebrates. Moreover, in order to identify the source of metal bioaccumulation, it is important to understand the bioaccumulation potential of different organisms and the surrounding metal concentration [5]. However, no comparable data from the KODS were available.

Biomonitoring by using the bioindicator is widespread in the aquatic environment. Ali and Fishar [25] reported that the arthropod and molluscs could be candidates for environmental biomonitoring. In the Netherlands, dumping sites are monitored by starfish as bioindicator for the accumulation of metals [22]. Based on results of the present study, the bottom dwelling benthic invertebrates indeed have a tremendous capacity of metal bioaccumulation (e.g. Cd and Hg). Han et al. [21] reported that a bioindicator should have the capacity to accumulate high amount of pollutants from the surrounding environment and its tissue concentrations must reflect metal availability.

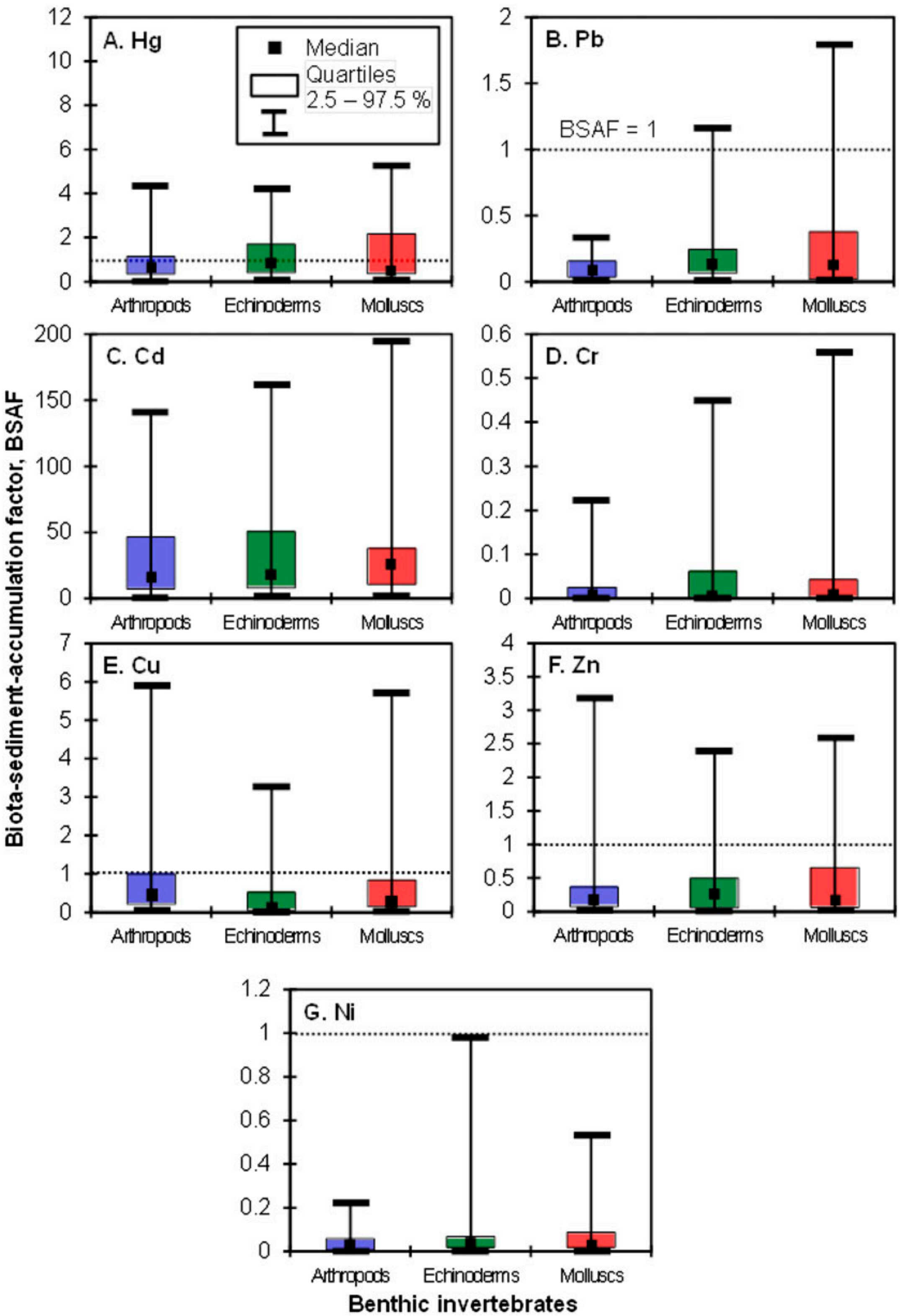

Fig. 2. BSAF in benthic invertebrates of arthropods, echinoderms, and molluscs at KODS, Taiwan. Boxes represent the median (square) with 25th and 75th percentiles and error bars extending to the 95th percentile. The dash lines denote that BSAF equal to 1.

A bioindicator must have the following attributes. It responses to trace element concentration in the environment and the past as well as the recent pollution level of the environment [26]. It enables the assessment of the pollution transfer between trophic levels by taking into account the feeding habit and the location of organisms. Based on above results, it is suggested that benthic invertebrates, especially arthropods, as the potential bioindicator be used to determine the bioaccumulation of metals in the associated sediment.

4. Conclusion

Seven metals (Hg, Pg, Cd, Cr, Cu, Zn, and Ni) in surface sediments and marine benthic invertebrates (arthropods, echinoderms, and molluscs) from the KODS were studied. Metal concentration of sediments in L3 was higher than that of other sampling lines, suggesting anthropogenic inputs. In general, metal concentration of sediments did not differ from the other marine systems. The metal content was lower than that of ERL except Hg. By the Pearson correlation analysis, there was no strong correlation in metal concentration between the sediments and benthic invertebrates in the present study. Among all collected invertebrates, arthropod *Acanthephyra* sp. accumulated high concentration of metals except Cr. Results indicated that arthropods had high Cd accumulation even if lived in low-Cd environment. However, the present study did not observe high concentration of metals in the benthic organisms comparing with other studies. For the bioaccumulation in the three benthic invertebrates, the BSAF value was larger than 1.0 for Cd and Hg, nearly 1.0 for Hg, and significantly low for Pb, Cr, and Ni. In conclusion, arthropods showed potential as bioindicators in terms of metal contamination. Results also suggested that studying bioindicators and metal distribution of sediments can help understand metal bioaccumulation between sediments and the benthic food webs.

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