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Bioaccumulation of trace elements in the hard clam, *Meretrix lyrata*, reared downstream of a developing megacity, the Saigon-Dongnai River Estuary, Vietnam

Viet Tuan Tran & Phuoc-Dan Nguyen  & Emilie Strady

Abstract A large number of white hard clam farms are in the estuary shoreline of Saigon-Dongnai Rivers, which flow through Ho Chi Minh City, a megacity, and numerous industrial zones in the basin catchment area. In this study, eleven trace elements (Mn, Fe, Co, Ni, Cu, Zn, As, Se, Cd, Hg, and Pb) in the hard clam *Meretrix lyrata* and its habitats including surface water, suspended particulate matter, and sediment were evaluated to understand the bioaccumulation of trace metals

from the environment into the whole tissues of the hard clam as well as its different organs. The samples were collected monthly in dry, transition, and wet seasons of the southern part of Vietnam from March to September 2016. The results showed that seasonal and spatial variations of the studied metal concentrations in the hard clam *M. lyrata* might be influenced by the sea current as well as the surface runoff in the rainy season. The relationship between condition index and the element concentrations in *M. lyrata* might be affected by the living environment conditions and farming methods. In addition, the hazard index values of all trace elements in the hard clam *M. lyrata* harvested in the sampling time show that the hard clams farmed in the study area were safe for local consumers.

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Keywords White hard clam · Trace metal · Condition index · Biomonitoring · Human health risk

Introduction

Trace metals in aquatic environment originate from either natural processes or human activities. Natural sources are mostly from erosion, chemical rock weathering, volcanic activity, or soil leaching, whereas the anthropogenic sources are mainly from urban surface runoff and agricultural, industrial, and domestic activities. Trace metals are ubiquitous in aquatic environment, but their speciation is changing according to the physicochemical conditions of the environment, especially at the estuarine interface. One of the most

serious problems associated with metals in the aquatic environment is their bioaccumulation in organisms, which can be toxic for the aquatic organisms themselves and can present a health risk for the humans who are consuming them (Sakellari et al. 2013; Tao et al. 2012).

The Bivalvia class has the capacity to accumulate trace metals in proportion to the environmental contamination levels (Baudrimont et al. 2005; Sakellari et al. 2013). The level of accumulation in biota (both the whole organism and its specific organs) is calculated using the accumulation factors, which are defined as the ratio of the concentration of pollutants accumulated in biota to the concentration of pollutants in the abiotic medium. For each environment media, a specific factor is used such as the bioaccumulation factor for the water, the biota-sediment accumulation factor for sediment (BSAF), and the biota-suspended particulate matter accumulation factor (BSPMAF) for suspended particles (Antunes et al. 2007; Belabed et al. 2013; Rzymiski et al. 2014). The metal accumulation differed according to the organs and tissues of bivalves: some organs might be more sensitive and so might be a specific indicator for an environmental pollution rather than the whole body burdens (Tarique et al. 2012; Vodopivec et al. 2015).

Ho Chi Minh City (HCMC), the biggest economical city in Vietnam, has a high rate of urbanization and industrialization that has resulted in serious water issues such as heavy metals and nutrient contaminations, in the Saigon-Dongnai (SG-DN) Rivers (Tuyet et al. 2019; Strady et al. 2016; Vo 2007). Thanh-Nho et al. (2018) show that the metal concentrations in the estuary of the SG-DN Rivers could be changed due to the effects of surface runoff and soil leaching level in different seasons. At the mouth of the SG-DN Rivers, on the left bank (Can Gio District) and on the right bank (Tien Giang Province) are localized important commercial aqua-products of Asiatic hard clam *Meretrix lyrata* (G.B. Sowerby II, 1851). The area of clam farms at Can Gio was 800 ha, while it was 2000 ha at Tan Thanh (van Duijn et al. 2012). Normally, the hard clam farming period suitable for market provision is in the range from 12 to 18 months. Some previous studies focused on the effects of nutrients, temperature, salinity, rainwater quality, and tidal region on the *M. lyrata* hard clam growth (Son and Tung 2011) or genetic studies (Wu et al. 2014). A few studies focused on the accumulation and excretion of Cd, As, and Pb (Pham 2007) and monitoring of the metal concentrations in hard clam species along the coastal of Vietnam (Le 2016; Tu

et al. 2010; Phuong and Khoa 2013). However, these studies only evaluated a few of typical metals in short survey time or the sampled hard clams collected at the local markets. Hop et al. (2017) sampled hard clams farmed at Tan Thanh beach in the rainy season in 2015 and found a significant correlation between metal concentrations in the clams and the sediment fractions and safe limit for human consumption. Until now, the metal concentrations in specific organs of the *M. lyrata* hard clam as well as the correlation between metals in the hard clam farmed in the natural habitat and its physiological state have not been deeply studied in Vietnam. Therefore, this study aimed (i) to determine trace elements (Mn, Fe, Co, Ni, Cu, Zn, As, Se, Cd, Hg, and Pb) in *M. lyrata* and its living environment along the shoreline of the SG-DN River Estuary in the southern part of Vietnam from March to September 2016 that lasted from the late half of the dry season to the early mid-rainy season; (ii) to assess the spatial and seasonal variation of trace element concentrations in the hard clam *M. lyrata* and its habitats; and (iii) to estimate the health risks for the local consumers of the *M. lyrata* clam using the hazard quotient.

Materials and methods

Study area

The sampling sites are located in the southern part of Vietnam, at the mouth of the SG-DN River system, which is the third biggest river basin in Vietnam (Fig. 1). They are under the area of tropical monsoon climate, where the rainy and dry seasons last from May to November and from December to April next year, respectively. In the year 2016, the transition period, which was determined based on the variation of measured monthly rainfalls, lasted from May to July—those were months of the late dry season and the early rainy season (Supplement 1) (IMHEN 2018). Under the tropical monsoon climate, the strong northeast monsoon occurs from March to April and the southwest monsoon starts in May, becoming the strongest in August (IMHEN 2018; SRHC 2018). Similarly, the sea currents flow in the same direction with the monsoons (i.e., from the southwest to the northeast in the rainy season and vice versa in the dry seasons) (Fang et al. 2012). In addition, the studied area is affected by semi-irregular diurnal tide.

The three following sites were selected in the study: (i) Can Thanh and (ii) Dong Hoa in Can Gio area, located on the northeast part of the mouth of the SG-DN Rivers, and (iii) Tan Thanh located between the southwest part of the SG-DN estuary and the mouth of the Tien River, the northern branch of the Mekong Delta. The *Meretrix lyrata* hard clams are reared in the intertidal silty sand flat beaches and are harvested during ebb tide (Tong and Nguyen 2011). Only 12–24-month-old hard clam individuals, of which size is normally big enough to harvest to sell, were selected to study. The hard clams sampled at the Can Thanh site had been raised from the clam seeds with the age of less than 3 months, whereas the ones collected at Tan Thanh had been reared from the 3–6-month-old clam seeds and the ones collected at the Dong Hoa were drifted from the clam farms in the neighboring beaches.

Sampling and handling

At each sampling site, seawater, suspended particulate matters (SPM), sediment, and hard clam samples were collected once per month from March to September 2016. During high tide, 50 mL of seawater was filtered through a 0.2- μ m polytetrafluoroethylene (PTFE) filter paper (Omnipore™), acidified with a 0.05-mL HNO₃ (65%, Merck, Suprapur®), and stored in a polyethylene (PE) bottle at 4 °C. SPM were collected by filtering 200 mL of seawater using a pre-weighted 0.45- μ m Whatman® filter paper. During low tide, sediment and hard clam were sampled. Sediment sample was a composite of five samples collected within an area of 5 × 5 m. At each site, forty individuals of 12–24-month-old hard clam with shell length ranging from 26.6 to 42.6 cm were manually collected using the handy clam harvesting tools (Truong 2000). Then, they were stored in plastic bags, transported to the laboratory, and cleaned with tap water before preservation at – 20 °C.

Sample preparation, digestion, and metal analysis

For each clam individual, the shell and soft body were separated and its soft body was dissected into three parts, the gill (G), the digestive gland (DG), and the remaining tissues (R), using a stainless steel knife. The condition index (CI), which represents the physiological state of the sampled hard clam, was determined by Eq. 1 (Markert et al. 2003):

$$CI = \frac{1}{4} \frac{m_{issue}}{m_{shell}} \times 100$$

where m_{issue} is the wet weight of the soft body (g) and m_{shell} is the weight of the shell (g).

Each sample of whole body or dissected part was a composite of five individual clams, of which the total weight was big enough to analyze the metals. Then, the composite sample was dried using a freeze dryer (Alpha 1-2 LDplus Christ®) for at least 24 h and ground homogeneously using a stone pestle and mortar and stored in a PE zip bag. A 200 mg of the ground sample was added to a 5-mL HNO₃ (65%, Merck, Suprapur®) in a PTFE vial at 110 °C for 3.5 h on the hot plate (Strady et al. 2011). Subsequently, 4 mL of digested solution was mixed with 10 mL of the purified water (Elga®) and stored in a polypropylene (PP) tube at 4 °C before analysis. Eleven elements including Mn, Fe, Co, Ni, Cu, Zn, As, Se, Cd, Hg, and Pb were analyzed by the inductively coupled plasma mass spectrometry (ICP-MS, Agilent 7700x series).

Sediment and SPM samples were dried in a freeze dryer (Alpha 1-2 LDplus Christ®) for at least 24 h. Then, 100 mg of homogeneous ground (i.e., using stone pestle and mortar) dried sediment and SPM samples were placed in PTFE vials and 2-mL HNO₃ (65%, Merck, Suprapur®) and 4-mL HCl (30%, Merck, Suprapur®) were added to those vials (Sekabira et al. 2010). The vials were put in ultrasonic bath for 20 min before heating by a hot plate at 120 °C for 4 h. The digested solution was then evaporated to dryness at 60 °C on the hot plate. Subsequently, 10 mL of purified water (Elga®) and a 0.5-mL HNO₃ (65%, Merck, Suprapur®) were added into the dried sample and the solution was kept at 65 °C for 30 min. Finally, 3.5 mL of the solution and a 6.5-mL purified water (Elga®) were added into a PP tube and it was kept at 4 °C before analysis. Eleven elements including Mn, Fe, Co, Ni, Cu, Zn, As, Se, Cd, Hg, and Pb were analyzed using the ICP-MS (Agilent 7700x series).

Quality assurance and quality control

The PTFE vials were cleaned, soaked in 10% HNO₃ at 80 °C for 24 h, and then filled with 2% HNO₃ solution for storage. The other laboratory apparatuses including bottles, pestles, mortars, PP tubes and stainless steel knives were cleaned and soaked in 10% HNO₃ for more than 24 h, then rinsed with purified water (Elga®) at least three times, dried, and stored in a PE zip bag.

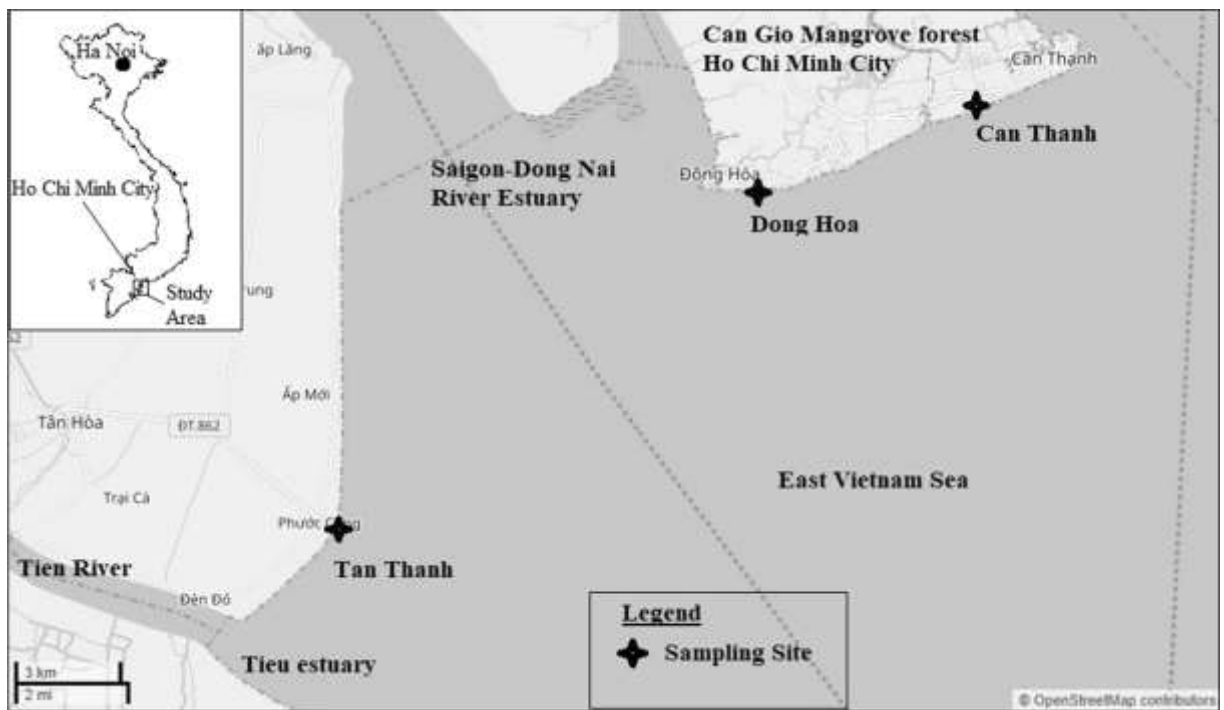


Fig. 1 Three sampling sites (Can Thanh, Dong Hoa, and Tan Thanh) near the estuary of the SG-DN River system

The certified material references (CRM) of the National Research Council Canada were used for trace metal analysis in the study including (i) MESS-3 as marine sediment CMR and (ii) TORT-3 which is a flesh of the lobster *hepatopancreas* as CMR of mollusk flesh. The recoveries of Mn, Fe, Co, Ni, Cu, Zn, As, Se, Cd, Hg, and Pb for MESS-3 were 101, 100, 90, 96, 96, 96, 99, 93, 100, 107, and 105%, respectively, whereas those for TORT-3 were 94, 91, 98, 90, 95, 96, 106, 103, 95, 95, and 93%, respectively.

Risk assessment

The hazard quotient (HQ) in the study was used for the human health risk assessment of the local people consuming metal-contaminated hard clams. The HQ is calculated by Eq. 2 (U.S. EPA 2011):

$$HQ \approx \frac{EDI}{RfD} \approx \frac{C_{bivalve} * EF * ED * \frac{dc_{bivalve}}{bw}}{RfD * AT} \quad (2)$$

where bw is the body weight (kg). The average local body weight is 60 kg which is equivalent to the Asian body weight of 57.7 kg in 2005 (Walpole et al. 2012);

EDI is the estimated daily intake ($\mu\text{g}/\text{kg}$ bw/day); $C_{bivalve}$ is the metal concentration in hard clam tissue ($\mu\text{g}/\text{g}$ wet weight); $dc_{bivalve}$ is the daily bivalve consumption of 4.97 g bivalve/capita/day (FAOSTAT 2017); EF is the exposure frequency, 350 days/year (U.S. EPA 2011); ED is the exposure duration, 30 years for adults (U.S. EPA 2011); AT is the actual exposure time ($AT = 365 \text{ days/year} \times ED = 19,950 \text{ days}$); RfD is the reference dose interpreted as the tolerable daily intake ($\mu\text{g}/\text{kg}$ of body weight/day). The values of RfD is presented in Table 1.

In general, HQ is used for risk assessment of a single contaminant that a human receptor is exposed via a single pathway like ingestion, while hazard index (HI) is the sum of HQ of contaminants in the mixture, which the receptor is exposed (U.S. EPA 2005). This method assumes that the potential risk concern is attributed to the additional effects of the contaminants and entry associated with each exposure pathway such as inhalation or ingestion does not directly consider. In this study, the health risk for human receptor being exposed to all metals available in the hard clam including Mn, Fe, Co, Ni, Cu, Zn, As, Se, Cd, Hg, and Pb was evaluated by using HI (Bilgin and Uluturhan-Suzer 2017) that is calculated by Eq. 3:

$$HI = \sum HQs$$

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where HI is the hazard index for a specific exposure pathway and HQs is the hazard quotient for chemicals of potential concerns or studied metals.

Metal bioaccumulation factors

The biota-suspended particulate matter accumulation factor (BSPMAF) and biota-sediment accumulation factor (BSAF) were calculated based on Eq. 5 (Antunes et al. 2007):

$$BSPMAF = \frac{C_{clam}}{C_{SPM}}$$

36

$$BSAF = \frac{C_{clam}}{C_{Sediment}}$$

37

where C_{clam} is the metal concentration in *M. lyrata* or its organ (mg/kg dry weight) and C_{SPM} (mg/kg dry weight) and $C_{Sediment}$ (mg/kg dry weight) are the metal concentrations in SPM and sediment, respectively.

Data analysis

The SPSS 16.0 and Microsoft Excel 2013 were used for data analysis in this study. They were used to calculate the mean values, standard deviation, analysis of variance (ANOVA), Pearson correlation, Tukey post hoc test, and other statistical indices.

Results and discussion

Seasonal trends of metal concentrations in *M. lyrata* and its habitats

Figure 2 illustrated that the mean metal concentrations in surface sediment samples were stable over the sampling period, while those in SPM and soft tissues of hard clams significantly fluctuated. Table 2 shows that the mean concentrations of Co, Ni, Cu, Zn, Se, Cd, and Hg in the total soft tissues of all hard clams were significantly different between seasons (ANOVA test results p -values < 0.05), with lower concentrations during the dry season (Tukey post hoc test, Supplement 2) and higher ones in May (Fig. 2). The mean concentrations

of trace elements in SPM, except Hg and Cd, also increased from March in the dry season to May in the transition period. Similarly, the total metal concentrations in the seawater (i.e., sum of particulate and dissolved metal concentrations, Supplement 3) were higher during the rainy season than those during the dry season. Thanh-Nho et al. (2018) claimed that the increase of rainfall in the SG-DN River basin in the transition time mobilized both dissolved and particulate metals (Fe, Cr, Ni, and Pb) from the terrestrial environment to the aquatic environment. This seasonal change of metal concentrations in the living habitat may lead to the different exposures of clams to metals. The result was similar to that of George et al. (2013), who observed higher metal (Fe, Co, Ni, Cu, Zn, Cd, and Pb) concentrations in the black clam *Villorita cyprinoides* during the pre-monsoon period than those in the dry season in India.

The metal concentrations in clams, especially in the gills, digestive glands, and in the remaining tissues, varied with seasons. Indeed, Table 2 presented that the metal concentrations significantly increased from the dry to wet seasons (ANOVA test, p -values < 0.05 except Pb in G-DG-R; As in R; Se in G; Hg in DG-R), and the peak concentrations in all organs were obtained during the transition time (Fig. 3). The increase of both dissolved and particulate metal concentrations seems to affect both the gills and the digestive glands and subsequently the remaining tissues. The sediment bioaccumulation factors (BSAF) and the suspended particulate one (BSPMAF) for all metals did not vary between seasons (Supplement 4), except BSPMAF for Ni and BSAF for Ni, Co, and Hg. The absence of seasonal variation in the bioaccumulation factors claimed that the seasonal variation of metals in clams reflects the metal bioavailability in the suspended particulates and the sediment.

Rzyski et al. (2014) addressed that metal bioaccumulation in the species happened from the environmental compartments as the value of the bioaccumulation factor is greater than 1. The BSAF and BSPMAF for each studied metal were determined in three seasons (Supplement 4). The values of BSAF for Mn, Fe, Co, and Pb and BSPMAF of Mn, Fe, Co, Ni, Cu, Zn, As, Se, and Pb were less than 1, and thus those metals might not accumulate in *M. lyrata* via the pathways of sediment and SPM. The values of BSAF for Cd, Cu, Zn, As, and Se and BSPMAF for Cd higher than 1 in all three seasons indicated that the bioaccumulation of Cd, Cu,

Table 1 The tolerable daily intake of the studied metals

Metal	Mn	Fe	Co	Ni ^a	Cu	Zn	As ^b	Se	Cd	Hg	Pb ^c
RfD (µg/kg bw/day)	140	800	23	20	500	1,000	3	5	0.833 ^d	0.571 ^e	1.2
Reference	(U.S. EPA 1995)	(FAO/WH O 1983)	(EVM 2003)	(U.S. EPA 1991a)	(FAO/WH O 1982)	(FAO/WH O 1982)	(FAO/WH O 2010a)	(U.S. EPA 1991b)	(FAO/WH O 2010a)	(FAO/WH O 2010a)	(FAO/WH O 2010b)

^a Value for nickel in soluble salts; ^b the inorganic As benchmark dose modeling (BMDL) for a 0.5% increased incidence of lung cancer; ^c the exposure level of 1.2 µg/kg bw/day associated with a population increase in systolic blood pressure of 1 mm Hg; ^{d,e} the values calculated from PTWI and PTMI

Zn, As, and Se by sediment and Cd by SPM clearly happens in the hard clam *M. lyrata*. The values of BSAF for Ni in both transition and wet seasons and Hg in only the wet season were higher than 1. Those BSAF and BSPMAF show the effects of the above metals from the solid-phase compartments on bioaccumulation.

Spatial metal concentration variation in *M. lyrata* and its habitats

Spatially, significant differences of Co, Ni, Zn, Se, Cd, and Hg concentrations in the soft tissues of clams collected at the three sampling sites were measured (ANOVA test, $p < 0.05$). The higher concentrations were observed at the Tan Thanh site based on the result of the Tukey post hoc test (Supplement 5). Note that trace metals in the living habitats may accumulate into the bivalves (Wu et al. 2013); therefore, the higher metal accumulation in the clams at Tan Thanh may have a significant correlation to the higher metal contents of the sediment and SPM (Supplements 6 and 7).

The concentrations of Mn, Fe, Co, Ni, Cu, Zn, Se, Cd, Hg, and Pb in the clams were lower in the dry season at both the Can Thanh and Dong Hoa sites in Can Gio District, while at Tan Thanh in Tien Giang Province, the concentrations of Mn, Fe, Cu, As, Se, Hg, and Pb in the dry season were higher in comparison with those in the transition and wet seasons (Fig. 4). Those opposite seasonal changes of some trace metal concentrations in *M. lyrata* between the Tan Thanh site and sites in Can Gio District might be caused by the effect of coastal current around the SG-DN River Estuary. During the dry season, the sea current flows from the North to the South and during the rainy season it flows from the South to the North (Fang et al. 2012). Lower total metal concentrations were found in seawater (Supplement 3) and in *M. lyrata* (except As) at sites in Can Gio District in comparison with those at Tan Thanh during the dry season. The seasonal change of sea current influences on the SPM concentration at the Tan Thanh site, where more SPM concentrations come from the Tien River, a branch of the Mekong Delta (Marchesiello et al. 2019). Consequently, the change of SPM concentrations could affect the total metal concentrations (i.e., particulate and dissolved metals) in seawater (Strady et al. 2017; Thanh-Nho et al. 2018), and thus it may result in the potential exposure of clams to metals available in SPMs.

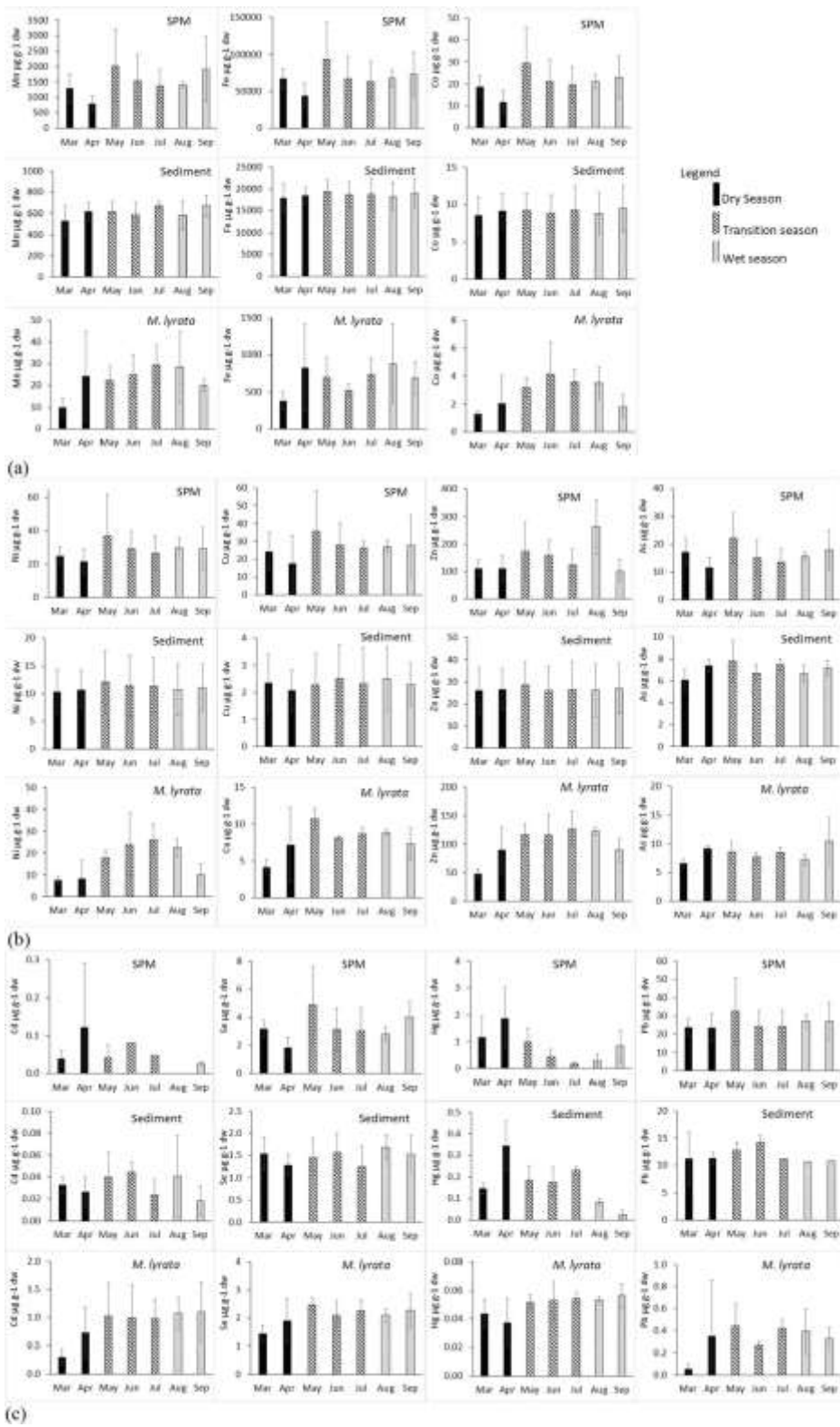


Fig. 2 Mean metal concentrations (Mn, Fe, Co (part a); Ni, Cu, Zn, As, (part b); and Se, Cd, Hg, Pb (part c)) in SPM, sediment, and *M. lyrata* during the dry season, the transition season, and the wet season at all sampling sites

Table 2 The seasonal differences of element concentrations in the hard clam *M. lyrata* based on ANOVA test results

Element	<i>p</i> -value (Sig.)			
	Whole body	Gill	Digestive gland	Remainder
Mn	0.338	0.000*	0.371	0.012*
Fe	0.318	0.002*	0.029*	0.026*
Co	0.000*	0.001*	0.000*	0.000*
Ni	0.000*	0.000*	0.000*	0.000*
Cu	0.000*	0.000*	0.000*	0.003*
Zn	0.000*	0.000*	0.000*	0.001*
As	0.744	0.012*	0.007*	0.140
Se	0.001*	0.704	0.008*	0.033*
Cd	0.000*	0.000*	0.000*	0.000*
Hg	0.002*	0.000*	0.393	0.474
Pb	0.395	0.660	0.913	0.011*

*Statistically significant difference with *p*-value < 0.05

The condition index of organism is very sensitive to the pollutant levels and nutrient concentrations in its living habitat (Rainer and Mann 1992). Therefore, it is claimed that the different environment conditions and hard clam farming methods may influence the relationship between the CI and metal concentrations. CI values presented significant negative correlations with mean Mn, Fe, Co, Ni, Cu, Zn, Se, Cd, and Pb concentrations in the whole body of *M. lyrata* at the three sampling sites (Supplement 8). It means that the worse the physiological state of the hard clam, the higher metal concentrations in it were found. Similarly, the negative correlations were observed between CI and Hg, Cd, Cu, Ag, Zn, and Pb in *Mytilus edulis* (Borchardt et al. 1988) and Zn, As, Cd, Pb, Hg, Cu, Ni, and Cr in *Mytilus galloprovincialis* from the Mediterranean Sea (Andral et al. 2004). The CI values negatively correlated with the concentrations of Mn, Fe, Co, Ni, Cu, Zn, and Pb at the Can Thanh site; Co, Ni, Zn, Cd, and Hg at Tan Thanh; and Fe, Cd, and Pb at Dong Hoa (Supplement 8). As mentioned, the hard clams at the Can Thanh site are raised from juvenile until adult clams (12–18 months old), so that the CI of adult hard clam reflects the quality of their living environment. At the Tan Thanh site, the 3–6-month-old hard clams are brought from other farms and then they are raised to the 12-month-old ones. Therefore, the number of trace elements having a correlation with CI at the Tan Thanh site was less than that at the Can Thanh

site. The similar situation was observed at Dong Hoa, the CI values only correlated with the concentrations of minor number of elements because those hard clams collected at Dong Hoa might not grow on-site.

The results of statistical analysis (in Supplement 9) show that the correlations between the metal concentrations in the whole tissues of *M. lyrata* and its living environmental components including SPM, sediment, and surface water have been only found for a few trace elements. In the previous studies, Dan et al. (2014) and Hop et al. (2017) observed the same situation at the Tan Thanh site. Some other studies investigated the non-significant statistical correlation between the metal concentrations in bivalve species and in their living environment (de Astudillo et al. 2005; Madkour et al. 2011; Salahshur et al. 2012). Madkour et al. (2011) presented that heavy metal accumulation in hard clams might not come directly from one source such as sediment but it could derive from other sources such as SPM or surface water. Therefore, some authors studied on correlations between metal concentrations in not only whole body tissue of bivalve species but also in their specific organs and their living environment such as sediment or even the specific fractions of sediment (Wong et al. 2016; Yap et al. 2014). In this study, the significant statistical correlations were found between Cu and Zn concentrations in SPM and the gill, Se in SPM and the digestion gland, and Ni and Co in SPM and both the gill and digestion gland of *M. lyrata*. The particulate metals mostly derive from the terrestrial environment (Thanh-Nho et al. 2018), and thereby the element concentrations in SPM might depend on the contamination of topsoil as well as the runoff surface in the river basin.

Risk assessment of hard clam consumption

Table 3 illustrated that the estimated hazard quotient (HQ) and the hazard index (HI) in this research were all less than the value of 1, which indicates that the hard clams farmed in the study area were safe for consumers in terms of the studied metals as chemicals of potential concern. The similar observation was found in the study of (P. C. T. Nguyen et al. 2010). The HQs of total As at all three sampling sites were the highest in comparison with those of other metals. The fact that is that only inorganic As may adversely impact on the human health (Ratnaik 2003), whereas this study focused on total As concentration. Even though the HQs of Cd were smaller

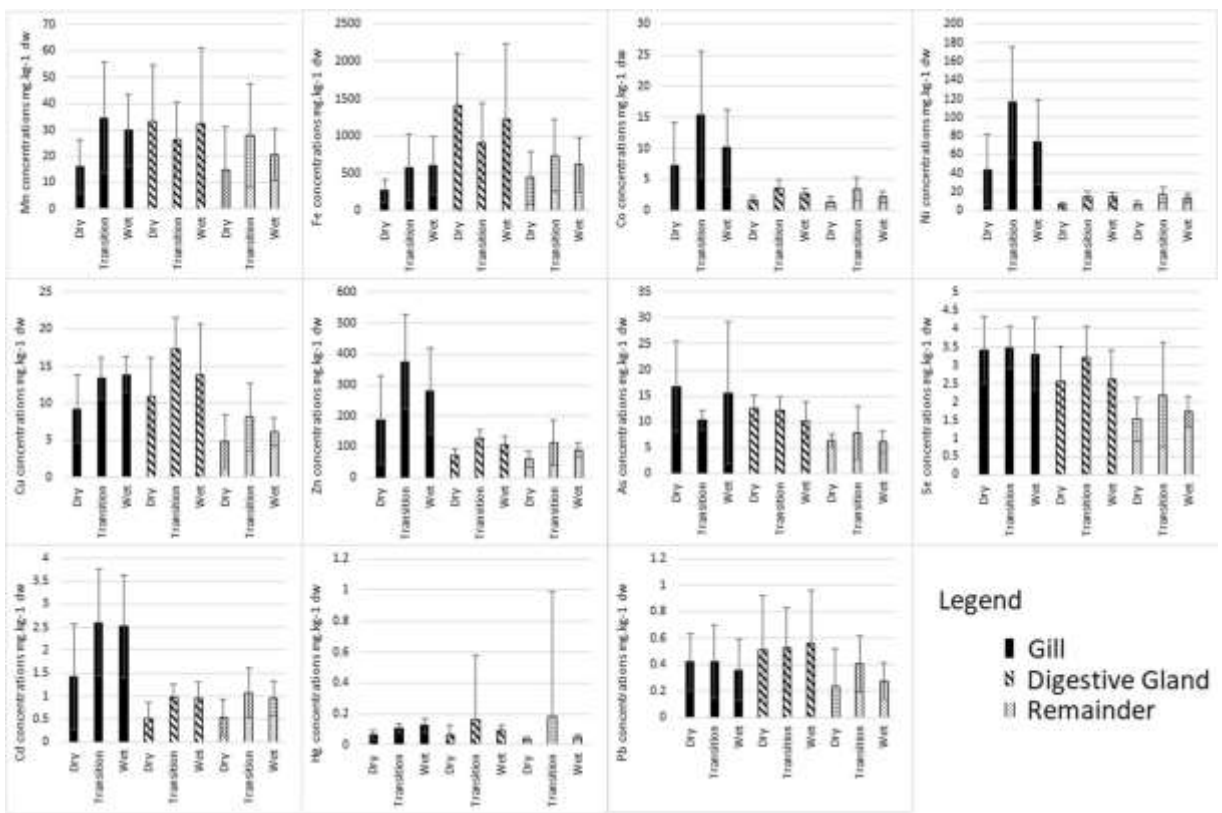


Fig. 3 Seasonal mean metal concentrations in various organs of the hard clam *Meretrix lyrata*

than those of As, the BSAF and BSPMAF values of Cd were the highest. This pointed out that Cd is an element which should be considered as a priority parameter to

assess health risk and food safety for human consumption of hard clams farmed in the shoreline of the SG-DN River Estuary.

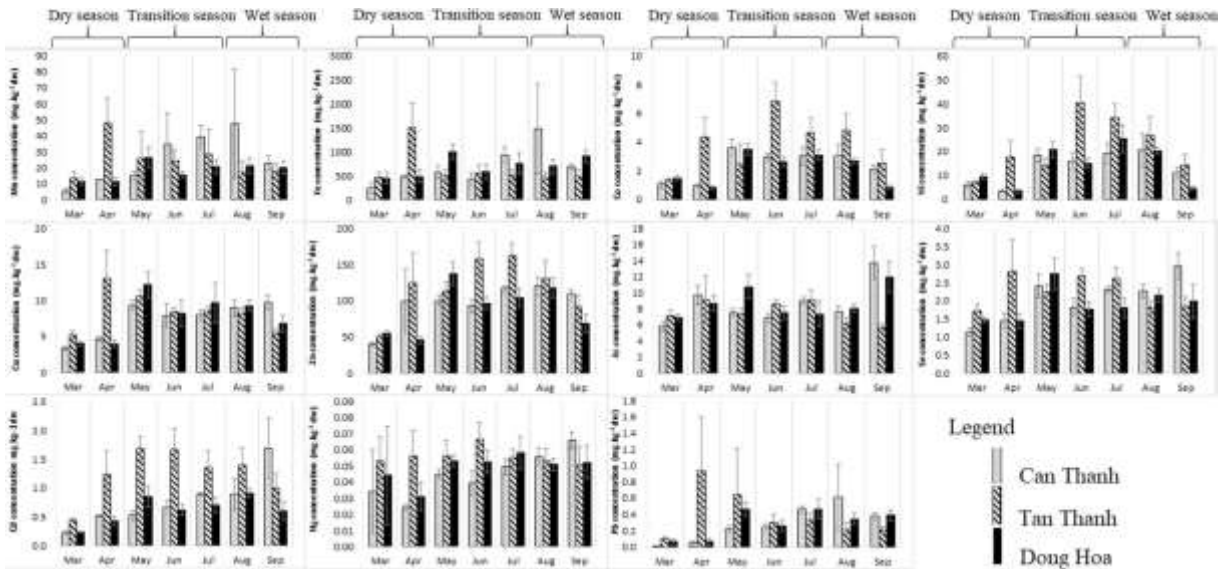


Fig. 4 Mean metal concentrations in *M. lyrata* at the Can Thanh, Tan Thanh, and Dong Hoa sites in 2016

Table 3 The HQs and HIs of trace elements for the local consumer of the hard clam *M. lyrata*

Site	HQ											HI
	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Cd	Hg	Pb	
Can Thanh	0.0026	0.0130	0.0015	0.0097	0.0002	0.0014	0.0418	0.0059	0.0134	0.0012	0.0034	0.094
Dong Hoa	0.0018	0.0119	0.0013	0.0100	0.0002	0.0013	0.0403	0.0053	0.0106	0.0012	0.0033	0.087
Tan Thanh	0.0027	0.0120	0.0025	0.0162	0.0003	0.0017	0.0363	0.0065	0.0224	0.0014	0.0050	0.107

Although the HQ of Hg was low, the BSAF and BSPMAF values of Hg ranged widely. It meant that a few of BSAF and BSPMAF values for Hg were greater than 1. Mercury is one of the strong toxic elements; its presence in *M. lyrata* should be paid attention. Burger et al. (2012) and Olmedo et al. (2013) suggested that Se might protect the organisms from Hg toxicity. Therefore, the Hg/Se molar ratio has been used for Hg toxicity risk assessment. In the case that the ratio is less than 1, an excess of Se concentration in hard clams might protect against Hg toxicity. In this study, the Hg/Se molar ratio in the hard clam samples ranged between 0.0065 and 0.0374. This result indicated that Se may moderate Hg toxicity in *M. lyrata*.

Conclusions

This study showed that the concentrations of studied elements in *M. lyrata* were much dependent on the seasonal and spatial variations. The changes of sea current and precipitation (surface runoff) might be the main effects on the metal concentrations in the hard clams and its living habitats. Based on the obtained results, it is suggested that the hard clam *M. lyrata* should have not been harvested in the transition time due to the high metal concentrations in hard clam tissues. The significant correlations between concentrations of studied trace elements and the physiological state of *M. lyrata* addressed that the CI can be used for prediction of the contamination level of some trace metals in these hard clams. Finally, the obtained HQ and HI values presented a low toxicological risk of trace elements for local consumers and it is claimed that the hard clam *M. lyrata* farmed in all sampling sites is safe for consumption when they are harvested during the study time (March to September 2016).

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Data availability All measurement and analysis data in this manuscript have been conducted by the authors and they could be published without any conflict.

Compliance with ethical standards

Conflict of interest This manuscript presents the original research from the authors. So far, it has been submitted to only EMA Journal for publication.

Code availability Not applicable.

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