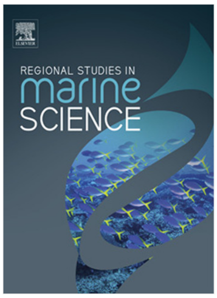


Target gastropods for standardizing the monitoring of tar mat contamination in the Arabian Gulf

Bruno Welter Giraldes, Jassem Abdulaziz K.H. Al-Thani, Samah Dib,
Amanda Engmann, Hamood Abdulla Alsaadi, Ponnumony Vethamony,
Juha Mikael Alatalo, Oguz Yigiterhan

PII: S2352-4855(22)00086-X
DOI: https://doi.org/10.1016/j.rsma.2022.102328
Reference: RSMA 102328

To appear in: *Regional Studies in Marine Science*

Received date : 1 November 2021
Revised date : 4 March 2022
Accepted date : 18 March 2022

Please cite this article as: B.W. Giraldes, J.A.K.H. Al-Thani, S. Dib et al., Target gastropods for standardizing the monitoring of tar mat contamination in the Arabian Gulf. *Regional Studies in Marine Science* (2022), doi: https://doi.org/10.1016/j.rsma.2022.102328.

Target gastropods for standardizing the monitoring of tar mat contamination in the Arabian Gulf

Bruno Welter Giraldes*, Jassem Abdulaziz K. H. Al-Thani, Samah Dib, Amanda Engmann, Hamood Abdulla Alsaadi, Ponnumony Vethamony, Juha Mikael Alatalo, Oguz Yigiterhan**

Environmental Science Centre, Qatar University, P.O. Box: 2713, Doha, Qatar

***Corresponding Author**

Dr. Bruno Welter Giraldes

E-mail: bweltergiraldes@qu.edu.qa / Phone: +974-4403-6859 / Fax: +974-4403-394

****Corresponding Author for Chemical analysis**

Dr. Oguz Yigiterhan[2]

E-mail: oguz@qu.edu.qa / Phone: +974-4403-3956 / Fax: +974-4403-3940

Abstract:

This study proposes a standardization process for the monitoring the level of tar mat contamination in the Arabian Gulf. In the study, we selected target gastropod species and evaluated the ecological and ecotoxicological effects of tar mats on their populations, the bioaccumulation of heavy metals, and these species' potential as bioindicator taxa for tar mat-associated heavy metals. The study was carried out at two sites on the Qatar coast on shoreline rocks, both of which have areas of tar mat coverage and areas without tar mats. The species selected as representative species for the ecoregion were the endemic *Clypeomorus bifasciata persica* (Houbrick, 1985) in the intertidal zone and the *Echinolittorina arabica* (El Assal, 1990) in the supratidal zone. Both are grazers and are niche restricted to hard substrates and daily scraping/grazing on the tar mat deposition zone of the shorelines. The key heavy metal indicators chosen were As, Ba, Cd, Co, Cr, Cu, Fe, Mn, Ni and Zn, and the gastropod species were divided into classes according to their size. Tar mat presence was found to negatively affect both the overall population size of *Clypeomorus* and different size classes, and lead to high levels of assimilation of heavy metals. Tar mat presence also negatively affected different size classes of *Echinolittorina,* where large sizes were found to be most significantly affected. The results also demonstrated that Cu and Ni are the heavy metals most associated with tar mat contamination of this kind. Overall, our results confirmed that grazer gastropods are good bioindicators of tar mat-associated contaminants in shoreline ecosystems. Our study provides the database on the heavy metal contamination of the proposed target gastropods, and offers information that will be relevant for further monitoring and comparisons among threatened coastal areas in the Arabian Gulf.

Keywords: Tarmat, Biomonitoring, Heavy metals, *Echinolittorina arabica, Clypeomorus bifasciata persica*, Arabian Gulf

1. Introduction:

Among the human influences recorded in the Anthropocene, oil spills deserve particular attention for their potential to contaminate coastal ecosystems in the long run (Darwish and Mohtar, 2013; Sheppard et al., 2010; Smith and Zeder, 2013). In the Arabian Gulf, the 1991 Gulf War oil spill represents the main environmental disaster affecting the entire marine ecosystem and associated biodiversity in this semi-enclosed sea (Gerges, 1993; Jones et al., 1998; Price, 1998; Vaughan et al., 2019). After the initial deleterious impact of a spill on natural biodiversity, oil begins to dehydrate and forms 'tar mats' on the shoreline of the affected region (Arekhi et al., 2020; Veerasingam et al., 2020). Given its physical and chemical properties, tar mat adheres to hard substrates (rocks) in the supratidal and intertidal zones of the shoreline (Rajendran et al., 2021). The exact toxicity of spilled oil (consisting of aliphatic and aromatic hydrocarbons) to marine organisms depends on the persistence and bioavailability of specific hydrocarbons. The formation and deposition of tar mats along the Qatar coast, caused by the 1991 oil spill (Rajendran et al., 2021), have been determined by weathering processes such as evaporation, emulsification, dissolution, oxidation, horizontal and vertical movement, and sedimentation.

It is possible, therefore, that the toxic chemicals from the tar mats may have reduced over the past three decades, but may still be contaminating the environment and associated flora and fauna for a long time. The matter of 'how long' is a question that needs to be resolved.

On shorelines around the world, different species have evolved to be able to inhabit specific coastal zones through evolutionary specialization, where isolated congeners are recorded in niche equivalence inhabiting the same zone, but within different ecoregions (Al-khayat and Giraldes, 2020; Spalding et al., 2007). Amongst coastal marine fauna, gastropod assemblages merit particular focus for their high diversity and niche restriction, with groups of species inhabiting specifically hard or soft substrates, and with assemblages living in supratidal, intertidal or subtidal zones (Bosch et al., 1995). Moreover, species which have physiologically and anatomically evolved to inhabit supratidal or intertidal sites may exhibit desiccation avoidance (Reid et al., 2010, 2007). The radula (mouth parts) are adapted to scrape the hard substrate, allowing the animals to graze on the organic layer that covers the hard substrate in each tidal zone (Amini-Yekta et al., 2019; Houbrick, 1985; Ronald Janssen et al., n.d.). As a result, tar mat contamination can be expected to have more significant long-term impacts on grazers in niches restricted to hard substrates in supratidal and high-intertidal sites, because those species inhabit rocks with tar mats and feeding on it on a daily basis.

Gastropods are recognized as valuable for their ability to serve as bioindicators of anthropogenic impacts. For this reason, they are commonly used in environmental assessment programmes and protocols (Smith, 2005), including monitoring of environmental pollution (Baroudi et al., 2020) and heavy metal accumulation (Astani et al., 2012; Krupnova et al., 2018). Assessments are usually based on ecological data and indices of abundance and diversity, in which a variation in abundance of target species may point to a specific anthropogenic pressure (Smith, 2005). Tar mats may affect gastropods by acting as a source of pollutants, which will accumulate in their bodies for a significant period. Heavy metals are considered to be major inorganic pollutants for marine ecosystems because of their persistence, bioaccumulation and natural bio-transfer from low to high trophic levels in the food chain (Bo et al., 2015; Krupnova et al., 2018). These metals pose a direct threat, and may negatively impact aquatic organisms and entire ecosystems with their high toxicity, carcinogenicity, non-biodegradability, persistence and bioaccumulation properties (Feng et al., 2017). Furthermore, tar mats from oil spills are major sources of bio-concentrated heavy metals (Amin et al., 2009; Humood A. Naser, 2013). These contaminants can enter the trophic chain in coastal environments through contaminated water, and pass into soft tissue (e.g. into the gills during respiration) or trophic fractions (e.g. sediment and substrates), contaminating basic trophic levels and transferring to upper trophic levels (Baroudi et al., 2020). As the last consumer in the food chain, the contaminants reach humans when they consume contaminated organisms which have ingested gastropods, either directly or indirectly, through such means as trophic transfer to upper levels of the food web (Gawad, 2018; Yüzereroğlu et al., 2010a). It is therefore safe to assume that grazer gastropods which scrape hard substrates on tar mat-contaminated shorelines during feeding could be a practical target for monitoring heavy metal accumulation.

In the Arabian Gulf, multiple oil spills have been reported in recent decades (Al Maslamani et al., 2018; Arekhi et al., 2020; Darwish and Mohtar, 2013; Sheppard et al., 2010). Consequently, we can expect tar mats to be present along specific stretches of the Qatar coast, covering the hard substrate of the supratidal and intertidal shorelines. In the present study, we evaluated the ecological effect of tar mats on populations of common grazer gastropod species in intertidal and subtidal shoreline zones, and assessed the heavy metal contaminants which had accumulated in those species. The aim of this study is to provide a standardization process for monitoring the level of tar mat contamination in the Arabian Gulf. Selecting target tar-associated heavy metals and selecting dominant and abundant gastropod species in the Gulf which leaves and feed on coastal areas where tar is deposited.

2. Materials and Methods:

2.1. Selection of Target Gastropod Species:

In conducting our literature review, we sought suitable target gastropods which met the following requirements: 1) ecological zoning on supratidal and high-intertidal levels, the shoreline areas where tar mats are deposited; 2) inhabitants of hard-substrate, the main substrate where tar mats stick; 3) grazer on hard substrates as feeding behaviour, eating/scraping the micro-organic layer which covers the rocks and tar mats; 4) species which are abundant, for easy location on shorelines; 5) species which are widespread in the Gulf and north-eastern Indian Ocean, allowing for standardized use of the same species in the Arabian Gulf.

2.2. Biological Field Sampling:

We selected the following two sampling sites on the Qatar coast: Al-Khor (25°40′02.8″N, 51°32′11.6″E), in the mangrove ecosystem and Al-Ruwais (25°08′50.7″N, 51°11′15.6″E), near a coral reef ecosystem (Figure 1A). Each sampling site contained hard substrates with tar mat (Figure 1D, E) and without tar mat (Figure 1F, G), in both the supratidal and intertidal zones. Highlighting that tar mats are irregularly speeded on the rocks and the areas with high concentration of tar mat was considered as the contaminated samples and the rocks without tar coverage considered as the control samples. In March 2020, 10 quadrats (each 0.5 m^2) were placed randomly on the hard substrate in each zone (supratidal, intertidal) (10 on tar mat and 10 on the “clean” rocks) at the two studied sites during low tide (Figure 1B, C), resulting in a total of 40 quadrats. Areas with tar and without tar they were more than 50 meters apart avoiding the bias regarding the displacement of the grazer species. Photos were taken in each quadrat for evaluation of the tar mat coverage (Figure 1D-G). All gastropods of the selected target species within the quadrats were recorded, collected using plastic or Teflon forceps, and placed in plastic re-sealable Ziploc bags. All samples were kept in an icebox, and transported to the laboratory where they were stored in the freezer at -20 °C.

2.3.Ecological Data Analysis:

Sampled specimens were identified in the laboratory using taxonomic references (Bosch et al., 1995; Houbrick, 1985; Reid et al., 2007) to the lowest taxonomic level (i.e. species). Tar mat coverage was analysed by dividing the photo-quadrats into sub-quadrats using Illustrator software. The tar mat coverage in each sub-quadrat was then evaluated as a percentage (%) of quadrat area. Based on the percentage tar mat coverage in the sub-quadrats, each quadrat was categorized as being with tar mat (1-100%) or without tar mat (0%). All the specimens collected in each quadrat were divided into size classes (large, medium, and small), according to species dimension (specific size per species within each size class is described below). The dominant size class at each site and the percentage of tar mat in each quadrat were compared for each species. The influence of tar mats on the population of each species was established by comparing their abundance in quadrats with tar mat and quadrats without tar mat (total population and population in different size classes).

Specimens collected from rocks with tar mat (or species which would presumably graze the microorganism layer that covers the tar mat), and specimens collected on clean rocks without tar mat (or species which would presumably graze the natural microorganism layer, unaffected by tar mat deposits), were separated for the chemical analysis.

2.4. Sample Processing and Chemical Analysis:

The gastropod samples were rinsed in double-distilled deionized (DDI) water, in order to remove any particles, and oven-dried at 55 °C for 24 hours. Samples for analysis were created by measuring 1 g portions (dry weight) into Teflon tubes. The dry samples were subjected to strong acid digestion by adding 5 mL of 16M trace-metal grade nitric acid (HNO_3) on a hot block inside a fume hood, at 95 °C for 30 minutes. Initially, the hot block temperature was gradually raised to 135 °C for 1 hour, then to 150 °C until the sample volume reduced to a few drops. 3 mL of HNO_3 and 20 mL of DDI water were then added to all the samples, which were then heated again until the digest volume was reduced to being particle-free, and a clear solution was obtained. The totally digested samples were transferred to acid-cleaned volumetric flasks, and the final sample volume brought up to 50 mL by adding DDI water at room temperature. The digest solutions were transferred to trace element-certified 50 mL sample vials in Ziploc bags, and kept at room temperature until analysis for the key heavy metal indicators arsenic (As), barium (Ba), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni) and zinc (Zn). These analyses were carried out at the Environmental Science Center Laboratories of Qatar University, which are accredited and certified for ISO17025 analysis by the American Association for Laboratory Accreditation (A2LA). Heavy metal concentrations were determined by means of an inductively coupled plasma-optical emission spectrometer (ICP-OES), using a Perkin Elmer Optima 5300 DV device. Data analysis was performed using Syngistix-ICP software. Duplicate samples, field-sampling replicates, spiked samples and certified reference materials (see below) were digested and analysed twice, for quality control and assurance. Three samples were analysed in duplicate during sample run-off, within the same batch. The correlation coefficient was always greater than 0.9999 for a calibration curve plotted using freshly prepared certified standards of each element. The precision was about 10%. In almost all cases, the average measured values were within the 95% confidence limit of certified values, meaning the accuracy was comparable to, or higher than, the precision. Limit of detection (LoD) and limit of quantitation (LoQ) were also calculated for each element.

For quantification of trace metal content, and to ensure the accuracy of these measurements, three certified reference materials (CRM) were included in the analyses: PACS-3, Nist 2976, and Nist 1643f. PACS-3 is the marine sediment reference material for trace metals, collected in Esquimalt by the National Research Council of Canada (NRC), while Nist 2976 is a freeze-dried mussel tissue (trace elements and methylmercury) reference material, and Nist 1643f is a reference material of trace elements in water. The average recovery of all CRM was 102.72, with percentage error within 5% of the expected value for all elements. Heavy metal concentrations in gastropods were reported using μg/g for all samples.

2.5.Statistical Data Analysis:

All chemical data were analyzed using IBM SPSS statistics software (version 28). In order to evaluate the variability of the heavy metals in the selected gastropod species with the existence of tar and with location. Normality of data was investigated using Shapiro-Wilk test, and the heavy metal data did not follow normal distribution. Therefore, data were log transformed before conducting the multivariate analysis (MANOVA). Tukey post-hoc test was performed to analyze the interaction of heavy metals in the gastropod species with location and tar mat existence. We also performed Pearson correlation to compare the significant correlations of the various heavy metals in gastropods with other metals in order to further investigate the trends within the heavy metals and their influence on gastropod population abundance.

The tar mat coverage of the rock substrate was presented in percentage illustrated on box plots. Population analysis was performed correlating the abundance of each species (per size classes) with their presence on tar mat. Statistical analyses based on F and T-tests were performed to compare the species in quadrats with tar mat and quadrats on clean rock (without tar), with the significance level set at $p<0.05$. Significant results were then plotted in boxplots. Secondary data analysis was performed for Cu, Ni and Zn, which are known contaminants in gastropods after oil spills (Bu-Olayan and Subrahmanyam, 1997), and their concentrations evaluated for the entire population of each species. Aiming illustrate the target contaminants effects on the target gastropod species.

3. Results

3.1. Target species

Previous studies have demonstrated the gastropod biodiversity that inhabits coastal zones in the marine ecosystems in the entire Arabian Gulf (Al-Maslamani et al., 2015; Bosch et al., 1995; Houbrick, 1985; Reid et al., 2007). From these, we identified two target species that met the specified requirements. The first was *Echinolittorina arabica* (El Assal, 1990), a species from the *Littorinidae* family, which exhibit high diversity and physiological adaptation for living and grazing on supratidal hard substrates (Reid et al., 2007). The second was

Clypeomorus bifasciata persica (Houbrick, 1985), from the genus *Clypeomorus* in the family *Cerithiidae* (Houbrick 1983), which are adapted for living and grazing on intertidal hard substrates.

In the study, taxonomic analysis confirmed that the primary species collected in the supratidal zone at the study sites was the endemic *E. arabica* (Figure 2A, B). At the intertidal sites, the hard substrate was completely dominated by *C. bifasciata persica* (Figure 2 C-E). The sizes for *E. arabica* in the selected categories were large (>5 mm), medium (2-5 mm) and small (<2 mm); and for *C. bifasciata persica* they were large (>16 mm), medium (9-16 mm) and small (<9 mm).

3.2. Ecological Influence of Tar mats

At both sites (Al-Khor and Al-Ruwais), the supratidal zone had higher coverage of tar mats than the corresponding intertidal zone (figure 3). Quadrats with tar mat had an average of 70% tar mat coverage in the supratidal zone at both sites, and only 5% and 38% tar mat coverage in the intertidal zone at Al-Khor and Al-Ruwais, respectively. Therefore, the influence of tar mat was expected to be more significant for the gastropods in the supratidal zone, which is also more exposed to the atmosphere, to solar radiation, and to heat.

A total of 3,856 specimens of *E. arabica* were recorded in quadrats in the supratidal zone, with an average of 120 specimens per m^2. Regarding the influence of tar mat deposition on *E. arabica*, a total of 1,619 specimens were found in quadrats with tar mat and 2,227 specimens in quadrats without tar mat, with an average of 101 and 140 specimens per m^2, respectively ($p=0.369$) (Figure 4A). Comparing the proportion of specimens withing each size classes (Figure 4B) the areas with tar mats have more smaller specimens and less larger specimens. Suggesting a recent occurrence of massive recruitment in the populations of this species. Differences between the populations of *E. arabica* in quadrats with and without tar (rock) were mainly found in the larger size classes (Figure 4C), with an average of 4 and 8.4 specimens in quadrats with and without tar mat, respectively ($p=0.0515$; $F=5.14$); medium and small specimens were also more abundant on rocks, but those differences were not significant ($p=0.102$; $F=1.99$) and ($p=0.499$; $F=1.8$) respectively (Figure 4D,E).

In the intertidal zone 1,347 specimens of *C. bifasciata persica* were recorded, with an average of 33.7 specimens per m^2. In comparing *C. bifasciata persica* on tar mat and on rocks without tar, we found a statistically significant difference ($p=0.0298$; $F=1.8$), with an average of 31 specimens per m^2 tar mat and 83 specimens per m^2 in quadrats without tar (Figure 4F). Regarding sizes, on rocks with tar we found fewer large and small specimens, with higher dominance of medium size animals (Figure 4G). In large animals there was an average of 6.2 specimens per m^2 on rocks without tar and 2.3 on tar (Figure 4H) ($p=0.506$; $F=2.5$); on medium an average of 69.3 specimens per m^2 on rocks without tar and 30.2 on tar (Figure 4I) ($p=0.0592$; $F=7.2$); and on small sizes, an average of 10.5 specimens per m^2 on rocks without tar and 2.4 on tar (Figure 4J) ($p=0.098$; $F=7.9$).

3.3. Heavy Metal Contamination

For heavy metal contamination analysis, we used and processed a total of 1,339 specimens of *Echinolittorina* and 262 specimens of *Clypeomorus*. All representative specimens were found within the 40 quadrats. The concentrations of certain heavy metals in the two target gastropod species were found to increase with the presence of tar mat in their habitat (Fig. 4), with mean accumulated metal concentrations in samples decreasing in the order Zn > Cu > Mn > Ni > Cd > Cr. In Al-Khor, the mean concentrations of these heavy metals in the gastropod *C. bifasciata persica* in tar mat-contaminated areas followed the order Fe > Zn > Mn > Cu > As > Ni > Ba > Cr > Cd > Co, while for *E. arabica*, it followed the order Fe > Zn > Cu > Mn > As > Ba > Ni > Cd > Cr > Co. In Al-Ruwais, meanwhile, the mean concentrations of the heavy metals in tar mat-contaminated areas followed the order Fe > Zn > Cu > Mn > As > Ni > Ba > Cr > Cd > Co for *C. bifasciata persica*, and Fe > Zn > Cu > As > Mn > Ni > Ba > Cr > Cd > Co for *E.*

arabica. The mean concentrations (and standard deviations) of As, Ba, Cd, Co, Cr, Cu, Fe, Mn, Ni and Zn are shown in the supplementary material.

There were some differences in the concentrations of heavy metals, both between the sampling sites and between quadrats with and without tar mat. The concentrations of Ba, Cd, Cr, Cu, Fe, Mn, Ni and Zn differed according to whether tar mat was present (Figure 5 and supplementary material). In the gastropod samples, we observed pronounced metal enrichment in the order Zn > Cu > Mn > Ni > Cd > Cr. We also observed a marked difference in concentrations between species in Al-Khor and Al-Ruwais, indicating differential accumulation in the species at the two sites. There were also differences in heavy metal bioaccumulation patterns between the species and sites. Some heavy metals were found in higher concentrations in Al-Khor, and others in Al-Ruwais. Cd, Cr and Zn, for example, were found in higher concentrations in *C. bifasciata persica* at Al-Khor, particularly in areas contaminated by tar mat. In tar mat-contaminated areas at Al-Ruwais, Ni was found in higher concentrations in both species.

The intertidal *C. bifasciata persica*, in general was found to be the species of gastropods with the most enriched heavy metals found in their bodies, especially in Al-Khor; with high concentrations of As, Cd, Cr, Cu and Zn in their bodies in Al-Khor when they were exposed to tar mats, while they were found to have high concentrations of Cd, Cr, Cu, and Ni in Al-Ruwais (Supplementary material).

Correlation analysis was performed on the concentrations of the heavy metals, seeking trends in the concentrations of metals and their association with other metals and the abundance of the gastropod populations, in gastropods which inhabit the tar mat areas. Table 2 shows the ensuing correlation matrix (Pearson) for tar mat-contaminated areas in Al-Khor. Pearson correlation analysis revealed strong and significant relationships between some metals, with different trends at the two sites. At Al-Khor, the metals were mainly positively correlated with each other. As and Cu ($R^2 = 0.96$), for example, showed a strong correlation ($p < 0.01$) in areas with tar mats, as did Ba, Cd and Fe (R^2=0.97, 0.90, 0.98). Additionally, the presence of heavy metals in the gastropod bodies was found to have some influence on the gastropod population. This was confirmed by the correlation analysis of heavy metals vs. abundance of the population (Table 3). While only two metals were shown to significantly correlate ($R^2 = 0.9$; $p < 0.05$), which were Cu and Fe, with the population abundances in Al-Khor, none were found in Al-Ruwais. In figure 5 it is highlighted the higher concentration of tar-associated heavy metals Cu and Ni on the target gastropods recorded inhabiting the rocks covered by tar mat.

4. Discussion:

4.1. Heavy Metal Contamination:

The sediment and food sources of the targeted grazer gastropods were certainly contaminated with heavy metals due to the presence of petroleum hydrocarbons from tar, which are known to be major sources of specific tar-associated heavy metals (El-Sorogy and Youssef, 2015; Humood A. Naser, 2013; Veerasingam et al., 2020). Previous studies have found Zn, Cu and Mn to be the most dominant and highly concentrated metals in the bodies of gastropods (Astani et al., 2012; Bu-Olayan and Thomas, 2001; Yüzereroğlu et al., 2010a), and the present study also has recorded comparable results for the oil-contaminated shores of the Arabian Gulf. With the proposed target gastropod shown a significant bioaccumulation of tar-associated heavy metals (As, Cu, Ba, Cd, Cr, Zn).

On the other side, the studied gastropods display higher concentration of some other metals even without the presence of tar. Suggesting an introductory pathway from other contaminant sources. For instance, Cu and Fe were much higher in Al-Khor, a bay area near a small fishing port located close to the largest urban centre at Qatar, a known polluted marine urban zone (Liu et al., 2021). Receiving other anthropogenic inputs of heavy metals. Other example is the high concentrations of Mn that is naturally incorporated into the shell of gastropods, replacing the calcium in $CaCO_3$, and is was previously detected in high concentrations in molluscs in the Arabian Gulf region (El-Sorogy and Youssef, 2015). Even in areas without tar, Fe was also recorded in high concentrations in the target gastropods. Highlighting that Iron can originate from the dust storms which occur frequently in the Arabian Gulf (Yigiterhan et al., 2020), and enter sediments by deposition of dust. This could lead to Fe accumulation in the gastropods' food sources (e.g., macroalgae), and subsequently to Fe accumulation in the gastropods themselves, after grazing on their food sources.

Regarding the correlation of size classes and metal contamination smaller gastropods had displayed higher bioaccumulated concentrations of heavy metals in this study. Contradicting previous study that recorded a positive correlation between body size and tissue metal concentrations (Al-Ansari et al., 2017; Elsayed et al., 2020). However, within the population of a same species, the enrichment of heavy metals in the body of smaller gastropods could be due to differences in metabolic rate, physiological response and exposure time, given that smaller gastropods engage in less movement than larger ones (Catsiki et al., 1994). However, considering that Potentially Toxic Elements (PTEs) as the mentioned heavy metal accumulation on specimens grazing on tar and that PTEs in high concentrations can cause visible physical deformities of the calcite shell (Amao et al., 2019), it is possible that species grazing on tarmat simply die before reaching large sizes or that the contamination interfere in the optimal growing of this gastropods.

Despite the multiple sources of contaminants, recent studies show that most tar mats had originate with the 1991 Gulf War oil spill (Arekhi et al., 2020) and as recorded here, the main heavy metals accumulated in molluscs after the spill were Ni, Cu, and Zn (Bu-Olayan and Subrahmanyam, 1997). Corroboration with the hypothesis that these tar-associated heavy metals can be used for monitoring the contamination level of the entire marine environment using the proposed target gastropods. The results also suggest that old tar mats are still present along the coast of Qatar (Arekhi et al., 2020), and certainly will continue to contaminate ecosystems and result in bioaccumulation in marine flora and fauna.

4.2. Influence of Tar mats on Gastropod Ecology

The size classes observed in this study indicate the potential for population plasticity in the target species. As discussed above, heavy metal contamination was found to be higher in smaller specimens and in an ecological point of view this might be relate to their displacement, their recruitment, and their growing rates. In a given marine gastropod population, recruitment is usually represented by large numbers of small specimens appearing seasonally in the population, while larger specimens are usually older representatives of the same population (Richardson et al., 2005). On this basis, and given the fact that environmental influences and harsh conditions (pollutants) can influence the growth of molluscs (Zdelar et al., 2018), the larger number of small specimens recorded here may being just reflecting a recent recruitment or a large mortality of older specimens due the contamination. The displacement potential is a relevant factor considering that larger animals have better fitness for avoiding contaminated rocks. However, considering that we found during the long low tide period many animals resting on the tar mat, we can assume that those gastropods are adapted to feed and live with tar mats covering their natural niche. Whatever the reason, our ecological and contaminant results indicate an influence of tar mat on the abundance (and the size classes) of each species, providing a foundation for future monitoring research on the studied area.

As expected, both species assimilated heavy metal contaminants when grazing on tar mat and in areas surrounded by tar mat (as discussed above). In addition, the species more exposed to water exhibited higher contamination rates, suggesting that tar mats continue to contaminate the environment (sediment, substrate, and water) for a long time, thereby affecting the surrounding organisms. One unexpected finding, based on the recorded abundance of species inside and outside tar mat areas, was that tar mat had a more significant impact on the population of *C. bifasciata persica* than on the population of *E. arabica*, even though the tar mat concentration was much higher in the supratidal zone, the domain of *E. arabica*. In the intertidal zone, the domain of *C. bifasciata persica*, tidal oscillations are constantly washing the hard substrate, and the organisms are constantly exposed to water. The abundance results, which found significantly more *C. bifasciata persica* specimens in areas without tar mat and uncovered no significant difference for *E. arabica*, indicate that contaminants in water can directly enter the soft tissue of *C. bifasciata persica* (Baroudi et al., 2020; Bu-Olayan and Thomas, 2001; Yüzereroğlu et al., 2010b). Contradicting the previous hypothesis (discussed below) and suggesting that the leaching of tar by seawater and the exposed time to this contaminated coastal water is an important introductory pathway for tar-associated heavy metals, and not only the ingestion of tar particles during the grazing/feeding behaviour and the contamination of their food sources as was previously expected.

4.3. Efficiency of Gastropods as Bioindicators of Tar mat Contamination

The results obtained suggest that the intertidal gastropod species studied can indeed be used as bioindicators of heavy metal contamination, as has been previously suggested (Cardoso et al., 2013; Sáez et al., 2012). By combining population ecology studies with a contamination assessment, we were able to better illustrate the ecological problem. Gastropods are already considered to be efficient bioindicators of several other contamination sources (Amin et al., 2009; Baroudi et al., 2020; Bu-Olayan and Subrahmanyam, 1997; Catsiki et al., 1994; El-Sorogy and Youssef, 2015; Krupnova et al., 2018; H. A. Naser, 2013), and this study demonstrated that this title can now be extended to include tar mat contaminants.

Both target species (*E. arabica* and *C. bifasciata persica*) are highly abundant and widespread in the Gulf region (Al-Maslamani et al., 2015; Bosch et al., 1995). Despite significant accumulation of heavy metals and niche restriction in the supratidal zone, where tar mats are deposited, the endemic species *E. arabica* showed less contamination than the endemic subspecies *C. bifasciata persica.* This suggests that *Clypeomorus* species, abundant intertidal grazers with representatives in several ecoregions in the Indo-Pacific (Houbrick, 1985), would be better-suited to further studies and comparisons of tar mat contamination in different regions and ecoregions.

5. Conclusion

The selected target species can be found in abundant quantities in all regions of the Gulf, occupying virtually all hard substrates in supratidal and intertidal zones. These zones are easy to access, facilitating the species' collection by scientists and their use for chemical analysis and pollution level assessment. This study provides a reliable database on the tar mat contamination of grazer gastropod species in intertidal and supratidal zones and offers information that will be relevant for further monitoring and comparisons among threatened coastal areas in the Arabian Gulf. Additionally, the study suggests more straightforward alternatives for standardizing information on long-term effects of oil spills. In addition, and in contrast to what had been hypothesized, the grazer gastropod which inhabits the supratidal zone with higher tar mat deposition was less contaminated than the gastropod from the intertidal zone. This suggests that the leaching of tar by seawater and the exposure to this water in the intertidal zone has a direct impact on heavy metal accumulation.

Acknowledgments

The authors of this research would like to acknowledge and thank Prof. Hamad A. Al Saad, the Director of the Environmental Science Center (ESC), Qatar University, for his encouragement and continuous support. We also would like to thank the Technical Manager, Mrs. Hajer

Ammar Al Naimi, and the technical staff for their dedicated work, especially, Mr. Ahmed Helmy, Mr. Caesar Flonasca Sorino, Mrs. Marwa Mustafa Al-Azhari, Mr. Muhammed Rafeek Punthiyakath, Mr. Mohammed AbdulKader and Mr. Muhammed Kunhi Pindath during sampling, preparation, pre-treatment and analysis. This research was supported by the Qatar Petroleum through the project of QU (QUEX-ESC-QP-TM-18/19).

5. References

Al-Ansari, E.M.A.S., Abdel-Moati, M.A.R., Yigiterhan, O., Al-Maslamani, I., Soliman, Y., Rowe, G.T., Wade, T.L., Al-Shaikh, I.M., Helmi, A., Kuklyte, L., Chatting, M., Al-Ansi Al-Yafei, M.A., 2017. Mercury accumulation in Lethrinus nebulosus from the marine waters of the Qatar EEZ. Mar. Pollut. Bull. 121, 143–153. doi:10.1016/J.MARPOLBUL.2017.04.024

Al-khayat, J., Giraldes, B.G., 2020. Burrowing crabs in arid mangrove forests on the southwestern Arabian Gulf: ecological and biogeographical considerations. Reg. Stud. Mar. Sci. (Publishin.

Al-Maslamani, I., Al-Masdi, A., Smyth, D.M., Chatting, M., Obbard, J., Giraldes, B.W., 2015. Baseline monitoring gastropods in the intertidal zone of Qatar - target species and bioindicators for hyper-thermic and hyper- saline Conditions. Int. J. Res. Stud. Biosci. 3, 62–72.

Al Maslamani, I., Smyth, D., Giraldes, B., Chatting, M., Al Mohannadi, M., Le Vay, L., 2018. Decline in oyster populations in traditional fishing grounds; is habitat damage by static fishing gear a contributory factor in ecosystem degradation? J. Sea Res. doi:10.1016/j.seares.2018.07.006

Amao, A.O., Qurban, M.A., Kaminski, M.A., Joydas, T. V., Manikandan, P.K., Frontalini, F., 2019. A baseline investigation of benthic foraminifera in relation to marine sediments parameters in western parts of the Arabian Gulf. Mar. Pollut. Bull. 146, 751–766. doi:10.1016/J.MARPOLBUL.2019.06.072

Amin, B., Ismail, A., Arshad, A., Yap, C.K., Kamarudin, M.S., 2009. Gastropod Assemblages as Indicators of Sediment Metal Contamination in Mangroves of Dumai, Sumatra, Indonesia. Water. Air. Soil Pollut. 201, 9–18. doi:10.1007/s11270-008-9922-6

Amini-Yekta, F., Shokri, M.R., Maghsoudlou, A., Rajabi-Maham, H., 2019. Intertidal gastropod assemblages shaped by key environmental variables across the northern Persian Gulf and the Gulf of Omanss. Mar. Ecol. 40. doi:10.1111/maec.12545

Arekhi, M., Terry, L.G., John, G.F., Al-Khayat, J.A., Castillo, A.B., Vethamony, P., Clement, T.P., 2020. Field and laboratory investigation of tarmat deposits found on Ras Rakan Island and northern beaches of Qatar. Sci. Total Environ. 735, 139516. doi:10.1016/J.SCITOTENV.2020.139516

Astani, M., Vosoughi, A.R., Salimi, L., Ebrahimi, M., 2012. Comparative study of heavy metal (Cd, Fe, Mn, and Ni) concentrations in soft tissue of gastropod Thais mutabilis and sediments from intertidal zone of Bandar. Adv. Environ. Biol. 6, 319–326.

Baroudi, F., Al Alam, J., Fajloun, Z., Millet, M., 2020. Snail as sentinel organism for monitoring the environmental pollution; a review. Ecol. Indic. 113, 106240. doi:10.1016/J.ECOLIND.2020.106240

Bo, L., Wang, D., Li, T., Li, Y., Zhang, G., Wang, C., Zhang, S., 2015. Accumulation and risk assessment of heavy metals in water, sediments, and aquatic organisms in rural rivers in the Taihu Lake region, China. Environ. Sci. Pollut. Res. 22, 6721–6731.

doi:10.1007/s11356-014-3798-3

Bosch, D.T., Dance, S.P., Moolenbeek, R.G., Oliver, P.G., 1995. Seashells of eastern Arabia. Dubai: Motivate publishing.

Bu-Olayan, A.H., Subrahmanyam, M.N.V., 1997. Accumulation of copper, nickel, lead and zinc by snail, Lunella coronatus and pearl oyster, Pinctada radiata from the Kuwait coast before and after the gulf war oil spill. Sci. Total Environ. 197, 161–165. doi:10.1016/S0048-9697(97)05428-4

Bu-Olayan, A.H., Thomas, B. V., 2001. Heavy Metal Accumulation in the Gastropod, Cetithium Scabridum L., from the Kuwait Coast. Environ. Monit. Assess. 68, 187–195. doi:10.1023/A:1010707826081

Cardoso, P.G., Sousa, E., Matos, P., Henriques, B., Pereira, E., Duarte, A.C., Pardal, M.A., 2013. Impact of mercury contamination on the population dynamics of Peringia ulvae (Gastropoda): Implications on metal transfer through the trophic web. Estuar. Coast. Shelf Sci. 129, 189–197. doi:10.1016/J.ECSS.2013.06.002

Catsiki, V.A., Bei, F., Nicolaidou, A., 1994. SIZE DEPENDENT METAL CONCENTRATIONS IN TWO MARINE GASTROPOD SPECIES, NETHERLANDS JOURNAL OF AQUATIC ECOLOGY.

Darwish, M.A., Mohtar, R., 2013. Qatar water challenges. Desalin. Water Treat. 51, 75–86. doi:10.1080/19443994.2012.693582

El-Sorogy, A.S., Youssef, M., 2015. Assessment of heavy metal contamination in intertidal gastropod and bivalve shells from central Arabian Gulf coastline, Saudi Arabia. J. African Earth Sci. 111, 41–53. doi:10.1016/J.JAFREARSCI.2015.07.012

Elsayed, H., Yigiterhan, O., Al-Ansari, E.M., Al-Ashwel, A.A., Elezz, A.A., Al-Maslamani, I.A., 2020. Methylmercury bioaccumulation among different food chain levels in the EEZ of Qatar (Arabian Gulf). Reg. Stud. Mar. Sci. 37, 101334.

Feng, J., Zhu, X., Wu, H., Ning, C., Lin, G., 2017. Distribution and ecological risk assessment of heavy metals in surface sediments of a typical restored mangrove–aquaculture wetland in Shenzhen, China. Mar. Pollut. Bull.

Gawad, A.S.S., 2018. Acute toxicity of some heavy metals to the fresh water snail, Theodoxus niloticus (Reeve, 1856). Egypt. J. Aquat. Res. 44, 83–87. doi:10.1016/J.EJAR.2018.06.004

Gerges, M., 1993. On the impacts of the 1991 Gulf War on the environment of the region: general observations. Mar. Pollut. Bull. 27, 305–314.

Houbrick, R.S., 1985. Genus Clypeomorus Jousseaume (Cerithiidae : Prosobranchia). Smithson. Contrib. to Zool.

Jones, D., Plaza, J., Watt, I., Bulletin, M.A.S., 1998. Long-term (1991–1995) monitoring of the intertidal biota of Saudi Arabia after the 1991 Gulf War oil spill. Mar. Pollut. Bull. 36, 472–489.

Krupnova, T.G., Mashkova, I. V., Kostryukova, A.M., Schelkanova, E.E., Gavrilkina, S. V., 2018. Gastropods as potential biomonitors of contamination caused by heavy metals in South Ural lakes, Russia. Ecol. Indic. 95, 1001–1007. doi:10.1016/J.ECOLIND.2017.12.005

Liu, L., Aljathelah, N.M., Hassan, H., Giraldes, B.W., Leitão, A., Bayen, S., 2021. Targeted and suspect screening of contaminants in coastal water and sediment samples in Qatar. Sci. Total Environ. 774, 145043. doi:10.1016/J.SCITOTENV.2021.145043

Naser, Humood A., 2013. Assessment and management of heavy metal pollution in the marine environment of the Arabian Gulf: A review. Mar. Pollut. Bull. 72, 6–13. doi:10.1016/J.MARPOLBUL.2013.04.030

Naser, H. A., 2013. Assessment and management of heavy metal pollution in the marine environment of the Arabian Gulf: A review. Mar. Pollut. Bull. 72, 6–13. doi:DOI 10.1016/j.marpolbul.2013.04.030

Price, A., 1998. Impact of the 1991 Gulf War on the coastal environment and ecosystems: current status and future prospects. Environ. Int. 24, 91–96.

Rajendran, S., Al-Khayat, J.A., Veerasingam, S., Nasir, S., Vethamony, P., Sadooni, F.N., Al-Kuwari, H.A.-S., 2021. WorldView-3 mapping of Tarmat deposits of the Ras Rakan Island, Northern Coast of Qatar: Environmental perspective. Mar. Pollut. Bull. 163, 111988. doi:10.1016/J.MARPOLBUL.2021.111988

Reid, D.G., Dyal, P., Williams, S.T., 2010. Global diversification of mangrove fauna: a molecular phylogeny of Littoraria (Gastropoda: Littorinidae). Mol. Phylogenet. Evol. 55, 185–201. doi:10.1016/j.ympev.2009.09.036

Reid, D.G., Habe, E., Littorinidae, G., Ocean, I.P., 2007. The genus Echinolittorina. Zootaxa.

Richardson, C.A., Kingsley-Smith, P.R., Seed, R., Chatzinikolaou, E., 2005. Age and growth of the naticid gastropod Polinices pulchellus (Gastropoda: Naticidae) based on length frequency analysis and statolith growth rings. Mar. Biol. 148, 319–326. doi:10.1007/s00227-005-0072-8

Ronald Janssen, B., Zuschin, M., Baal, C., n.d. Serie A 373-509 Wien.

Sáez, C.A., Pérez-Matus, A., Lobos, M.G., Oliva, D., Vásquez, J.A., Bravo, M., 2012.

Environmental assessment in a shallow subtidal rocky habitat: approach coupling chemical and ecological tools. Chem. Ecol. 28, 1–15. doi:10.1080/02757540.2011.619529

Sheppard, C., Al-Husiani, M., Al-Jamali, F., Al-Yamani, F., Baldwin, R., Bishop, J., Benzoni, F., Dutrieux, E., Dulvy, N.K., Durvasula, S.R. V., Jones, D.A., Loughland, R., Medio, D., Nithyanandan, M., Pilling, G.M., Polikarpov, I., Price, A.R.G., Purkis, S., Riegl, B., Saburova, M., Namin, K.S., Taylor, O., Wilson, S., Zainal, K., 2010. The Gulf: A young sea in decline. Mar. Pollut. Bull. 60, 13–38. doi:10.1016/j.marpolbul.2009.10.017

Smith, B.D., Zeder, M.A., 2013. The onset of the Anthropocene. Anthropocene 4, 8–13. doi:10.1016/j.ancene.2013.05.001

Smith, S.D.A., 2005. Rapid assessment of invertebrate biodiversity on rocky shores: Where there's a whelk there's a way. Biodivers. Conserv. 14, 3565–3576. doi:10.1007/s10531-004-0828-3

Spalding, M.D., Fox, H.E., Allen, G.R., Davidson, N., Ferdaña, Z.A., Finlayson, M., Halpern, B.S., Jorge, M.A., Lombana, A., Lourie, S.A., Martin, K.D., McManus, E., Molnar, J., Recchia, C.A., Robertson, J., 2007. Marine ecoregions of the world: A bioregionalization of coastal and shelf areas. Bioscience 57, 573–583. doi:10.1641/B570707

Vaughan, G.O., Al-Mansoori, N., Burt, J.A., 2019. The Arabian Gulf, in: Sheppard, C. (Ed.), World Seas: An Environmental Evaluation. Academic Press, pp. 1–23. doi:10.1016/B978-0-08-100853-9.00001-4

Veerasingam, S., Al-Khayat, J.A., Haseeba, K.P., Aboobacker, V.M., Hamza, S., Vethamony, P., 2020. Spatial distribution, structural characterization and weathering of tarmats along the west coast of Qatar. Mar. Pollut. Bull. 159, 111486. doi:10.1016/J.MARPOLBUL.2020.111486

Yigiterhan, O., Al-Ansari, E.M., Nelson, A., Abdel-Moati, M.A., Turner, J., Alsaadi, H.A., Paul, B., Al-Maslamani, I.A., Mehsin, A.-A., Al-Yafei, A., Murray, J.W., 2020. Trace element composition of size-fractionated suspended particulate matter samples from the Qatari Exclusive Economic Zone of the Arabian Gulf: the role of atmospheric dust. Biogeosciences 17, 381–404.

Yüzereroğlu, T.A., Gök, G., Coğun, H.Y., Firat, Ö., Aslanyavrusu, S., Maruldalı, O., Kargin, F., 2010a. Heavy metals in Patella caerulea (Mollusca, Gastropoda) in polluted and non-polluted areas from the Iskenderun Gulf (Mediterranean Turkey). Environ. Monit. Assess. 167, 257–264.

Yüzereroğlu, T.A., Gök, G., Çoğun, H.Y., Firat, Ö., Aslanyavrusu, S., Maruldalı, O., Kargin, F., 2010b. Heavy metals in Patella caerulea (Mollusca, Gastropoda) in polluted and non-polluted areas from the Iskenderun Gulf (Mediterranean Turkey). Environ. Monit. Assess. 167, 257–264. doi:10.1007/s10661-009-1047-x

Zdelar, M., Mullin, F., Cheung, C., Yousif, M., Baltaretu, B., Stone, J.R., 2018. Pollution-, temperature- and predator-induced responses in phenotypically plastic gastropod shell traits. Molluscan Res. 38, 34–40. doi:10.1080/13235818.2017.1358587

Figure 1. Illustration of the study area and environment, highlighting (A) the location of Al-Khor and Al-Ruwais; (B and C) the large intertidal area during low tide where the species were sampled; the quadrats in areas (D) fully covered by tarmat, (E) partially covered by tarmat, (F) without tarmat, and (G) without tarmat and with a microbial mat

Figure 2. Details of *E.arabica* (A) on the tarmat layer that covers the rocks and (B) on the rock in the supratidal zone; and *C. bifasciata persica* (C) on tarmat (D) close-up and (E) on rock (without tarmat).

Figure 3. Tar mat coverage (%) in the quadrats recorded in the intertidal and supratidal zone; the quadrats considered as covered by tar on the present study.

Figure 4. Abundance of *E.arabica* (A-E) and *C. bifasciata persica* (F-J) on tarmat and on rock (without tarmat); considering the number of specimens on entire population (A, F), and on the different size classes, Large (C, H), Medium (D, I) and Small (E, J), and the dominance (%) of each size classes (B, G).

Figure 5. Average (± standard error) of the heavy metals: As, Ba, Zn (A); Cd, Co, Cr (B); Cu, Mn, Ni (C) in *C. bifasciata persica* and *E. arabica* gastropod species in Al-Khor and Al-Ruwais. The averages of heavy metals are displayed according to tar existence in the aforementioned sampling locations, without tar (top) and with tar (bottom).

Figure 6. Concentrations of the heavy metals (A) Cu and (B) Ni [μg/g] in the populations of *C. bifasciata persica* in Al-Ruwais, comparing quadrats with tarmat coverage and quadrats without. The same comparison is then made for Cu [μg/g] concentrations in the populations of *E.arabica* in (C) Al-Ruwais and (D) Al-Khor.

Figure 1

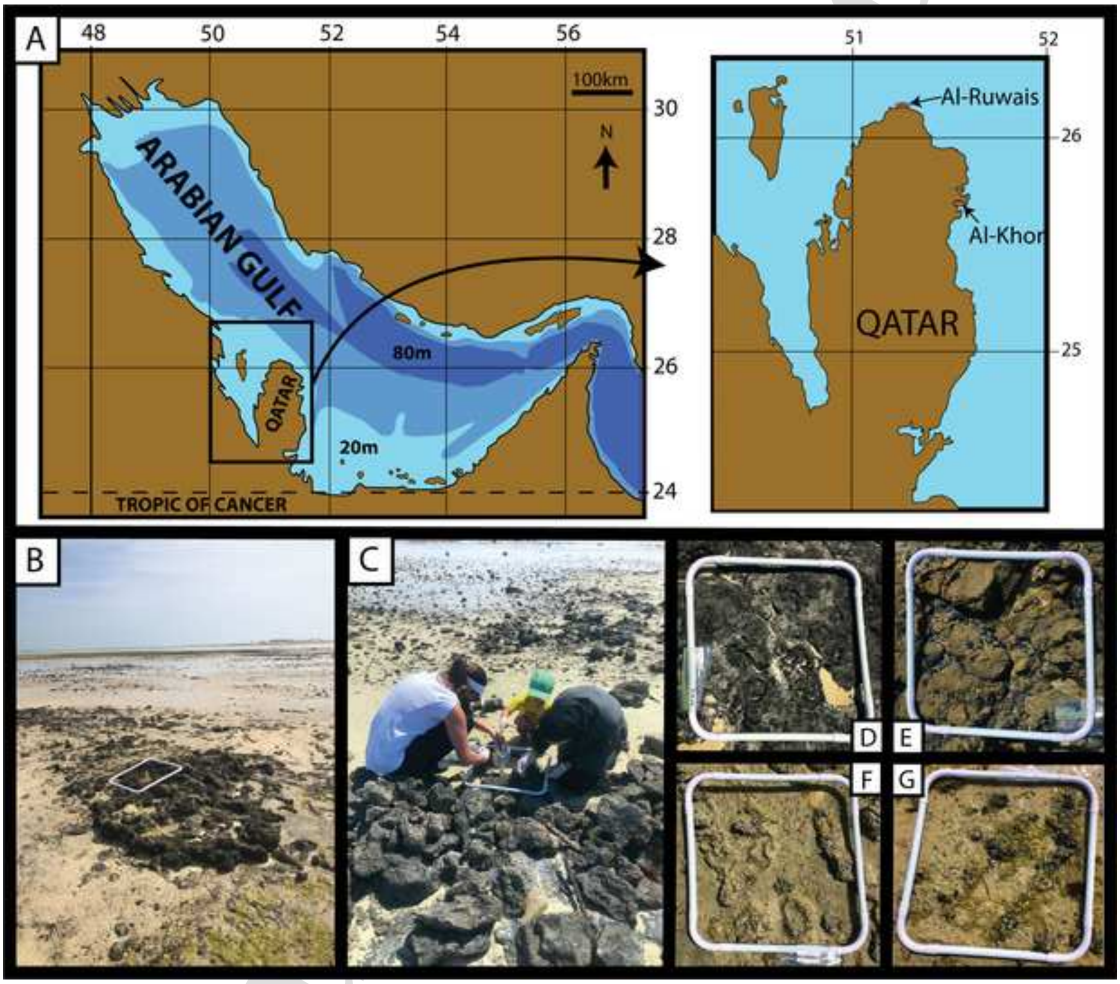

A
48
50
52
54
56
100km
30
28
26
24
N
ARABIAN GULF
80m
20m
QATAR
TROPIC OF CANCER
51
52
Al-Ruwais
Al-Khor
26
25
QATAR
B
C
D
E
F
G

Figure 2

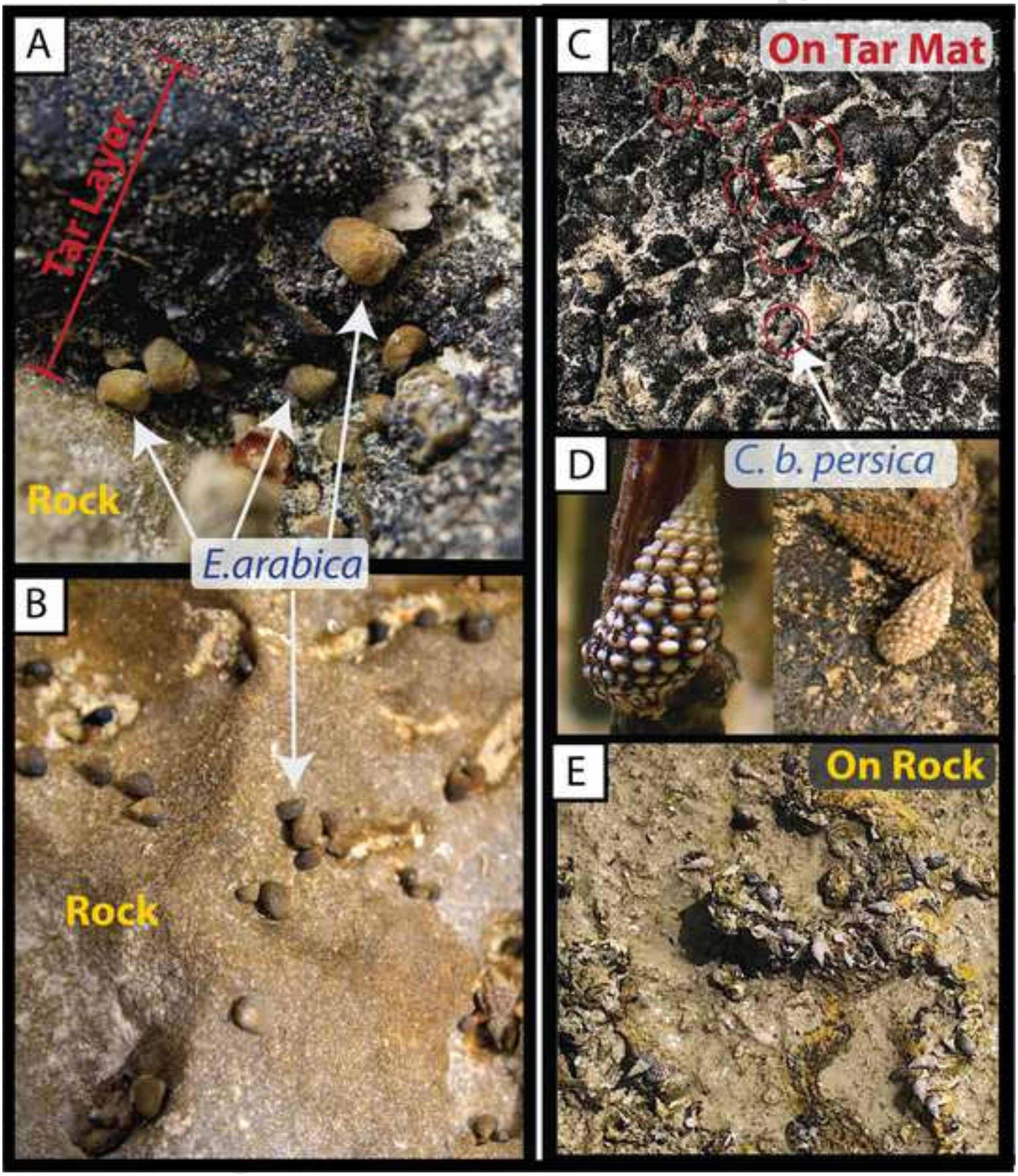

A
Tar Layer
Rock
E.arabica
B
Rock
C
On Tar Mat
D
C. b. persica
E
On Rock

Figure 3

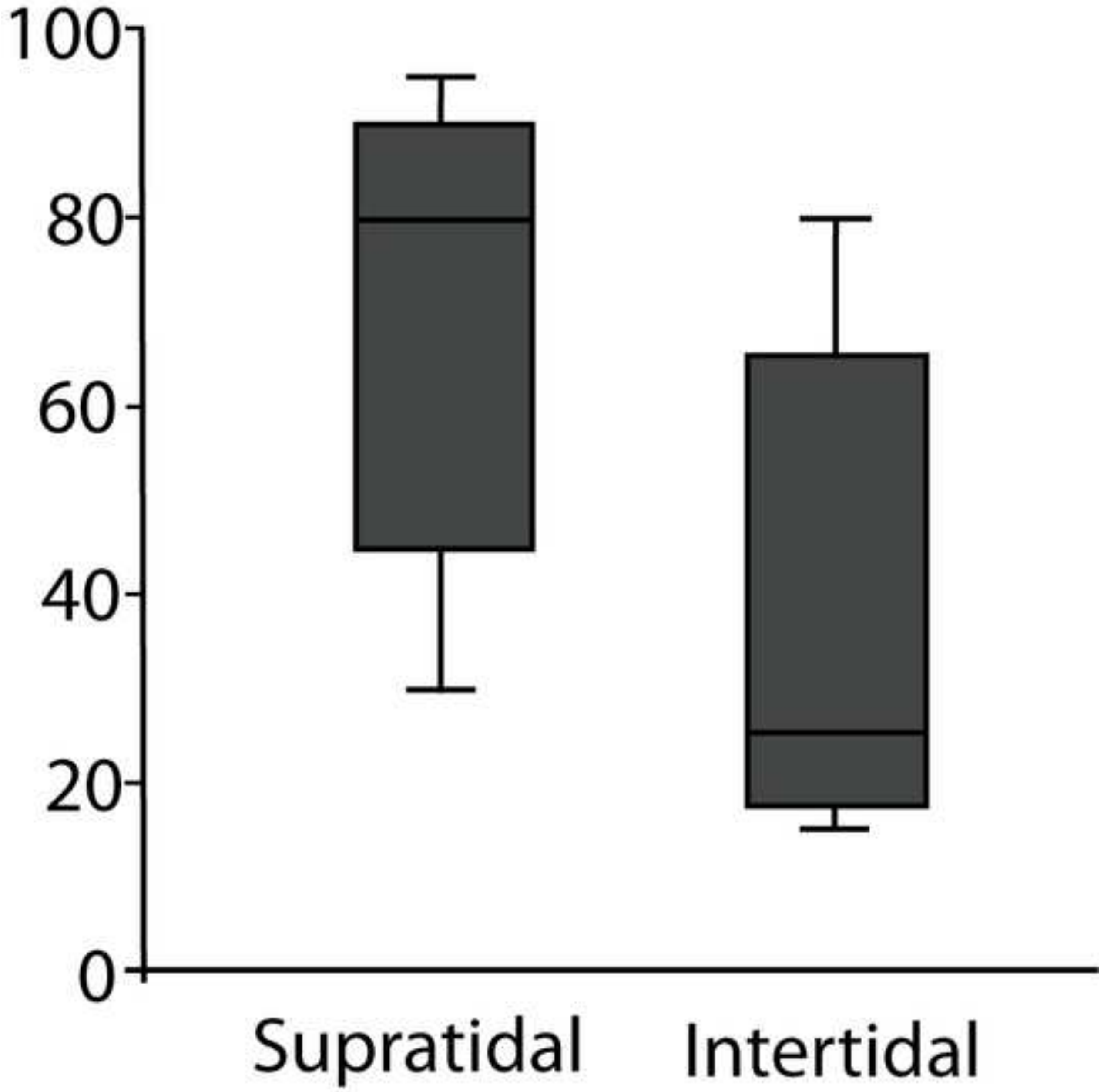


Figure 4

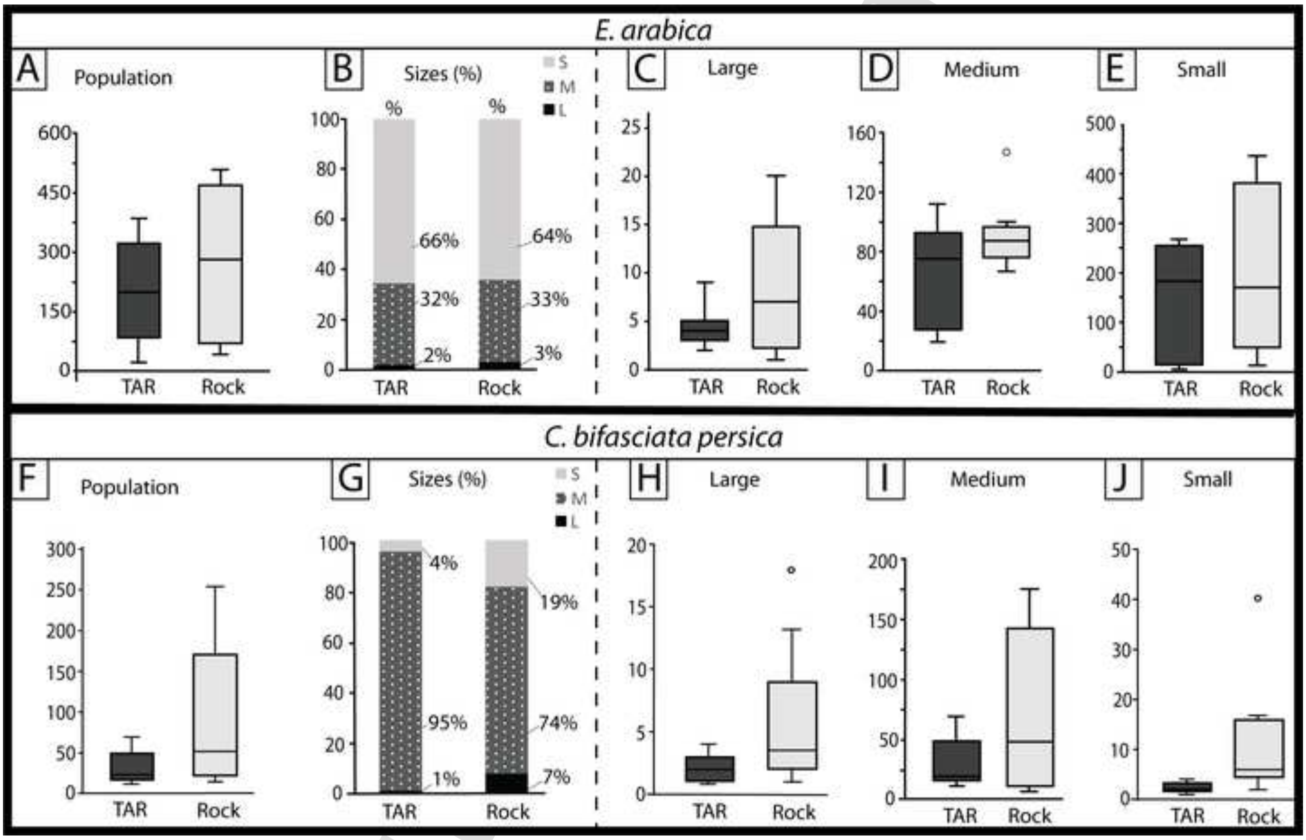

E. arabica
A
Population
600
450
300
150
0
TAR
Rock
B
Sizes (%)
S
M
L
%
%
100
80
60
40
20
0
66%
32%
2%
64%
33%
3%
TAR
Rock
C
Large
25
20
15
10
5
0
TAR
Rock
D
Medium
160
120
80
40
0
TAR
Rock
E
Small
500
400
300
200
100
0
TAR
Rock
C. bifasciata persica
F
Population
300
250
200
150
100
50
0
TAR
Rock
G
Sizes (%)
S
M
L
100
80
60
40
20
0
4%
95%
1%
19%
74%
7%
TAR
Rock
H
Large
20
15
10
5
0
TAR
Rock
I
Medium
200
150
100
50
0
TAR
Rock
J
Small
50
40
30
20
10
0
TAR
Rock

Figure 5

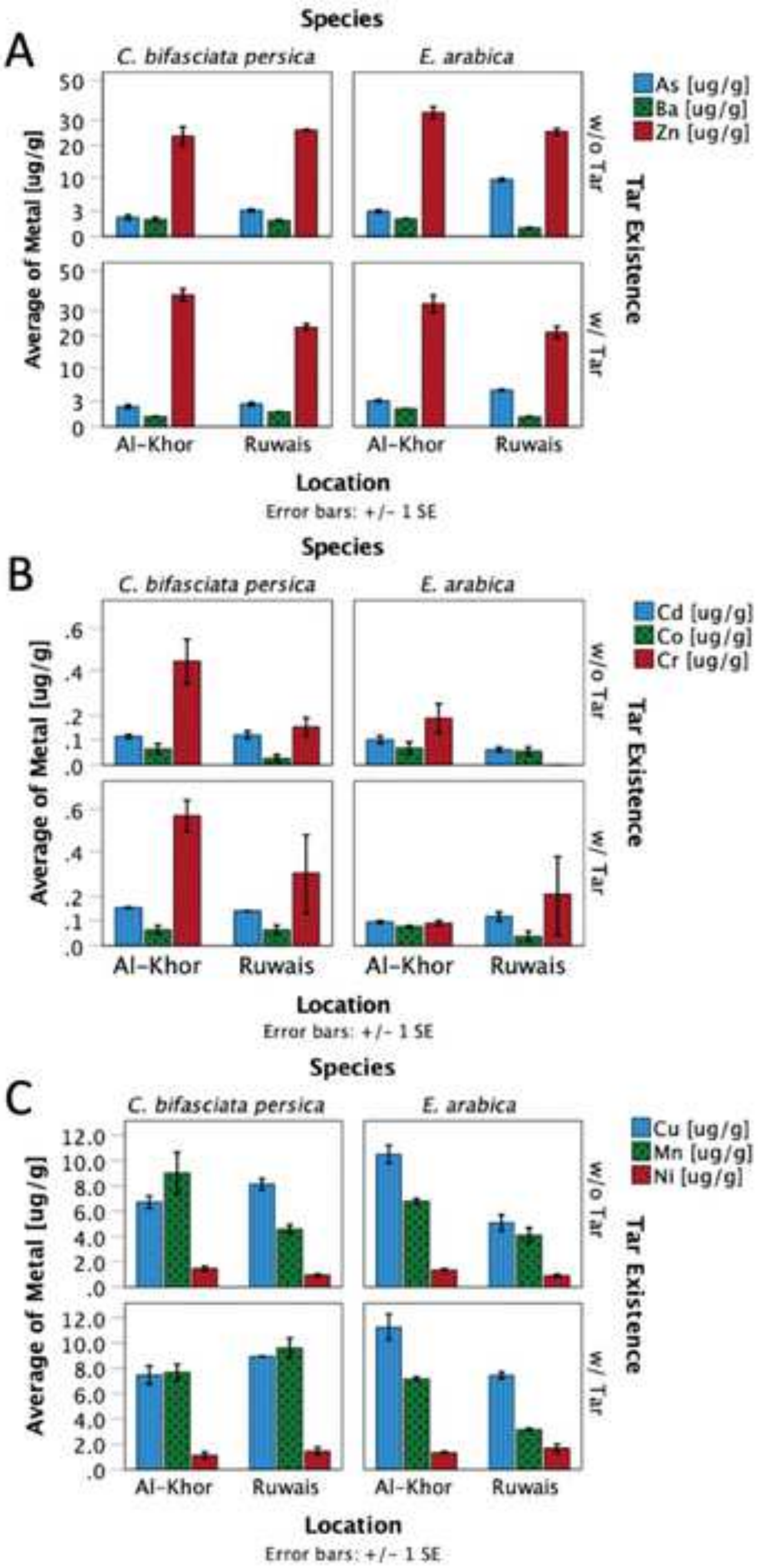
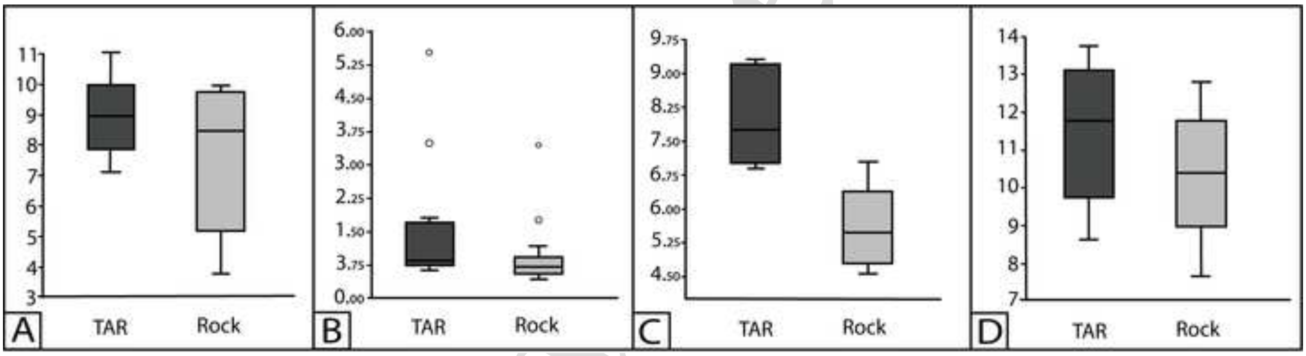

A
Species
C. bifasciata persica
E. arabica
Average of Metal [ug/g]
50
30
20
10
3
0
w/o Tar
w/ Tar
Tar Existence
As [ug/g]
Ba [ug/g]
Zn [ug/g]
Al-Khor
Ruwais
Location
Error bars: +/- 1 SE
B
Species
C. bifasciata persica
E. arabica
Average of Metal [ug/g]
.6
.4
.2
.1
.0
w/o Tar
w/ Tar
Tar Existence
Cd [ug/g]
Co [ug/g]
Cr [ug/g]
Al-Khor
Ruwais
Location
Error bars: +/- 1 SE
C
Species
C. bifasciata persica
E. arabica
Average of Metal [ug/g]
12.0
10.0
8.0
6.0
4.0
2.0
.0
w/o Tar
w/ Tar
Tar Existence
Cu [ug/g]
Mn [ug/g]
Ni [ug/g]
Al-Khor
Ruwais
Location
Error bars: +/- 1 SE

Figure 6


A
11
10
9
8
7
6
5
4
3
TAR
Rock
B
6.00
5.25
4.50
3.75
3.00
2.25
1.50
3.75
0.00
TAR
Rock
C
9.75
9.00
8.25
7.50
6.75
6.00
5.25
4.50
TAR
Rock
D
14
13
12
11
10
9
8
7
TAR
Rock

Highlights – Tarmat contaminants

- Shoreline gastropods can be used to standardize tarmat contamination monitoring
- Grazer snails are target for the bioaccumulation of tarmat-associated heavy metals
- *Clypeomorus* and *Echinolittorina* representatives are the bioindicators in the Gulf
- Intertidal grazer (Clypeomorus) was more contaminated than the supratidal species
- Cu, Ni were the target heavy metals associated to the tarmat contaminations

Table 1. Pearson Correlation matrix of the heavy metals As, Ba, Cd, Cr, Cu and Fe [µg/g] and their strong positive (black) and negative (red) correlations with each other ($R^2 > 0.80$, $p < 0.05$ and < 0.01) at the Al-Khor site with tarmat contamination. In the table, a dash represents weak or no strong relationship between the heavy metals

Metal	**As**	**Ba**	**Cd**	**Co**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Population Abundance**
As	–	–	–	–	–	**0.96**^{a}	0.89^b	–	–	–
Ba	_	_	**0.97**^{a}	_	-0.91^b	**0.90**^{a}	**0.98**^{a}	_	_	_
Cd	_	**0.97**^{a}	_	_	**0.97**^{a}	_	**-0.97**^{a}	_	_	_
Co	_	_	_	_	_	_	_	_	_	_
Cr	_	-0.91^b	**0.97**^{a}	_	_	_	-0.89^b	_	_	_
Cu	**0.96**^{a}	**0.90**^{a}	_	_	_	_	0.95^b	_	_	0.90^b
Fe	0.90^b	**0.98**^{a}	**-0.97**^{a}	_	-0.89^b	0.95^b	_	_	_	0.93^b
Mn	_	_	_	_	_	_	_	_	_	_
Ni	_	_	_	_	_	_	_	_	_	_

[a] Correlation is significant at the 0.01 level (values were highlighted as bold)

[b] Correlation is significant at the 0.05 level

Table 2. Pearson Correlation matrix of the heavy metals As, Ba, Cd, Cr, Cu and Fe [µg/g] and their strong positive (black) or negative (red) correlations with each other ($R^2 > 0.80$, $p > 0.05$ and > 0.01) at the Al-Ruwais site with tarmat contamination. In the table, a dash represents weak or no strong relationship between the heavy metals

Metals	**As**	**Ba**	**Cd**	**Co**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**
As	_	**-0.94**^{a}	_	_	_	**-0.92**^{a}	_	**-0.99**^{a}	_
Ba	**-0.94**^{a}	_	_	_	_	**0.95**^{a}	_	**0.90**^{a}	_
Cd	_	**_**	_	_	_	_	**-0.93**^{a}	_	_
Co	_	**_**	_	_	0.89^{b}	_	_	_	_
Cr	_	_	_	0.89^{b}	_	_	_	_	0.83^{b}
Cu	**-0.92**^{a}	**0.95**^{a}	_	_	_	_	_	**0.92**^{a}	_
Fe	_	_	**-0.93**^{a}	_	_	_	_	_	_
Mn	**-0.99**^{a}	0.90^{b}	_	_	_	**0.92**^{a}	_	_	_
Ni	_	_	_	_	0.83^{b}	_	_	_	_

Manuscript Number: RSMA-D-21-01095

Target gastropods for standardizing the monitoring of marine life tarmat contamination in the Arabian Gulf

Author statement

- Bruno Welter Giraldes - Conceptualization; Investigation; Project administration; Roles/Writing - original draft; Writing - review & editing.
- Jassem Abdulaziz K. H. Al-Thani - Formal analysis; Investigation; Visualization; Roles/Writing - original draft; Writing - review & editing.
- Samah Dib - Data curation; Formal analysis; Investigation; Methodology
- Amanda Engmann - Data curation; Formal analysis; Investigation; Methodology
- Hamood Abdulla Alsaadi - Data curation; Formal analysis; Investigation; Methodology
- Ponnumony Vethamony - Conceptualization; Funding acquisition; Project administration; Resources; Supervision; Validation
- Juha Mikael Alatalo - Supervision; Validation
- Oguz Yigiterhan - Conceptualization; Investigation; Roles/Writing - original draft; Writing - review & editing.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: