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Accumulation of Trace Metal in Sediment and Soft Tissue of *Strombus canarium* in a Tropical Remote Island of Thailand

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Citation: Kobkeatthawin, T.; Sirivithayapakorn, S.; Nitiratsuwan, T.; Muenhor, D.; Loh, P.-S.; Pradit, S. Accumulation of Trace Metal in Sediment and Soft Tissue of *Strombus canarium* in a Tropical Remote Island of Thailand. *J. Mar. Sci. Eng.* **2021**, *9*, 991. <https://doi.org/10.3390/jmse9090991>

Academic Editors: Nathalie Fagel and Olivier Radakovitch

Received: 20 July 2021

Accepted: 8 September 2021

Published: 11 September 2021

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Abstract: The present study determined the metal levels in surface sediment and in soft tissue of the *Strombus canarium* at Libong Island, Thailand, and estimated the possible risk from consuming the shellfish. The mean concentrations of the metals Fe, Cu, Co, Pb, Mn, and Ni in sediment were 2711.94 ± 1424.83 , 0.47 ± 0.37 , 0.11 ± 0.09 , 1.32 ± 1.48 , 40.41 ± 16.12 , and 2.75 ± 4.04 $\mu\text{g/g}$, respectively, and are below the sediment quality guidelines. The enrichment factor (EF) and geoaccumulation index (Igeo) showed that the sediment conditions ranged from “no pollution” to “moderate contamination”. The mean concentrations in *Strombus canarium* had rank order Fe > Mn > Cu > Ni > Co > Pb. The bioaccumulation (BSAF) suggests that the *Strombus canarium* accumulated Cu and Co the most. The estimated daily intakes of these metals through shellfish consumption were below the oral reference dose (Rfd) and the calculated target hazard quotients (THQ) were less than 1. The results from this study inform about the background levels of metals in the sediment and in *Strombus canarium* species at Libong Island. In addition, these data might help ensure that the consumption of shellfish in this area remains safe.

Keywords: trace metal; surface sediment; *Strombus canarium*; bioaccumulation (BSAF); human consumption risk

1. Introduction

In recent decades, environmental pollution in the coastal seas has received increasing attention, not only because of the effects on ecosystems, but also on human health. Among the various types of pollution, trace metal contaminants have become a serious problem because of their toxicity, persistence, and hazardous bioaccumulation in the food chains of an aquatic ecosystem [1–4]. Most of these trace metals, copper (Cu), cobalt (Co), iron (Fe), nickel (Ni), lead (Pb), and manganese (Mn) are listed as priority pollutants to be monitored by the US Environmental Protection Agency (U.S. EPA) [5]. High concentrations of trace metals could have adverse health effects on living organisms, not only on aquatic animals, but also on humans who consume contaminated seafood. Recently, Pereira and coworkers studied toxicokinetics in context of the central nervous system and sensory organs of fish exposed to Hg, and the effects on mammals [6]. In addition, many previous studies have shown that trace metals are transported into body cells of humans, and can cause

neurological changes, cancer, Alzheimer's disease, and cardiovascular diseases [7–9]. It is well known that the sediments in a water body serve as both a sink and a source of trace metals, and most of the trace metals loaded in aquatic systems are related to suspended particulate matter and sediments [10,11].

The wing shell (*Strombus canarium*) is an economically important mollusk in the Indo-Pacific region, which is widely distributed in Myanmar [12], Malaysia [13], Southern India [14], Sri Lanka [15], and along the Andaman sea of Thailand [16]. It is a popular seafood item consumed by villagers in the Andaman Sea region and by domestic and foreign tourists, because the soft tissue of *Strombus canarium* is delicious and a high quality protein, and the catches can generate considerable amounts of income to fishermen. *Strombus canarium*, also known as live in various types of habitats. Generally, this species is present in mudflats and seagrass bed areas, along the coastlines of Libong Island, Thailand. This island has a diverse ecosystem, including coral reefs, mangrove forests, and an extensive seagrass bed. In addition, it is the habitat of dugongs. Since *Strombus canarium* is a filter-feeder organism similar to cockles and mussels, contamination of the highly productive mudflats with metals leads to accumulation throughout the body tissue [17]. Recently, concerns have been raised about possible trace metal contamination in the coastal areas of Thailand, especially around Libong Island. An increasing number of tourists are visiting this island to observe the dugong and enjoy seafood, particularly wing shell meals. Recently, Pradit et al. 2020 reported on marine waste and hazardous waste, including batteries, on Libong Island, which were released from the mainland [18]. Moreover, activities around Libong Island, such as household activities, tourism, rubber industry, and agricultural activities, could be sources of trace metals that may affect aquatic animals and humans who consume the shellfish contaminated with trace metals.

Thus, the aim of this study was to assess the accumulation of trace metals (Fe, Cu, Co, Pb, Mn, and Ni) in surface sediments and in the soft tissues of the *Strombus canarium* at Libong Island, Thailand, and assess potential risks to humans from consuming this shellfish. In addition, our investigation is the first study regarding trace metal contamination on Libong Island. The study results will be used as baseline data for the present state of metal in sediment and in shellfish in the region. In addition, this information is very important for better management of this Island in the future.

2. Materials and Methods

2.1. Study Area

The study site is situated on the east coast of Libong Island. It is located at latitude 07°14'–07°17' N and longitude 99°22'–09°27' E, in Trang province, Thailand (Figure 1). There are four villages and an estimated 717 people who live in this area; the majority are involved with fishing, tourism, and agricultural activities. The area of Libong Island consists of coral reef, mangrove forests, and seagrass bed, which have high biodiversity and abundance. Thus, this is an important food source of dugongs and many other aquatic species, especially the *Strombus canarium*. In addition, this ecological system is very delicate and sensitive to marine waste pollution. The selected stations are covered with sandy beach (stations 1–9) next to mud flats (stations 10–33) and seagrass plants (found around stations 7, 8, and 9).

2.2. Sample Collection and Storage

2.2.1. Sediment Samples

The surface sediments were collected from 33 stations (Figure 1) on May 2019, near the shore (stations 1–9) where the sediment type has more sand than mud, and further away from the shore (about 500 m, stations 10–33) where the sediment type is muddy. Quadrant frames (50 × 50 cm) were used for sampling the surface sediment in each block. The sediment was collected using a shovel, by scooping to about a 10 cm depth, and placing the samples in plastic Ziploc bags. The samples were transported immediately to the laboratory and preserved at –20°C for later analysis. The wet sediments were air-dried,

ground with a mortar and pestle, and sieved through a 1 mm nylon sieve to obtain a fine homogeneous powder before analysis.

Figure 1. Sampling stations at Libong Island, Thailand.

2.2.2. Biological Samples

Strombus canarium samples were collected from Libong Island in the same period (Figure 1). A total of 35 *Strombus canarium* samples were bought from the local people who handpicked them from the mud flats in the study area. It was reported that *Strombus canarium* can reproduce all year round, but a high growth rate and a good survival rate prevail in the wet season [13]. Thus, the studied samples were collected in May, which is at the start of the wet season on Andaman Sea, Thailand. The *Strombus canarium* samples were kept in clean plastic bags and were transported immediately to the laboratory in an icebox and then kept at -10°C . Before analysis, the samples were cleaned with distilled water. In addition, the total lengths, weights, and fresh tissue of the *Strombus canarium* samples were measured. Then, the soft tissue was dried at 60°C in an oven and ground to a fine powder with a mortar and pestle.

2.3. Digestion Procedure

2.3.1. Sediment Samples

Sample preparation and analysis procedures was performed according to the U.S. EPA [19] and Pradit et al., (2010) [20]. Approximately, 0.1 g of sediment (dw) was weighed in the Teflon digestion vessel before being digested with 2 mL of HNO_3 (65%, Merck, Suprapur) and 6 mL HCl (30%, Merck, Suprapur). The samples were heated in an oven at 120°C for 7 h. After cooling to room temperature, the digested solution was filtered by using Whatman No. 1 paper. Then, 30 mL of Milli-Q water was added and the samples were stored in acid-cleaned polyethylene storage bottles before analysis (60 mL, Nalgene).

2.3.2. Biological Samples

Digestion of *Strombus canarium* was conducted according to the U.S. EPA [19] and Pradit et al. [20]. A dry soft tissue sample (0.05 g) was transferred to a Teflon digestion vessel for acid digestion using 1.5 mL HNO₃ (65%, Merck). Samples were digested similarly as the sediment. After cooling to room temperature, the samples were filtered through Whatman No. 1 paper. Then, the obtained solution was diluted to 10 mL with Milli-Q water and stored in polyethylene storage bottle for analysis.

2.4. Analysis of Metals

All equipment used for sample preparation and analysis was soaked in nitric acid (3%, Merck) overnight and then rinsed several times with Milli-Q deionized water prior to use. All used reagents were of analytical grade. Analytical data quality controls were performed using calibration curves prepared from multi-element (Merck) or single element (Johnson Matthey Specpure) internal standard solutions [21,22]. The minimum correlation coefficient of the calibration curve accepted was 0.999. Blank samples were also prepared for each set by using the digestion acids mixture used above without adding a sample. Trace metal concentrations were analyzed with an Inductively Coupled Plasma-Mass Spectrometer (ICP-MS, Shimadzu ICP-MS-2030LF). The efficiency of the analysis was assessed by three replicates. The detection limit was 0.1 mg/kg for Fe, Cu, Co, Mn, Ni, and Pb.

2.5. Data Processing and Statistical Analysis

All calculations and statistics were carried out using MS Excel 2007 (Office Professional Plus 2019) software. Pearson correlation analysis was employed to test the relationship of trace metals in *Strombus canarium*, and weight, and statistical significance required a 95% confidence level ($p < 0.05$) or a 99% confidence level ($p < 0.01$).

2.5.1. The Enrichment Factor (EF)

The enrichment factor (EF) was used to assess metal accumulation compared to the average occurrence of that metal in the Earth's crust [23], and was calculated by Equation (1).

$$EF = (M_{\text{sample}}/Fe_{\text{sample}})/(M_{\text{background}}/Fe_{\text{background}}) \quad (1)$$

Here, M_{sample} and Fe_{sample} are the sediment sample concentrations of the trace metal and Fe, whereas $M_{\text{background}}$ and $Fe_{\text{background}}$ are background concentrations of the trace metal and Fe [24]. Fe was used to normalize the trace metals in the sediment because it is a conservative element in the Earth [25]. The regional background values used in this study were those reported from offshore sediments in the Gulf of Thailand by Shazili et al. [26] and Taylor and McLennan [27]. The background concentrations were 12,200 µg/g for Fe, 12.7 µg/g for Cu, 15 µg/g for Pb, 104 µg/g for Mn, 10 µg/g for Co and 20 µg/g for Ni [26,27]. If $EF < 1$ there is "no enrichment" of the metal; EF 1 to 3 is for "minor enrichment"; EF 3 to 5 for "moderate enrichment"; EF 5 to 10 for "moderately severe enrichment"; EF 10 to 25 for "severe enrichment"; EF 25 to 50 for "very severe enrichment" and $EF > 50$ for "extremely severe enrichment" [28].

2.5.2. The Geoaccumulation Index (I_{geo})

The geoaccumulation index (I_{geo}) was used to assess the metal contamination caused by both natural events and anthropogenic activities [29]. This value was calculated according to Equation (2), as introduced by Muller [30].

$$I_{\text{geo}} = \log_2 C_n/1.5 \times B_n \quad (2)$$

Here, C_n is the measured concentration of the sediment for a trace metal, B_n is the geochemical background concentration of the trace metal, and 1.5 is the correction factor for variation in the background value because of lithogenic effects [30]. If $I_{\text{geo}} > 5$, then the result is "extremely contaminated"; 4–5 for "strongly to extremely contaminated";

3–4 for “strongly contaminated”; 2–3 for “moderately to strongly contaminated”; 1–2 for “moderately contaminated”; 0–1 for “uncontaminated to moderately contaminated”, and <0 for “uncontaminated” [31].

2.5.3. Biota-Sediment Accumulation Factor (BSAF)

Biota-sediment accumulation factor (BSAF) was used to assess the trace metal accumulation abilities in the target organism from that of the associated sediment [32,33]. BSAF was calculated according to Equation (3).

$$\text{BSAF} = C_t/C_s \quad (3)$$

Here, C_t and C_s are the mean metal concentrations in tissue and in sediment, respectively. The BSAF values can be classified into three groups “macroconcentrator” ($\text{BSAF} > 2$), “microconcentrator” ($1 < \text{BSAF} < 2$), and “deconcentrator” ($\text{BSAF} < 1$) [34].

2.5.4. The Conversion Factor (CF)

The trace metal concentrations by dry weight were converted to wet weight to compare with the permissible limits, by following guidelines by Yap and coworkers, as in Equation (4).

$$M_c(\text{wet}) = CF \times M_c(\text{dry}) \quad (4)$$

Here, $M_c(\text{wet})$ is the wet weight-based metal concentration, $M_c(\text{dry})$ is the dry weight-based metal concentration, and CF is the conversion factor, namely wet weight/dry weight ratio, taken as 0.26 in this study [35].

2.5.5. Estimated Daily Intake (EDI)

The estimated daily intakes (EDI) were calculated based on trace metal concentration in the targeted shellfish samples and on the average daily shellfish consumption rate in Equation (5) [36].

$$\text{EDI} = (M_c(\text{wet}) \times W_{\text{food}})/BW \quad (5)$$

Here, $M_c(\text{wet})$ is the wet weight-based metal concentration in contaminated shellfish (mg/kg), W_{food} is the daily average consumption of shellfish by a Thai person (135 g/day) [37], and BW is the body weight of a single people in the range of 14–60 years of age (the normal average body weight is 60 kg in Thailand) [37].

2.5.6. The Target Hazard Quotient (THQ)

The target hazard quotient (THQ) was calculated using the following Equation (6) [38].

$$\text{THQ} = \text{EDI}/R_{\text{fd}} \quad (6)$$

Here EDI is the estimated daily intake (mg/kg bw/day) and R_{fd} is the oral reference dose of the trace element according to the US EPA (mg/kg bw/day) [39].

3. Results and Discussion

3.1. Concentrations of Trace Metals in Surface Sediment

Table 1 summarized the minimum, maximum, and average concentrations of the six trace metals in the surface sediment from Libong Island, with comparisons to other published studies. The trace metals observed had wide variations in concentrations, with Fe, Cu, Co, Pb, Mn, and Ni ranges 1264.00–5711.00 µg/g, 0.10–1.34 µg/g, 0.10–0.42 µg/g, 0.18–7.69 µg/g, 20.06–82.79 µg/g, and 0.42–22.88 µg/g, respectively. The mean $\pm$ SD concentrations of Fe, Cu, Co, Pb, Mn, and Ni were 2711.94 ± 1424.83 , 0.47 ± 0.37 , 0.11 ± 0.09 , 1.32 ± 1.48 , 40.41 ± 16.12 , and 2.75 ± 4.04 µg/g, respectively. Overall, the average concentrations of trace metals in the surface sediments had the rank order $\text{Fe} > \text{Mn} > \text{Ni} > \text{Pb} > \text{Cu} > \text{Co}$. High concentrations of Fe and Mn were found in this area, consistent with previous studies (Table 1). It is possible that the soil in this area has a

presence of ferromanganese crust [40]. However, the sediments of Libong Island still did not have much trace metals accumulate when compared worldwide to many coastal areas, except for Pb and Mn, which had higher concentrations than many coastal areas of Iran [41,42]. It might be that, while the study area is located on a National Marine park, anthropogenic activities in households and agriculture around the park might contribute trace metal contamination to this area. Recently, Pradit et al. reported on marine waste, such as ceramic garbage, microplastic, batteries, etc., being released from the communities on Libong Island, due to influences of monsoon winds from May to October [18]. Thus, it might be that pollution from the mainland is released and transported by the seawater, and accumulates in the sediments at this remote location.

Table 1. Trace metal concentrations in surface sediments ($\mu\text{g/g}$ by dry weight) at Libong Island with comparisons to prior published studies.

Locations	Values	Metal Concentration ($\mu\text{g/g}$, Dry Weight)						Ref
		Fe	Cu	Co	Pb	Mn	Ni	
Libong Island, Thailand	Mean	2711.94	0.47	0.11	1.32	40.41	2.75	This study
	S.D.	1428.83	0.37	0.09	1.48	16.12	4.04	
	Min	1264.00	0.10	0.10	0.18	20.06	0.42	
	Max	5711.00	1.34	0.42	7.69	82.79	22.88	
Kharg coral, Iran	Mean	-	16.40	6.60	0.72	14.40	18.20	[41]
Lark coral, Iran	Mean	-	5.00	4.00	0.35	5.00	8.40	
Hormuz, Iran	Mean	32,555.00	2.03	1.09	0.49	4.87	17.25	[42]
Lark, Iran	Mean	33,699.00	3.93	2.10	0.63	7.52	33.91	
Qeshm, Iran	Mean	34,935.00	2.44	1.31	0.53	5.41	19.49	
Hengam, Iran	Mean	30,553.00	4.78	2.32	0.75	7.92	28.07	
Thondi Coast, India	Mean	52,802.30	54.70	-	14.1	686.1	27.7	[43]
Hainan island, china	Mean	-	14.97	13.21	26.82	-	25.26	[44]
Arabian Gulf, Saudi Arabia	Mean	8474.21	297.29	4.01	5.25	111.57	77.07	[45]
Gulf of Thailand	Mean	-	12.25	-	21.35	-	-	[46]
Xiamen Bay, China	Mean	32,783.00	52.51	19.87	37.49	674.00	23.93	[47]
Bohai Sea, china	Mean	13,000.00	16.84	7.69	11.36	502.96	18.50	[48]
Gulf of Thailand	Mean	17,860.00	7.41	-	1.81	-	-	[49]
Mediterranean Sea, Egypt	Mean	13,256.00	8.46	8.24	13.17	381.00	25.93	[50]
Egyptian Red Sea Coast	Mean	3490.00	1.94	9.69	3.26	127.08	11.40	[51]
Selangor, Malaysia	Mean	-	24.89	-	96.02	219.10	13.90	[52]
Gulf of Gemlik, Turkey	Mean	44,000.00	41.00	19.00	29.00	634.00	110.00	[53]

3.2. The Spatial Distribution of Trace Metals

The spatial distribution pattern is a powerful tool for identifying the contamination hotspots and possible sources of trace metals. The spatial distributions of the trace metals (Fe, Cu, Co, Pb, Mn, and Ni) are shown in Figure 2. The ecosystems in this study area can be divided into sandy beach, mud flats, and seagrass plants. It is interesting that high concentrations of Fe, Cu, Mn, and Co elements tended to be associated with sediments, especially in the seagrass bed area (Stations 7, 8, and 9). Generally, Fe, Cu, and Mn are essential nutrients, and play important roles to seagrass growth [54,55]. In addition, seagrass beds can act as trace metal reservoirs that accumulate pollutants to their environmental

concentrations [56,57]. These phenomena possibly explain the high contents of Fe, Cu, Mn, and Co in the seagrass bed area. Accordingly, sediment samples from the sandy beach had a higher content of Fe. One possible reason is that Fe is an abundant transition metal in the Earth's crust and present in most rocks and soil types. Overall, most of the high levels of these metals were associated with sediments from the mudflat. It is well known that mudflat sediments contain clay particles with large specific surfaces. The surfaces of clay particles are negatively charged and can adsorb trace metals, and tend to be deposited into coastal areas and estuaries [58].

Figure 2. The trace metal distribution at Libong Island when (a) Fe, (b) Cu, (c) Co, (d) Pb, (e) Mn, and (f) Ni. Noted: detection limit of Fe, Cu, Co, Mn, Pb, and Ni is 0.1 mg/kg.

3.3. Environmental Risk Assessment of Trace Metals in Surface Sediment

To assess the possible toxicity levels of the trace metals in sediments, three sets of sediment quality guideline (SQGs) were used to evaluate the collected samples (Table 2). Our assessment of sediment contamination was based on US EPA sediment quality guidelines [59], the effect range low (ERL)/effect range median (ERM) [60], and threshold effect level (TEL)/probable effect level (PEL) [61]. A comparison of the SQGs indicates that the concentrations of Cu, Pb, Mn, and Ni did not pose any environmental risks at any sampling location. Integration of additional tools, such as enrichment factor (EF), and the geoaccumulation index (Igeo) is highly recommended in order to assess the degree of contamination in sediments. The levels of EF and Igeo of trace metals in surface sediments are displayed in Table 3.

Table 2. Sediment quality guidelines (SQGs) for the analyte metals.

Metals	US EPA			Canadian Sediment Quality Guidelines		NoAA	
	Non-Polluted	Moderately Polluted	Heavily Polluted	TEL	PEL	ERL	ERM
Fe (%)	-	-	-	-	-	-	-
Cu	<25	25–50	>50	18.7	108.2	34	270
Co	-	-	-	-	-	-	-
Pb	<40	40–60	>60	30.2	112.0	46.7	218.0
Mn	<300	300–500	>500	-	-	-	-
Ni	<20	20–50	>50	15.9	42.8	20.9	15.9

Table 3. The Enrichment factors (EF) and geoaccumulation indexes (Igeo) of surface sediments.

Values	Enrichment Factor (EF)					Geoaccumulation Index (Igeo)				
	Cu	Co	Pb	Mn	Ni	Cu	Co	Pb	Mn	Ni
Mean	0.18	0.06	0.50	2.48	1.16	0.04	0.01	0.10	0.50	0.18
S.D.	0.13	0.03	0.55	1.13	1.78	0.03	0.01	0.11	0.23	0.36
Min	0.02	0.00	0.06	0.63	0.07	0.00	0.00	0.01	0.13	0.00
Max	0.52	0.12	2.68	5.46	10.13	0.10	0.03	0.54	1.10	2.03

The EF values of trace metals in this study varied as follows: 0.02–0.52 (mean = 0.18 ± 0.13) for Cu, 0.00–0.12 (mean = 0.06 ± 0.03) for Co, 0.06–2.68 (mean = 0.50 ± 0.55) for Pb, 0.63–5.46 (mean = 2.48 ± 1.13) for Mn and 0.07–10.13 (mean = 1.16 ± 1.78) for Ni (Table 3). The average EF values of Cu, Co, and Pb were less than 1. These indicate no enrichment at the sampling stations. In contrast, Mn and Ni were higher than 1, which indicates minor enrichment. According to Zhang and Liu, elements with EF between 0.5 and 1.5 are considered to originate from the crustal materials or natural processes, while those elements with EF > 1.5 are most attributable to human activities [62]. Mn occurs naturally in sediments because of the weathering of the parent material [63]. However, human activities, such as wastewater discharges and batteries, and agricultural activities, such as rubber plantations, may contribute to the trace metal deposition in the coastal areas, causing the high Mn contents in sediments.

The Igeo values of trace metals in this study varied as follows: 0.00–0.10 (mean = 0.04 ± 0.03) for Cu, 0.00–0.03 (mean = 0.01 ± 0.01) for Co, 0.01–0.54 (mean = 0.10 ± 0.11) for Pb, 0.13–1.10 (mean = 0.50 ± 0.23) for Mn and 0.00–2.03 (mean = 0.18 ± 0.36) for Ni (Table 3). The Igeo results show that all of the sampling stations can be classified as “no pollution” to “moderately contaminated” ($0 < \text{Igeo} < 1$). The highest Igeo was found for Mn. This suggests that the content of Mn has increased as a result of some anthropogenic activities.

3.4. Concentrations of Trace Metals in *Strombus canarium*

Accumulation of trace metals in the soft tissue of *Strombus canarium* was compared with other species of mollusks collected from various areas of the world (Table 4). In these studies, the metal concentrations were quantified based on tissue dry weights. Wide ranges of trace metal concentrations were observed as follows: Fe, 0.00–864.50; Cu, 0.00–58.93; Co, 0.00–0.92; Pb, 0.00–2.06; Mn, 0.00–67.72, and Ni, 0.00–1.38 µg/g by dry weight. The relative average concentration of trace metals in soft tissue of *Strombus canarium* decreased in the order Fe > Mn > Cu > Ni > Co > Pb. Among these metals, Fe, Cu, and Mn have average concentrations in the same range with the other locations. In contrast, Co, Ni, and Pb concentrations exhibited less accumulation than in other places. In addition, our results are in agreement with those of previous studies, confirming that many species of mollusks are able to accumulate high contents of Fe, Mn, and Cu in their bodies (Table 4). This might be due to the tendency of mollusks to accumulate essential elements for cell growth and metabolism. It is well known that Fe is an essential element in many enzyme reactions. Ferritin is an iron storage form in living cells, which plays an important role in the intracellular iron homeostasis of mollusks [64,65]. Mn is a cofactor in many enzymes, including arginase, glutamine synthetase (GS), pyruvate carboxylase, and Mn superoxide dismutase (Mn-SOD) [66]. However, an excess of essential and non-essential trace elements could affect aquatic animals negatively and cause human health risks from shellfish consumption. Previous studies have shown that excessive Fe exposure can result in gastrointestinal effects, lethargy, tachycardia, hepatic necrosis, and lung cancer [67]. Ni exposure can result in fibrosis, tumors, lung inflammation, and emphysema [68]. A negative effect of Mn on human health is via neurologic and psychological disorders [69]. Although copper is one of the essential metals, a high intake of Cu can cause anemia, neutropenia, osteoporosis, stomach cramps, and Wilson disease [70,71]. High levels of Co can cause hematological, cardiovascular, immunological, and neurological effects [72]. In addition, Pb is a non-essential element that is very toxic to humans, especially to children. Pb can damage the kidneys, nervous, and reproductive system [73], and it can cause neurotoxicity, anemic conditions, and fatigue [74]. However, concentrations of the metals in *Strombus canarium* might depend on habitat. *Strombus canarium* is a deposit feeder consuming algae, zooplankton, and particles on the sediment surface [75]. Thus, the trace metal accumulation in deposit feeders would be expected to relate to metal concentrations in the sediments.

Table 4. Concentration of trace metals in *Strombus canarium* and comparison to other localities worldwide.

Locations	Species	Values	Dry Weight Fraction (µg/g)						Ref
			Fe	Cu	Co	Pb	Mn	Ni	
Libong Island, Thailand	Gastropod (<i>Strombus canarium</i>)	Mean	200.86	8.40	0.29	0.08	18.30	0.46	This study
		S.D.	227.83	10.56	0.21	0.37	18.47	0.47	
		Min	0.00	0.00	0.00	0.00	0.00	0.00	
		Max	864.50	58.93	0.92	2.06	67.72	1.38	
Lake Manzala, Egypt	Gastropod (<i>Lanistes carinatus</i>)	Mean	567.28	2.65	3.08	0.37	24.91	6.19	[76]
South India	Gastropod (<i>Tibia curta</i>)	Mean	76.85	37.02	0.35	2.64	8.50	3.21	[77]
North–Eastern Mediterranean	Gastropod (<i>Monodonta turbinata</i>)	Mean	3176.85	334.47	12.76	90.80	49.40	26.93	[78]
Red Sea coast	Bivalve (<i>Tridacna maxima</i>)	Mean	600.00	39.73	1.63	33.66	41.77	38.88	[79]
El-Mex, Mediterranean coast	Bivalve (<i>Mytilidae</i>)	Mean	-	11.85	4.25	0.43	-	14.95	[80]
Marudu Bay, Malaysia	Bivalve (<i>Meretrix meretrix</i>)	Mean	285.50	74.90	-	2.77	20.30	4.23	[81]

3.5. Biota Sediment Accumulation Factor (BSAF)

Gastropod mollusks are known to have the ability to absorb a wide range of pollutants from the environment and accumulate them in the body. This makes them good candidates for bioindicators to assess the levels of metal pollutants in an aquatic system. Thus, The BSAF was studied to evaluate the ability of these aquatic organisms to accumulate trace metals from the sediment, and the results are shown in Figure 3. The capacity of the *Strombus canarium* to bioaccumulate Fe, Cu, Co, Pb, Mn, and Ni was 0.07, 17.87, 2.59, 0.06, 0.45, and 0.17, respectively. Based on BSAF, for Fe, Pb, Mn, and Ni this species could be classified as a de-concentrator ($BSAF < 1$), whereas for Cu and Co, the BSAF was higher than 2, indicating a macro-concentrator. This suggests that the organism can accumulate metals in its soft tissue from sediment, and has difficult to excrete and release them. It is noted that *Strombus canarium* could be used as a bioindicator for Cu contamination. Among the marine organisms, high accumulation of Cu has also been found in some parts of molluscan tissues, especially those of marine gastropods [82] and bivalves [83,84]. There are many ways for accumulating and storing metals. These findings suggest that bioaccumulated Cu may be involved in metal-binding proteins, such as Cu metallothionein (MTs), and stored in lysosome [85]. Accumulation of metals in the tissues of a marine animal can reflect the metabolic demands for essential elements and the abundance of the elements in the environment. However, it not only depends on the level of the element in the environment, but also on various other factors, such as the rate of metal absorption, metabolic rate, physiology of digestion, season, species, body weight, age, and sex reproductive condition [86].

Figure 3. Biota sediment accumulation factors (BSAF) for *Strombus canarium* at Libong Island.

3.6. The Relationship between Trace Metal Concentrations in Sediment and Soft Tissue of Shellfish

Table 5 shows the correlation coefficients (r) between metal concentrations in sediment and soft tissue of shellfish. Significant positive correlation was observed between Fe and Mn ($r = 0.770$) as well as for Cu with Co ($r = 0.390$). It was found that trace metal concentrations in shellfish may be directly affected by those in the bottom sediment where these shellfish live. Our results agree with Aljahdali et al. (2020), who found significant correlations between metal in the sediment and in the snail [87].

Table 5. Correlation between metal concentrations in sediment and soft tissue of shellfish.

	Fe	Cu	Co	Pb	Mn	Ni
Fe	1					
Cu	0.279	1				
Co	−0.116	0.390 *	1			
Pb	0.310	−0.063	−0.272	1		
Mn	0.770 **	0.283	−0.015	0.061	1	
Ni	0.073 *	−0.174	−0.033	0.036	0.084	1

** Correlation is significant at the 0.01 level (2-tailed); * correlation is significant at the 0.05 level (2-tailed).

3.7. The Relationship between Trace Metal Concentrations in the Soft Tissues of *Strombus canarium* and Weight

The weight of gastropod mollusk is an important factor that affects the metal accumulation rates in tissues [88]. The correlation coefficients between weight and trace metal concentrations of *Strombus canarium* are summarized in Table 6. The dry weight of *Strombus canarium* was in the range 0.14–2.53 g with the mean 0.75 ± 0.58 g. The results show that the weight of *Strombus canarium* was strongly positive correlated with Fe ($r = 0.559$) and Mn ($r = 0.426$). Meanwhile, Fe also showed a positive correlation with Mn ($r = 0.770$) as well as with Cu and Co ($r = 0.390$). This shows that metal concentrations are greatly affected by the size of the organism. When the *Strombus canarium* is larger, the essential minerals, such as Fe and Mn, are accumulated at a higher level. In addition, the significant positive correlations between Fe and Mn and Cu and Co indicate that these metals might have been emitted from the same source or from the same parent materials. However, negative correlations among Co, Pb, Ni, and weight were found in this study. One explanation may be the differences in metabolic activities between smaller and larger mollusks. In previous studies, several authors have suggested that the smaller and younger mollusks showed higher concentrations than the larger and older ones, which could be attributable to their higher metabolic rate [89]. In addition, Williamson (1980) suggested that an increased metabolic rate might affect the uptake and elimination of metals by their bodies [90].

Table 6. Correlation between metal concentrations in the soft tissues of *Strombus canarium* and dry weight.

	Weight	Fe	Cu	Co	Pb	Mn	Ni
Weight	1						
Fe	0.559 **	1					
Cu	0.127	0.279	1				
Co	−0.045	−0.116	0.390 *	1			
Pb	−0.042	0.310	−0.063	−0.272	1		
Mn	0.426 *	0.770 **	0.283	−0.015	0.061	1	
Ni	−0.086	0.073	−0.174	−0.033	0.036	0.084	1

** Correlation is significant at the 0.01 level (2-tailed); * correlation is significant at the 0.05 level (2-tailed).

3.8. Health Risk Assessment of the Trace Metals

The estimated daily intake (EDI) from shellfish consumption was calculated (Table 7) based on the metal concentrations (by wet weight) in *Strombus canarium* and the daily food consumption. The EDI was calculated with the dietary intake guidelines recommended for Thai people who are 14–60 years of age (average body weight = 60 kg). The EDI of Fe, Cu, Co, Pb, Mn, and Ni were 0.1175, 0.0049, 0.0002, 0.0001, 0.0107, and 0.0003 mg/kg bw/day, respectively. As shown in Table 7, the EDI of shellfish is lower than the oral reference dose (Rfd) guidelines for all trace elements studied. This strongly indicates that there is no health risk from the intake of trace metals by shellfish consumption. The THQ estimates no carcinogenic risk from this pollutant exposure. The THQ values for the targeted trace metals had the descending rank order Fe > Cu > Mn > Ni > Pb > Co. The THQ of each trace

metal in shellfish was less than 1, indicating that consumers of shellfish from this study area are not exposed to cancer hazards by that consumption.

Table 7. Estimated oral reference doses, estimated daily intakes, and target hazard quotients from shellfish consumption.

Metal	Mean Metal Concentration (mg/kg ww)	EDI (mg/kg bw/day)	Rfd (mg/kg bw/day)	THQ
Fe	52.22	0.1175	0.70	0.1679
Cu	2.18	0.0049	0.04	0.1229
Co	0.08	0.0002	0.03	0.0057
Pb	0.02	0.0001	0.004	0.0117
Mn	4.76	0.0107	0.14	0.0765
Ni	0.12	0.0003	0.02	0.0135

EDI: the estimated daily intake; Rfd: the oral reference dose [39]; THQ: the target hazard quotients.

4. Conclusions

The purpose of this study was to assess trace metal contamination in the surface sediments and *Strombus canarium* samples collected from Libong Island. The mean metal concentrations in the sediments had the rank order Fe > Mn > Ni > Pb > Cu > Co. Trace metals in the sediments were found in the range from “no pollution” to “moderate potential ecological risks” in this study. The sources of most trace metals appeared natural, except for Mn, which had minor enrichment over what was expected naturally. The higher content of Mn was probably attributable to domestic waste and agricultural activities. However, all metal content in the sediments were still lower than thresholds in the sediment quality guidelines. The mean metal concentrations in *Strombus canarium* had the rank order Fe > Mn > Cu > Ni > Co > Pb. Based on BSAF index, *Strombus canarium* has potential for use in biomonitoring of Cu. The correlation between soft tissue weight of *Strombus canarium* and trace metal concentration showed that the essential metals Fe and Mn bioaccumulated in mollusks, depending on body weight. Regarding concerns of human health risks, the EDI of trace metal from the targeted shellfish samples were calculated. It was found that EDI was below the reference dose according to the U.S. EPA. In addition, the THQs of individual elements were below 1, suggesting that no health risk was posed to consumers. The data from this study provide valuable information about the current status of trace metal pollution, and can serve as a baseline for future studies in the region. However, investigations and monitoring should assess the long-term effects of trace metals in Libong Island and elsewhere in the Andaman Sea.

Author Contributions: Conceptualization, T.K. and S.P.; formal analysis, T.K., S.S., T.N. and D.M.; methodology, S.S., T.N., D.M., P.-S.L. and S.P.; supervision, S.P.; writing—original draft, T.K.; writing—review and editing, P.-S.L. and S.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by Prince of Songkla University and the Ministry of Higher Education, Science, Research, and Innovation, Thailand, under the Reinventing University Project (grant number REV64030) and the Grand Challenges Thailand: Thai Ocean Waste Free, National Research Council of Thailand (sub project: marine litter and microplastic at Libong Island, Trang province).

Institutional Review Board Statement: All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

Informed Consent Statement: This study does not involve with human. The *Strombus canarium* samples were bought from the local people for consumption.

Data Availability Statement: The data that support the findings of this study are available from the authors upon reasonable request.

Acknowledgments: We express great thanks to the Research Development Office (RDO/PSU) and Seppo Karrila for the English proofreading support.

Conflicts of Interest: The authors declare no conflict of interest.

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