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Soft Corals as Efficient Bio-Indicators of Toxic Metals in the Reefs of Vaan Island, Gulf of Mannar

Mahalakshmi Boopathi and Patterson Edward, J.K.*

Suganthi Devadason Marine Research Institute, 44, Beach Road, Tuticorin 628001
(Affiliated to Manonmaniam Sundaranar University, Abishekapatti, Tirunelveli 627012)
**Email: edwardjkpatterson@sdmri.in*

Abstract

The concentration levels of seven heavy metals (Pb, Cd, Zn, Cr, Mn, Ni, and Cu) were analysed in sediment, seawater, and 4 soft coral species (*Sinularia brassica*, *Sarcophyton glaucum*, *Lobophytum* sp., and *Subergorgia suberosa*) collected from the reef areas of Vaan Island, Gulf of Mannar (GoM). The study is the first attempt to investigate any variation in the heavy metal concentrations in the recruits and matured colonies of soft corals; and also the variation due to the growth forms of soft corals. The overall concentrations of metals in decreasing order are Zn>Cd>Ni>Cu>Mn>Pb>Cr in the matured colonies and Zn>Cd>Pb>Ni>Mn>Cu>Cr in the recruits. However, the concentration of heavy metal ions in the recruits is below the detection limit, and hence we considered only the matured colonies for further analysis. Zn (111.32±6.38 $\mu g\ g^{-1}$) is the most accumulated metal in the soft corals (*S. brassica*). Analysis of variance indicates that there is no significant variation in the metal concentration of the soft corals collected from different study sites (df= 16, f=0.42, p-value =0.97). Based on the colony growth forms, the highest metal concentration is recorded in encrusting soft coral (*S. brassica*) as it has a large surface area available to bind the metal ions. Pollution load index and bioaccumulation factor are also recorded high for the soft coral *S. brassica* showing that this species can be used as a potential bio-indicator of the level of toxic metal pollution.

Keywords: Gulf of Mannar, Soft corals, Heavy metals, Bio-indicator

1. Introduction

Gulf of Mannar (GoM) is one of the richest biodiversity hotspots in India. It has 21 uninhabited islands situated between Rameswaram in the north to Tuticorin in the south. The islands and the surrounding shallow coastal waters covering an area of 560 km^2 were declared as Gulf of Mannar Marine National Park in 1986 by the Government of Tamil Nadu. The entire GoM covering 10,500 km^2 between Rameswaram and Kaniyakumari was declared as Marine Biosphere Reserve in 1989 by the Government of India. GoM harbors more than 4,223 nominal floral and faunal marine species (ENVIS, 2015). Worldwide, more than 3,649 (Daly *et al.*, 2007; Ramvilas *et al.*, 2019) valid species of soft corals have been identified. But only 47 species are recorded in the Gulf of Mannar (Padmakumar and Chandran, 2012). Factors like difficulty in the identification of soft corals, indefinite morphological features and lack of regional expertise have made them remain as underexplored fauna of GoM. They differ from hard corals in the absence of exoskeleton but instead have minute calcium carbonate structures called sclerites that bind with the body tissue and provide flexibility and support to the colonies.

The metal pollutants of the sea originate from different sources (Tornero and Hanke, 2016) and pose a very serious threat to marine ecosystems (Naser, 2013). These pollutants along with other biophysical factors affect the structure of the benthic communities (Williams *et al.*, 2015). Marine organisms ingest these pollutants from the marine environment and accumulate them in their body. The accumulated pollutant is passed on to higher trophic levels through the food chain (Wang, 2002; Chernova and Lysenko, 2019). Likewise hard corals too accumulate (Howard and Brown, 1986) huge quantities of pollutants by absorbing them along with the organic particles and fixing them in their tissue and skeleton. As hard coral traps metal components, it acts as indicator for variations of chemical composition of the seawater (Chen *et al.*, 2014) and the marine environment (Chan *et al.*, 2012) over a period of time. These metal pollutants generally affect the corals by expelling the symbiotic organisms (Peters *et al.*, 1981) reducing the rate of fertilization (Negri and Heyward, 2001), and causing cell death (Wyers *et al.*, 1986). Several studies reported the accumulation of heavy metals in the sediments (Sulochanan *et al.*, 2007), seawater (Palanichamy and Rajendran, 2000), hard corals (KrishnaKumar et al., 2010), coral rubble (Kumar and Geetha, 2012), pufferfish (Karunanidhi *et al.*, 2017), edible fishes and crab species (Rameshkumar *et al.*, 2016) of GoM. The ingested metal ions not only get accumulated but also actively participate in some essential biochemical process or they get converted into detoxified forms and stored. However, the accumulation process differs based on the metals and species (Rainbow, 1988, 1998). Soft corals accumulate larger quantities of metal ions than the hard corals do (Mohamed and Dar, 2010; Ali *et al.*, 2011). Taking this fact into account, we proposed to study the most commonly distributed soft corals to monitor the pollution status of the reef ecosystem around Vaan Island in GoM. Our study aimed to develop a relatively simple, accurate, and precise method for sample preparation and analysis of heavy metals in soft corals. The indices called concentration factors help to identify the relative ability of marine organisms to bio-accumulate metals from their environment (Szefer *et al.*, 1999). The study also utilized the opportunity to investigate the possible use of soft corals as marine pollution indicators.

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2. Materials and Methods

2.1 Study sites

Soft corals were collected from four reef sites (Fig.1) namely Site 1 (8^{0}50’11.35" N, 78^{0}12’36.96" E), Site 2 (8^{0}50’08.62" N, 78^{0}12’43.41" E), Site 3 (8^{0}50’11.83" N, 78^{0}12’57.23" E) and Site 4 (8^{0}50’23.32" N, 78^{0}12’57.64" E) around Vaan Island. The Vaan Island is the first of the 21 Islands in GoM from south, which is about 6 km off Tuticorin. The Tuticorin coast houses several industries and also receives voluminous untreated domestic sewage through buckle channel. Initial assessment of the soft coral cover was done using the Line Intercept Transect method following English *et al.* (1997) at a depth of 3-5 meters involving scuba diving. Three 20 m transect lines were laid in each site parallel to the shore at regular intervals. Data on benthic community structure and percentage of soft coral cover were recorded.

2.2 Sample collection

Most commonly available soft corals were collected from the study sites. 5 grams of samples were collected from the recruit (colonies less than <10cm diameter) and matured (>10cm diameter) colonies of soft corals. The samples were cut underwater and carefully transferred to zip-lock plastic bags and carried to the laboratory. The samples were identified based on the sclerites extracted from different regions of the soft coral body i.e. from the surface of the lobe, the interior of the lobe, surface of the stalk, and interior of the stalk. The sclerites embedded in the tissue were liberated by treating them with 10% sodium hypochlorite solution. The extracted sclerites were washed using double-distilled water. Then the rinsed sclerites were mounted on slides and viewed under a light microscope [CosLab (model No. HL-9(A)]. The specimens were identified based on the available literature (Muzik and Wainwright, 1977; Benayahu *et al.*, 1998; Verseveldt, 1982, 1983). Samples of sediment and seawater were also collected to check contamination levels in the marine environment so that we can know the extent of contamination to which the soft coral specimens are exposed.

2.3 Metal analysis

2.3.1 Soft corals

One gram of soft coral sample was weighed and transferred to clean dry glass beakers and washed thoroughly using deionised and Milli-Q waters to remove surface contaminants, debris, and sedimentary particles, and the preparations were left for drying overnight at 50^{o}C in the microwave oven. Dried samples were retrieved and dried for another 4 hours in the microwave oven prior to the test. Dried soft coral samples were digested with 10ml of concentrated nitric acid and kept aside for 3 hours for digestion and separation of the undigested particles in the test tubes. Then the samples were filtered and made up to 25 ml with distilled water and then analysed using graphite furnace Atomic Absorption Spectrophotometer (AAS, Agilent 200 series AA) following Jaffe and Fernandez (1992). Seven metals (lead, cadmium, zinc, manganese, nickel, copper, and chromium) were considered to study their concentration level in the soft coral tissue.

2.3.2 Sediment and seawater

1.0 g of the dried, finely sieved sediment sample was digested with 9:1ml of concentrated nitric acid and perchloric acid over a hot plate, and the sample solution was heated until it became clear. The digested samples were then filtered using Whatman No. 1 filter paper and the filtrate was diluted with double-distilled water and made up to 25 ml in a volumetric flask. Then the samples were analyzed in AAS for various metals. Blank was also prepared by the addition of the same quantities of reagents without samples and digested and made up to 25ml following (Chester, 1969).

Water samples were digested with a dilute solution of 20ml made of 5:1 ml concentrated nitric acid and perchloric acid in triplicate as in Lithnor (1975). The digestion process was allowed to continue until the sample evaporated to near dryness. The digested samples were cooled, filtered using Whatman No. l filter paper, and made up to 25ml with deionised double-distilled crystal clear water. The made-up samples were transferred to

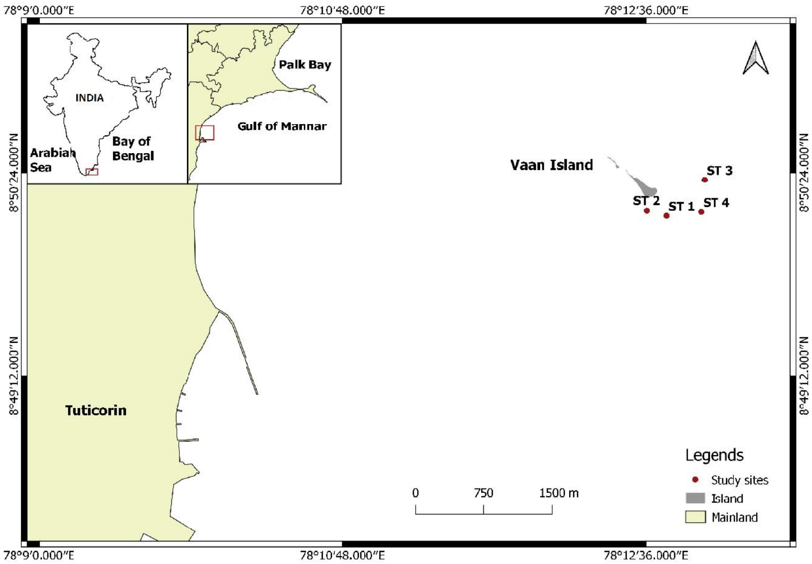

Fig. 1. Map showing study sites in the Vaan Island, Gulf of Mannar

plastic bottles and were analyzed for various metals like Pb, Cd, Zn, Cr, Mn, Ni, and Cu in AAS.

2.3.3 Bioaccumulation Factor (BAF)

The degree of relation between the heavy metal concentration in the organism and its environment are given by BAF. It is calculated as the ratio of the heavy metal concentration in the organism and in water or sediments. The following formula was used to calculate BAF,

$\mathrm{BAF} = C_{tissue}/(C_{sediment} \text{ or } C_{water})$

Where C_{tissue} is the metal concentration in the soft coral, $C_{sediment}$ is the metal concentration in the sediment (mg/g) and C_{water} is the metal concentration in the seawater (mg/L) (Jafarabadi *et al.*, 2018).

2.3.4 Pollution Load Index (PLI)

PLI indicates the contamination status of the study sites. It is calculated by the following formula.

Pollution Load Index (PLI) = $(CF1 * CF\ 2 \ldots * CF_n)^{1/n}$, where CF is the concentration of the metals in the organism and n is the number of contamination factor (Tomlinson *et al.*, 1980).

2.4 Statistical analysis

Analysis of variance was performed to test the difference in the accumulation level in the soft corals collected from study sites at the significance level $p<0.05$. Regression analysis was used to determine the difference in accumulation level between soft coral and the sediment and seawater. The magnitude of the correlation factor (r) helps to determine the strength of the correlation factor between the soft coral and sediment and the seawater based on the positive and negative regressions with the concentration using SPSS version 22 statistical packages.

3. Results and Discussion

3.1 Benthic community structure

On average, hard corals are the most dominant benthic occupants in the study sites with an area cover of 37.96% followed by algae with 22.41%, abiotic with 23.39%, and coralline algae with 4.57%. The percentage cover of soft corals is only 1.08%. Of this, the most common soft coral species found in the study sites are *Sinularia brassica* May, 1898, *Sarcophyton glaucum* (Quoy & Gaimard, 1833), *Lobophytum* sp., and *Subergorgia suberosa* (Pallas, 1766); (Table 1, Fig. 2-6).

3.2 Metal concentration in soft corals

Heavy metal concentration is the clearest evidence for man's meddling with the marine environment (Fallon *et al.*, 2002; Jayaraju *et al.*, 2009). Two types of soft coral colonies are considered for the study, namely matured colonies and recruits. Colonies with a diameter larger than 10 cm are considered as matured colonies and those with a diameter of less than 10 cm are called recruits. This is applicable for the species *S. brassica*, *S. glaucum*, and *Lobophytum* sp., and for the species *S. suberosa*, colonies less than 10 cm in height are considered as recruits based on the available literatures (Yamazato *et al.*, 1981; Benayahu and Loya, 1986; Bastida *et al.*, 2004; Gutierrez-Rodriguez and Lasker, 2004). The results of the present study show that metal accumulation is in the decreasing order of Zn>Cd>Ni>Cu>Mn>Pb>Cr in the matured colonies, and Zn>Cd>Pb>Ni>Mn>Cu>Cr in the recruits. In comparison with matured colonies (Table 2), recruits have far less metal concentration indicating that the soft corals assimilate metal ions as they grow up. On the contrary, Petroody *et al.* (2017) reported inverse trends of metal concentration on rock oysters. Immature oysters tend to bio-accumulate more metal pollutants as they filter-feed large quantities of food particles to match their high metabolic and growth rates (Savari, 1990). Ours is the first work to study the accumulation of metal contaminants in the recruits. Since the heavy metal contamination of coral recruits is below the detectable level, we made use of matured colonies for further analysis. Comparatively, zinc and cadmium (Table 3) are the major metal contaminants in the soft corals. The concentration of Zn ranges from 7.77±2.6 $\mu g\ g^{-1}$ to 111.32±6.38 $\mu g\ g^{-1}$ with the highest concentration in *Lobophytum* sp. collected from Site 2. Zinc is a vital constituent of enzymes and plays an active role in the enzyme-mediated carbonic acid inter-conversion process providing energy (Depledge and Rainbow, 1990). In soft corals, Zn is taken up for the aragonite crystallization (Ramos *et al.*, 2004; Hwang *et al.*, 2018) and mineral composition in the sclerite formation, possibly leading to its high accumulation. The concentration of cadmium ranges from 0.69±0.36 $\mu g\ g^{-1}$ to 25.97±0.54 $\mu g\ g^{-1}$. The soft coral *S. brassica* from Site 1 has the highest concentration of Cd. It is one of the most toxic elements (Puthiyasekar *et al.*, 2010) even in low concentrations. The high concentration of Cd in soft corals indicates that they accumulate this toxic metal and efficiently manage or tolerate the toxification effects if any (Brown and Howard, 1985; Ali *et al.*, 2011). This tolerance of soft corals for high Cd concentrations reduces the Cd contamination level in the reef ecosystem. Nickel, manganese, and copper are found in lower concentrations compared to cadmium and zinc. Copper concentration ranges from 0.83±0.01 $\mu g\ g^{-1}$ to 5.89±0.3 $\mu g\ g^{-1}$ with the highest concentration in the soft coral *S. glaucum* collected from Site 4. Copper readily gets attached to the particles suspended in the water (Turner, 2010) and so carried away by wave and water currents, and this is the possible reason for the lower Cu concentration. The concentration of nickel ranges from 1.18±0.23 $\mu g\ g^{-1}$ to 11.55±1.47 $\mu g\ g^{-1}$ and the highest concentration is found in the soft coral *S. suberosa* collected from Site 4. According to Krishnakumar *et al.* (2017a), the sediment of Vaan Island is moderately polluted by Ni (405.317ppm), and to this fact we may attribute the low Ni concentration in soft corals. The concentration of manganese ranges from 0.84±0.76 $\mu g\ g^{-1}$ to 5.17±0.2 $\mu g\ g^{-1}$ and the highest level is found in *S. suberosa* of Site 3. Lead and chromium are the least accumulated metals in soft corals. The concentration of lead ranges from 0.28±0.09 $\mu g\ g^{-1}$ to 3.69±1.36 $\mu g\ g^{-1}$ and is found in the highest concentration in *S. suberosa* collected from Site 1. Chromium is the least accumulated of all the metals analyzed by this study. Cr ranges from 0.28±0.03 $\mu g\ g^{-1}$ to 2.69±0.44 $\mu g\ g^{-1}$ with the highest concentration seen in the soft coral *S. glaucum* collected from Site 1. The uptake and accumulation of metal ions by this coral depends on the physical parameters, and hence the lower assimilation (Dam *et al.*, 2011). The sediment samples collected from the same study sites near

Table 1. Systematic and descriptive characters of the soft corals selected for the study

Systematics	**Description**	**Reference**
Alcyoniidae Lamouroux, 1812 Genus *Sinularia* May, 1898 Species *Sinularia brassica* May, 1898	Low encrusting colony with uneven distribution of lobes many fused to form flattened walls. Colony is hard with retracted polyps. Sclerites- spinny clubs with divergent heads with sharp or pointed handles; Small rods and spindles. (Fig. 3 a-d)	Benyahy *et al.*, 1997
Genus *Sarcophyton* Lesson, 1834 Species *Sarcophyton glaucum* (Quoy & Gaimard, 1833)	Mushroom shaped colony with distinct capitulum and stalk surface with folded margins. Sclerites- clubs, stick and spindles. (Fig. 4 a-c)	Verseveldt, 1982
Genus *Lobophytum* von Marenzeller, 1886 Species *Lobophytum* sp.,	Small encrusting colony with ridges like paralle lobes on the stalk surface. Sclerites- clubs, spindles, and capstans. (Fig. 5 a-c)	Verseveldt, 1980
Subergorgiidae Gray, 1859 Genus *Subergorgia* Gray, 1857 Species *Subergorgia suberosa* (Pallas, 1766)	Tree like, branched, smooth surface, polyps distributed on the either sides of braches with central furrow. Sclerites- capstans, fused forms, spindles and ovals. (Fig. 6 a-c).	Muzik and Wainwright, 1977

*-terminology used as per Bayer *et al.*, 1983

Fig. 2. *In situ* colony images of soft corals a. *Sinularia brassica* b. *Sarcophyton glaucum* c. *Lobophytum* sp. d. *Subergorgia suberosa*

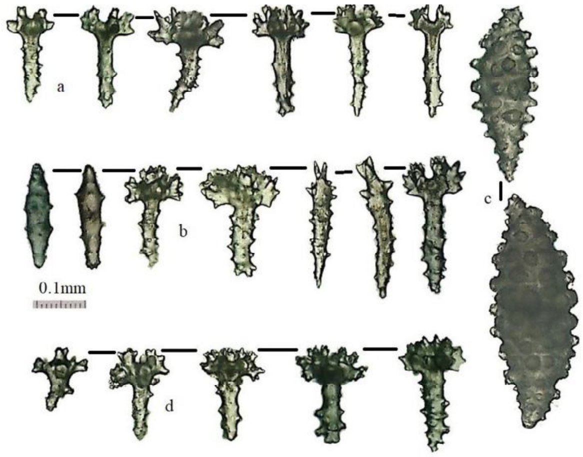

Fig. 3. *S. brassica* a. b. Sclerites from the lobe surface; c. sclerites from the lobe interior; d. sclerites from the surface of the base

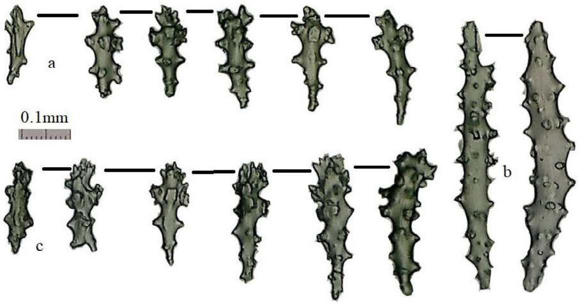

Fig. 4. *S. glaucum* a. sclerites from the surface of the disc, b. sclerites from the inner surface of the disc, c. sclerites from the surface of the stalk

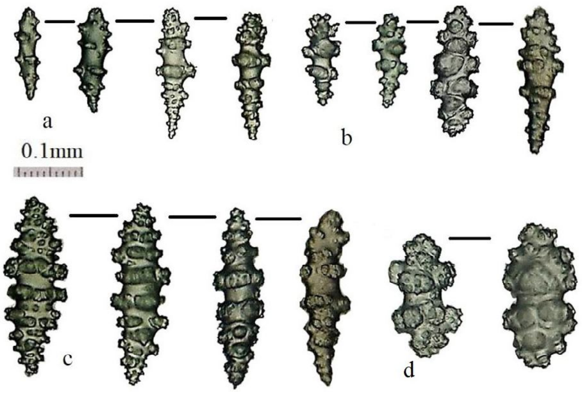

Fig. 5. *Lobophytum* sp., a. sclerites from the surface of the lobe, b. sclerites from the surface of the stalk c. sclerites from the interior of the lobe surface, d. sclerites from the interior of the stalk

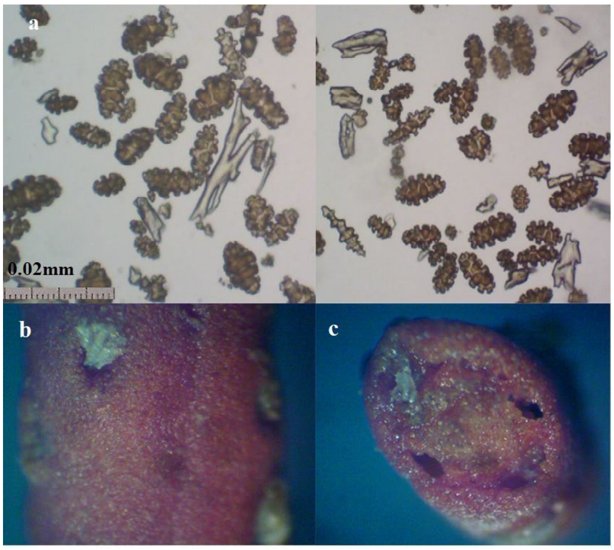

Fig. 6. *S. suberosa* a. capstans and fused sclerites from the surface of gorgonian b. image showing the external surface with white polyps distributed along the sides with the groove in the centre, c. image showing the cross-section coenenchyme and the central axis

Table 2. Mean metal concentration (μg g^{-1}) in the matured and recruits soft corals (mean±SE)

	***Sinularia brassica*(n=9)**		***Sacophyton glaucum*(n=6)**		***Lobophytum* sp.(n=7)**		***Subergogia suberosa* (n=9)**	
Metals	Matured	Recruits	Matured	Recruits	Matured	Recruits	Matured	Recruits
Pb	1.88(0.72)	0.94(0.27)	5.51(0.52)	1.1(0.92)	1.30(0.71)	0.53(0.51)	1.24(0.86)	BDL
Cd	21.55(0.72)	1.86(0.80)	2.96(0.43)	BDL	1.89(0.65)	1.14(0.85)	2.46(0.82)	0.62(0.55)
Zn	32.97(1.37)	BDL	32.70(2.12)	1.80(1.27)	81.70(3.78)	BDL	11.23(0.95)	0.76(0.75)
Cr	1.73(0.52)	0.22(0.08)	0.43(0.23)	0.36(0.09)	0.58(0.32)	0.24(0.02)	1.49(0.49)	0.37(0.07)
Mn	1.52(0.44)	0.54(0.21)	3.30(0.7)	0.99(0.38)	2.93(0.81)	BDL	4.26(0.61)	0.78(0.35)
Ni	2.98(0.54)	0.83(0.45)	3.11(1.11)	1.01(0.40)	3.49(1.40)	BDL	7.29(1.33)	0.42(0.18)
Cu	0.98(0.17)	0.87(0.24)	3.91(0.77)	0.39(0.04)	5.34(0.87)	0.41(0.19)	4.16(0.8)	BDL

Table 3. Metal concentration in the matured colonies of soft corals at different sites (Mean(SE))

Metals μg g^{-1}(SE)	**Pb**	**Cd**	**Zn**	**Cr**	**Mn**	**Ni**	**Cu**
Sinularia brassica							
Site 1	2.61(1.21)	25.97(0.54)	31.26(2.36)	2.69(0.44)	1.69(0.17)	1.36(0.03)	0.9(0.03)
Site 2	0.84(0.46)	21.35(3.23)	23.26(0.6)	1.36(0.78)	2.14(0.23)	3.49(0.14)	0.83(0.01)
Site 3	1.23(1.01)	17.83(1.14)	42.1(3.18)	1.14(0.23)	1.41(0.01)	4.23(0.74)	1.21(1.25)
Site 4	2.84(0.66)	21.05(1.54)	35.26(2.14)	1.73(0.03)	0.84(0.46)	2.84(0.05)	0.98(0.14)
Sarcophyton glaucum							
Site 1	3.69(1.36)	3.87(0.51)	16.35(2.23)	0.62(0.02)	4.36(1.14)	5.65(0.84)	2.36(1.47)
Site 2	6.21(0.48)	3.21(1.27)	36.54(10.26)	0.28(0.03)	2.84(1.27)	1.48(0.18)	3.16(2.15)
Site 3	5.91(1.36)	2.58(0.48)	45.32(5.69)	0.35(0.29)	1.74(0.84)	3.65(1.27)	4.23(3.25)
Site 4	6.23(0.48)	2.18(1.27)	32.63(3.47)	0.47(0.23)	4.38(0.39)	1.66(0.07)	5.89(0.33)
Lobophytum sp.							
Site 1	2.36(0.17)	2.14(1.22)	40.89(9.68)	0.68(0.08)	2.36(1.84)	2.69(0.87)	6.39(1.27)
Site 2	0.52(0.09)	2.82(1.77)	111.32(6.38)	0.33(0.84)	3.87(2.69)	7.25(1.74)	2.58(1.11)
Site 3	1.48(0.36)	0.69(0.36)	66.12(11.75)	0.87(0.33)	4.25(1.33)	2.84(0.07)	7.16(3.28)
Site 4	0.84(0.55)	1.91(0.97)	108.47(24.5)	0.44(1.02)	1.24(0.84)	1.18(0.23)	5.23(1.77)
Subergorgia suberosa							
Site 1	2.36(0.36)	2.01(1.29)	10.42(1.27)	1.36(0.14)	4.5(1.84)	8.84(0.87)	5.26(1.03)
Site 2	0.62(0.04)	4.21(2.68)	7.77(2.6)	2.36(1.88)	2.42(1.47)	5.12(0.87)	4.22(0.94)
Site 3	1.7(1.21)	2.47(0.18)	15.48(0.44)	1.18(0.98)	5.17(0.29)	3.65(2.55)	1.84(0.07)
Site 4	0.28(0.09)	1.15(0.23)	11.25(1.58)	1.06(0.27)	4.95(2.84)	11.55(1.47)	5.32(2.84)
Sediment							
Site 1	44(7.25)	0.56(0.12)	23.96(1.48)	5.2(1.23)	106.9(5.98)	12.36(2.14)	42(1.36)
Site 2	22(3.69)	2.91(1.36)	19.82(1.14)	3.1(2.36)	113.86(6.24)	42.12(3.69)	36(0.58)
Site 3	30(2.66)	3.63(1.25)	21.36(4.97)	6.8(1.87)	81.88(2.33)	36.36(2.39)	29(1.25)
Site 4	36(8.97)	2.22(2.36)	18.29(2.22)	1.29(0.36)	121.42(11.32)	15.94(2.33)	18(2.69)
Seawater							
Site 1	12.36(3.69)	0.92(0.77)	15.26(3.84)	0	15.26(1.87)	1.26(0.36)	2.36(0.11)
Site 2	7.54(1.03)	0.36(0.12)	37.28(1.23)	12(0.87)	1.33(0.84)	0.45(0.21)	3.12(0.25)
Site 3	6.26(0.58)	0.69(0.35)	10.26(0.87)	0.69(0.42)	6.35(1.47)	0.92(0.36)	4.5(1.25)
Site 4	1.02(0.99)	0.28(0.12)	12.14(1.58)	1.88(0.87)	45.88(2.69)	0.45(0.33)	2.23(0.84)

Vaan Island are grouped under a moderately polluted sediment category (Krishnakumar *et al.*, 2017a). However, the difference in the metal concentrations in coral body may be related to the selectivity of the coral for the metal (Esselmont *et al.*, 2000) and/or its concentration in the surrounding medium (Chan *et al.*, 2012). The normal route for the entry of heavy metal pollutants into the sea is through the inflow of untreated industrial effluents and domestic sewage (Palanichamy and Rajendran, 2000). The other important sources are run-off from fishing harbours, antifouling paints on ship hulls and fly ash from the thermal power plants (Asha *et al.*, 2010). Analysis of variance indicates that there is no significant variation in the metal concentrations in soft corals investigated among the different study sites (df= 16, f=0.42, p-value =0.97).

3.3 Metal concentration in soft corals based on growth form

Three growth forms of soft coral colonies were observed underwater during the study, and they are the encrusting type, mushroom type and branching type (Fig. 7). Among the three growth forms, the encrusting soft coral has greater capacity (22.95 µg g^{-1}) to trap metal ions than the other colony forms. It is followed by the mushroom (7.42 µg g^{-1}) and branching type soft corals (4.16 µg g^{-1}). By virtue of their large surface area exposed to the environment, soft corals take up large quantities of metal contaminants (Mohammed and Dar, 2010). Further, they feed on zooplanktons which are rich in metals (Howard and Brown, 1984). Activities like photosynthesis (Fabricius and Alderslade, 2001) and mucus production limits the metal uptake to some extent. Soft corals secrete large quantities of mucus in response to stresses, which makes them susceptible to trap more metal pollutants from the environment (Mohammed and Dar, 2010). The perspective of the study relating metal concentration with the colony growth form (Fig 2) is in concurrence with Mohammed and Dar (2010) conducted in Northern Red Sea, Egypt, which demonstrates that soft corals accumulate more metal ions than hard corals. According to the results of the study, the accumulation is based on factors such as surface exposure, turbidity, mucus secretion, and the metal substitute in the crystal lattice. However, the branching growth forms especially the gorgonian *S. suberosa* has the least surface area of exposure.

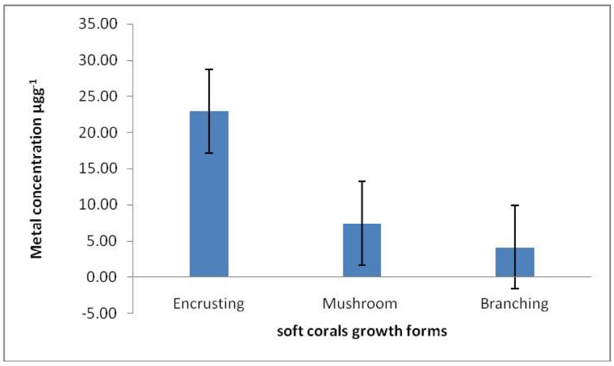

Fig. 7. Metal concentration in the soft corals growth forms

3.4 Comparison of metal accumulation in sediment, water, and the soft coral

The sediment samples have the largest amount of heavy metals (Fig. 8). The sediment acts as the reservoir for most of the pollutants and contaminants (Bazzi, 2014). Metal concentration in the sediment is the highest in Site 1 followed by Site 3, Site 2, and Site 4. Regression analysis (Table 4) reveals the strong positive relationship between the metal concentrations in the soft corals and sediment in Site 1 (r=0.39; p>0.05); between sediment and seawater (r=0.87;p>0.05); r-value shows a strong positive correlation between soft coral and the water in Site 2 (r=0.64; p>0.05). Vaan Island is close to the Tuticorin coast, and is severely affected by the domestic and industrial effluents from various industries, chemical plants, heavy water plants, thermal power plants and human activities (Asha *et al.*, 2010). Generally, metallic elements occur in the marine environments in solubilised form and as suspended particulate matter (Howard and Brown, 1984). However, they are dumped in the marine environment (Robin *et al.*, 2012), through industrial and urban discharges (Selvam *et al.*, 2017). Kumar *et al.* (2014) estimated a sedimentation rate in the range of 7.5-10.13 mg/cm^2/day in Vaan Island. Metal enrichment in the sediments is a function of the rate of sedimentation, and so a significant increase in sedimentation rates in the coral habitat brings about a corresponding rise in the metal concentration in the coral body (Chan *et al.*, 2012).

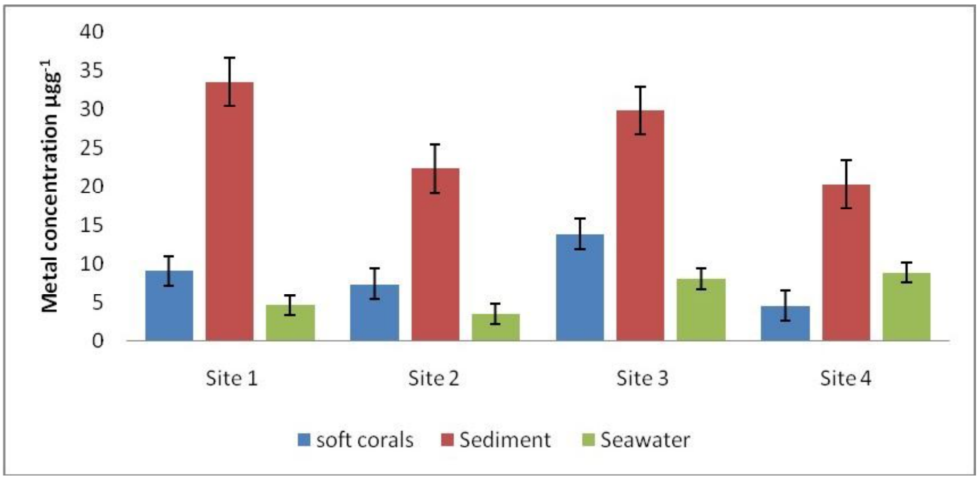

Fig. 8. Metal concentration in the sediment, water and soft corals

Table 4. Regression analysis between soft coral and sediment; soft coral and water

	Soft coral Vs. sediment			Soft coral vs. seawater			Sediment vs. seawater		
	r value	r^2	P value	r value	r^2	P value	r value	r^2	P value
Site 1	0.39	0.15	0.12	0.27	0.07	0.16	0.87	0.75	0.33
Site 2	0.05	0	0.35	0.64	0.41	0.59	0.11	0.01	0.07
Site 3	0.18	0.03	0.12	0.27	0.07	0.16	0.01	0	0.07
Site 4	0.18	0.03	0.16	0.04	0	0.12	0.76	0.58	0.06

3.5 Pollution Load Index (PLI)

Level of pollution and variation in the severity of pollution in the soft corals are determined using PLI (Table 5). PLI is an efficient tool to study the pollution status of soft corals. A PLI value of >1 indicates the polluted condition; and <1 indicates no pollution (Khan *et al.*, 2017). The results of the present study show that the pollution level is higher in *S. brassica* (0.22) than *S. glaucum*, *Lobophytum* sp., and *S. suberosa*. Savitha *et al.* (2017) report that the PLI value of less than one indicates the pollution by Cd metal being subdued by the existence of other elements.

3.6 Bioaccumulation factor (BAF)

The metal concentration in the soft coral and in the samples of sediment and seawater were determined using BAF value (Table 5). Here BAF <1 shows low contamination, 1 ≤ BAF >3 shows moderate concentration and 3 ≥ BAF ≤ 6 shows considerable contamination; BAF ≥ 6 indicates very high contamination (Khalafallah *et al.*, 2019). Among the heavy metals analysed in the present study, Pb level is the highest in the soft coral *S. glaucum* (0.81 µg L^{-1}). The Cd level is the highest in the soft coral *S. brassica* (9.25 µg g^{-1}). Zn level is the highest in the soft coral *Lobophytum* sp. (4.36 µg L^{-1}) Cr level is the highest in the soft coral *S. brassica* (0.02 µg g^{-1}). Mn level is the highest in the soft coral *S. suberosa* (5.53 µg L^{-1}). Ni level is the highest in the soft coral *S. suberosa* (2.39 µg L^{-1}). Cu level is the highest in the soft coral *Lobophytum* sp. (1.30 µg g^{-1}). Among the metal contaminants, Cd level is greater than 6, which represents high level contamination of sediment by this compound. Pb and Cr are much less than 1 and hence seawater is very minimally contaminated by these elements. Cu has a value of >1<3 and hence the sediment samples show moderate contamination by this element. Mn, Zn, and Ni have the values of >3<6 indicating that the seawater in the study sites is considerably contaminated by these elements. Earlier studies also report a higher level of Cu, Zn (Krishnakumar *et al.*, 2017a, b) and Cd (Savitha *et al.*, 2017) in the sediment samples collected from the Gulf of Mannar and soft corals have evidently accumulated them as in this study.

4. Conclusion

Heavy metal pollution in the reef ecosystem causes several impacts on the other marine biota as coral reefs provide food, shelter and nursery grounds for marine organisms. These metallic pollutants in the soft coral body get accumulated and bio-magnified by the organisms that feed on these corals and in due course get transferred to the higher trophic levels through food chain. Being sedentary marine organisms soft corals are sensitive to changes in their surroundings, and hence can serve as excellent bio-indicators of the level of pollution in the marine environment. The accumulation level varies between species to species depending on the concentration level and retention period of the metal pollutants in the marine environment. The study indicates that soft corals especially *S. brassica* has the ability to accumulate heavy metal contaminants. The uptake and accumulation of heavy metals by the soft corals helps in removing the elevated levels of the toxic metals and maintains the pollution level in the marine environment. They tend to accumulate metals by virtue of their feeding behavior, mucus production and their growth forms. The metal components remain trapped as aragonite crystals within the soft tissue. In species like *Sinularia*, the aragonite crystal gets cemented together at the base of the colony. Hence they can be used as bio-indicator species for the toxic metals in the marine environment. However, the mechanisms by which the soft corals accumulate metal components should be further investigated. Periodical assessment and analysis of the pollution status in particular areas of concern will prove beneficial. Based on the outcome of such analyses we can implement effective conservation measures so that the sensitive marine habitats can be protected.

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Table 5. Bio-Accumulation Factor (BAF) for sediment (s) and seawater (w), Pollution Load Index (PLI)

Soft corals	Pb		Cd		Zn		Cr		Mn		Ni		Cu		PLI
	S	W	S	W	S	W	S	W	S	W	S	W	S	W	
Sinularia brassica	0.06	0.28	9.25	7.18	1.58	0.16	0.02	nil	0.06	1.97	0.1	0.98	0.24	nil	0.22
Sarcophyton glaucum	0.17	0.81	1.27	5.26	1.57	1.75	0	Nil	0.12	4.29	0.1	1.02	0.95	nil	0
Lobophytum sp.	0.04	0.19	0.81	3.36	3.92	4.36	0.01	Nil	0.11	3.81	0.11	1.14	1.3	nil	0.21
Subergorgia suberosa	0.04	0.18	1.06	4.37	1.02	1.13	0.01	nil	0.16	5.53	0.23	2.39	1.02	nil	0.19

5. References

Ali, A.A.M., Hamed, M.A. and El-Azim, H.A. 2011. Heavy metals distribution in the coral reef ecosystems of the Northern Red Sea. *Helgol. Mar. Res.*, 65:67-80.

Asha, P.S., Krishnakumar, P.K., Kaladharan, P., Prema, D., Diwakar, K., Valsala, K.K. and Bhat, G.S. 2010. Heavy metal concentration in seawater, sediment and bivalves off Tuticorin, *J. Mar. Biol. Assoc. India*. 52(1): 48-54.

Bastidas, C., Fabricius, K.E. and Willis, B.L. 2004. Demographic aspects of the soft coral *Sinularia flexibilis* leading to local dominance on coral reefs. *Hydrobiologia*. 530(1-3): 433–441.

Bayer, F.M., Grasshoff, M. and Verseveldt, J. 1983. Illustrated trilingual glossary of morphological and anatomical terms applied to Octocorallia. Brill, Leiden, p 75

Bazzi, AO. 2014. Heavy metals in seawater, sediments and marine organisms in the Gulf of Chabahar, Oman Sea. *JOMS*. 5(3): 20-29.

Benayahu, Y. and Loya, Y. 1986. Sexual reproduction of a soft coral: synchronous and brief annual spawning of *Sarcophyton glaucum* (Quoy & Gaimard, 1833). *Biol. Bull*. 170: 32–42.

Benayahu, Y., Van Ofwegen, L.P. and Alderslade, P. 1998. A case study of variation in two nominal species of *Sinularia* (Coelenterata: Octocorallia), *S. brassica* May, 1898, and *S. dura* (Pratt, 1903), with a proposal for their synonymy. *Zool. Verh. Leiden*. 323: 277–309.

Brown, B.E. and Howard, L.S. 1985. Assessing the effects of stress on reef corals. *Adv. Mar. Biol*. 22:1–63.

Chan, I., Tseng, L., Kâ, S., Chang, C. and Hwang, J. 2012. An experimental study of the response of the gorgonian coral Subergorgia suberosa to polluted seawater from a former coastal mining site in Taiwan. *Zool. Stud*.. 51(1): 27-37.

Chen, X., Wei, G., Deng, W., Liu, Y., Zeng, Y. and Xiea, L. 2014. Decadal variations in trace metal concentrations on a coral reef: Evidence from a 159 year record of Mn, Cu and V in a *Porites* coral from the northern South China Sea. *J. Geophys. Res*. 120(1).

Chernova, E.N. and Lysenko, E.V. 2019. The content of metals in organisms of various trophic levels in freshwater and brackish lakes on the coast of the Sea of Japan. *Environ. Sci. Pollut. Res.*, 26, 20428–20438.

Chester, R.H. 1969. *Acanthaster planci*: impact on Pacific coral reef; final report to U.S.Department of the Interior, October 15, 1969. Pittsburgh, Pennsylvania: Westinghouse electric corporation research laboratories. pp. 151.

Daly, M., Brugler, M.R., Cartwright, P., Collins, G.A., Dawson, M.N., Fautin, D.G., France, S.C., McFadden, C.S., Opresko, D.M., Rodriguez, E., Romano, S.L. and Stake, J.L. 2007. The phylum Cnidaria: a review of phylogenetic patterns and diversity 300 years after Linnaeus. *Zootaxa* 1668(1): 127–182.

Dam, J.W.V., Negri1, A.P., Uthicke, S. and Mueller, J.F. 2011. Chemical pollution on coral reefs: exposure and ecological effects, Ecological impacts of toxic chemicals, 187-211.

Depledge, M.H. and Rainbow, P.S. 1990. Models of regulation and accumulation of trace metals in marine invertebrates: a mini-review. *Comparative Biochemistry and Physiology,* 97: 1–7.ENVIS 2015, Database on Gulf of Mannar Biosphere Reserve, ENVIS centre Department of Environment, Government of Tamil Nadu, Chennai.

English, S., Wilkinson, C. and Baker, V. 1997. Survey manual for tropical Marine resources: Australian Institute of Marine Science., Townsville Australia.

ENVIS, 2015. Database on Gulf of Mannar Biosphere Reserve, ENVIS centre Department of Environment, Government of Tamil Nadu, Chennai.

Esslemont, G., Harriott, V.S., McConchie, D.M. 2000. Variability of trace metal concentration within and between colonies of *P. damicornis*. *Mar. Poll. Bull*. 40(7): 637–642.

Fabricius, K. and Alderslade. P. 2001. Soft corals & sea fans: a comprehensive guide to the tropical shallow water genera of the central-west Pacific, the Indian Ocean and the Red Sea. Australian Institute of Marine Science, pp. i-vii - 1-264.

Fallon, S.J., White, J.C. and McCulloch, M. 2002. *Porites* corals as records of mining and environmental impacts, Misima Island, Papua, New Gunea. *Geochim. Cosmochim. Acta*. 66: 45–62.

Gutiérrez-Rodríguez, C. and Lasker, H.R. 2004. Reproductive biology, development, and planula behavior in the Caribbean gorgonian *Pseudopterogirgia elisabethae. Intertebr. Biol.* 123: 54-67.

Howard, L.S. and Brown, B.E. 1984. Heavy metals and reef corals. Oceanogr Mar Biol Ann Rev 22:195–210. IMCO., (1982). Joint group of Experts on the Scientific Aspects of Marine Pollution (GESAMP). The review of the health of oceans. Rep. Stud. GESAMP., 15: 108.

Howard, L.S. and Brown, B.E. 1986. Metals in tissues and skeleton of *Fungia fungites* from Phuket, Thailand. *Mar. Pollut. Bull*. 17: 569-570.

Hwang, J.S., Dahms, H.U., Huang, K.L., Huang, M.Y., Liu X.J., Khim, J.S. and Wong, C.K. 2018. Bioaccumulation of trace metals in octocorals depends on age and tissue compartmentalization. *PLoS ONE* 13(4): e0196222.

Jafarbadi, A.R., Bakhtiari, A.R., Aliabadian, M., Laetitia, H., Toosi, A.S. and Yap, A.K. 2018. First report on bioaccumulation and bioconcentration of aliphatic hydrocarbons (AHs) and persistent organic pollutants (PAHs, PCBs and PCNs) and their effects on alcyonacea and sclersctinian corals and their endosymbiotic algae from the Persian Gulf, Iran: inter and intra-species differences. *Sci. Total Environ*. 627:141-157.

Jaffe, R. and Fernandez, C.A. 1992. Trace metal analyses in octocorals by Microwave acid digestion and graphite furnace atomic-absorption spectrometry. *Talanta*. 39(2): 113-117.

Jayaraju, N. and Reddy, K.R. 1996. Impact of pollution on coastal zone monitoring with benthic foraminifera of Tuticorin, South India. *IJMS*, 29: 376–378.

Karunanidhi, K., Rajendra, R., Pandurangan, D. and Arumugam, G. 2017. First report on distribution of heavy metals and proximate analysis in marine edible puffer fishes collected from Gulf of Mannar Marine Biosphere Reserve, South India. Toxicol. Rep. 4:319–327.

Khalafallah AA, Salem E, Wahab MAE 2019. Contamination and Hazard Indices of Heavy Metals and Natural Radionuclides Activity in Mangrove and Seagrass Habitats, Red Sea Coast, Egypt. *Middle East J. Appl. Sci*. 9(2): 502-523.

Khan, M.Z.H., Hasan, M.R., Khan, M., Aktar, S. and Fatema, K. 2017. Distribution of Heavy metals in surface sediments of the Bay of Bengal coast. *J. Toxicol*. 2017: 1-7

Krishnakumar S., Ramasamy, S., Chandrasekar, N., Simon Peter, T., Godson, P.S., Gopal, V., Magesh, N.S., 2017b. Trace element concentration in reef associated sediments of Koswari Island, Gulf of Mannar biosphere reserve, southeast cost of India. *Mar. Pollut. Bull.* 117 (1-2), 512-522.

KrishnaKumar, S., Chandrasekar, N. and Seralathan, P. 2010. Trace elements contamination in Coral Reef Skeleton, Gulf of Mannar, India. *Bull. Environ. Contam. Toxicol.* 84, 141.

Krishnakumar, S., Ramasamy, S., Chandrasekar, N., Peter, T.S., Godson, P.S., Gopal, V. and Magesh, N.S. 2017a. Spatial risk assessment and trace element concentration in reef associated sediments of Van Island, southern part of the Gulf of Mannar, India. *Mar. Pollut. Bull*.115(1-2):444-450.

Kumar, J.S.Y., Geetha, S. and Sornaraj, R. 2014. Seasonal Changes of Sedimentation Rates and Sediment Characteristics Status in the Gulf of Mannar Coral Island, India. *ILNS*. 1: 8-24.

Kumar. J.S.Y. and Geetha, S. 2012. Seasonal variations of trace metal accumulation on coral reef in Gulf of Mannar, India. *IJABPT*. 3(3):61-88.

Lithor, G. 1975. Methods for detection measurement and monitoring of water pollution, FAO. Rome, pp. 41.

Masindi, V. and Muedi, K.L. 2018. Environmental Contamination by Heavy Metals, Heavy Metals, Hosam El-Din M. Saleh and Refaat F. Aglan, IntechOpen. 115-133.

Mohammed, T.A.A. and Dar, M.A. 2010. Ability of corals to accumulate heavy metals, Northern Red Sea, Egypt. *Environ. Earth Sci*. 59: 1525-1534.

Muzik, K. and Wainwright, S. 1977. Morphology and habitat of five Fijian sea fans. Bull. Mar. Sci. 27(2): 308-337.

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(1):6-13.

Negri, A. and Heyward, A. 2001. Inhibition of coral fertilization and larval metamorphosis by tributyl tin and copper. *Mar. Environ. Res*. 51: 17-27.

Padmakumar, K. and Chandran, R. 2012. Biodiversity of Octocorals, In: Coral reefs in India- status, threats and conservation measures (eds. By Bhatt JR, Patterson Edward JK, Macintosh DJ, Nilaratna BP.), IUCN India. p.53-70.

Palanichamy, S. and Rajendran, A. 2000. Heavy metal concentrations in sea water and sediments of Gulf of Mannarand Palk Bay, southeast coast of India. *Indian J. Mar. Sci*. 29: 116 -119.

Peters, E.C., Meyers, P.A., Yevich, P.P. and Blake, N.J. 1981. Bioaccumulation and histopathological effects of oil on a stony coral. *Mar. Pollut. Bull*. 12: 333-339.

Petroody, A.S.S., Hamidian, A.H., Ashrafi, S., Eagderi, S. and Khazaee, M. 2017. Study on age-related bioaccumulation of some heavy metals in the soft tissue of rock oyster (*Saccostrea cucullata*) from Laft Port – Qeshm Island, Iran. Iran. *J. Fish. Sci*. 16(3): 897-906.

Puthiyasekar, C., Neelakantan, M.A. and Poongotha, S. 2010 . Heavy Metal Contamination in Bore Water due to Industrial Pollution and Polluted and Non Polluted Sea Water Intrusion in Thoothukudi and Tirunelveli of South Tamil Nadu, India. *Bull. Environ. Contam. Toxicol.* 85:598–601.

Rainbow, P.S. 1988. The significance of trace metal concentrations in decapods. In:Fincham AA, Rainbow PS, editors. Aspects of decapod crustacean biology. *Symp. Zool. Soc. Lond*. 59:291–313.

Rainbow, P.S. 1998. Phylogeny of trace metal accumulation in crustaceans. In: Langston, W.J., Bebianno, M, editors. Metal metabolism in aquatic environments. London: Chapman and Hall. 285–319.

Rameshkumar, S., Prabhakaran, P., Radhakrishnan, K. and Rajaram, R. 2018. Accumulation of Heavy Metals in Some Marine Fisheries Resources Collected from Gulf of Mannar Marine Biosphere Reserve, Southeast Coast of India. Proc. Zool. Soc. 71, 294–298.

Ramos, A.A., Inoue, Y. and Ohde, S.2004. Metal contents in *Porites* corals: Anthropogenic input of river run-off into a coral reef from an urbanized area, Okinawa. *Mar. Pollut. Bull.* 48: 281–294.

Ramvilas, G., Shalu, K., Raghavan, R. and Ranjeet, K. 2019. Mapping octocoral (Anthozoa: Octocorallia) research in Asia, with particular reference to the Indian subcontinent: trends, challenges, and opportunities. J. Threat. Taxa. *11*(13): 14691-14721.

Robin, R.S., Munduli, P.R., Varrdhan, K.V., Ganguly, D., Abhilash, K.R., Balasubramanian, T. 2012. Heavy metals contamination and risk assessment in the marine environment of Arabian Sea, along the southwest coast of India. *Am. J. Chem*. 2(4): 191-208.

Savari, A., Lockwood, A.P.M. and Sheader, A., 1990. Effects of season and size (age) on heavy metal concentrations of the common cockle (*Cerastoderma edule* (L.)) from Southampton Water. *J. Mollus. Stud*. 57: 45-57.

Savitha S., Srinivasalu, S, Suresh, S, Jayamoorth k 2017. Distribution of heavy metals in the Marine sediments of various sites of Karaichalli Island, Tuticorin, Gulf of Mannar, India. *Silicon*, 10, 1419-1425.

Selvam, S., Ravindran, A.A., Venkatramanan, S. and Singaraja, C. 2017. Assessment of heavy metal and bacterial pollution in coastal aquifers from SIPCOT industrial zones, Gulf of Mannar, South Coast of Tamil Nadu, India, *Appl. Water Sci*. 7(2): 897-913.

Sulochanan, P.K.B., Krishnakumar, D., Prema, P., Kaladharan, K.K., Valsala, G.S. and Muniyandi, B.K. 2007. Trace metal contamination of the marine environment in Palk Bay and Gulf of Mannar. *Mar. Biol. Ass.* 49(1): 12-18.

Szefer, P., Ali, A.A., Ba-Haroon, A.A., Rajeh, A.A., Geldonn, J. and Nabrzyski, M. 1999. Distribution and relationships of selected trace metals in mollusks and associated sediments from the Gulf of Aden, Yemen. *Environ. Pollut.* 106:299–314.

Tomilson, D.C., Wilson, J.G., Harris, C.R. and Jeffrey, D.W. 1980. Problems in assessment of heavy metals in estuaries and the formation of pollution index. *Helgol. Meeresunlters*. 33: 566-575.

Tornero, V. and Hanke, G. 2016. Chemical contaminants entering the marine environment from sea-based sources: A review with a focus on European seas. *Mar. Pollut. Bull*. 112 (1-2): 17-38.

Turner, A. 2010. Marine pollution from antifouling paints. *Mar. Pollut. Bull.* 60, 159–171.

Verseveldt, J. 1982. A revision of the Genus Sarcophyton lesson (Octocorallia, Alcyonacea), *Zoolo. Verh. Lingen*. no 192, Leiden, 91 p.

Verseveldt, J. 1983. A revision of the genus *Lobophytum* Von Marenzeller (Octocorallia, Alcyonacea). *Zool. Verh*. Leiden 200: 1– 103.

Wang, W.X. 2002. Interaction of trace metal and different marine food chain. *Mar. Ecol. Prog. Ser.*, 243: 295-309.

Williams, G.J., Gove, J.M., Eynaud, Y., Zgliczynski, B.J. and Sandin, S.A. 2015. Local human impacts decouple natural biophysical relationships on Pacific coral reefs. Ecography. 38:1–11.

Wyers, S.C., Frith, H., Dodge, R.E., Smith, S., Knap, A.H. and Sleeter, T. 1986. Behavioural effects of chemically dispersed oil and subsequent recovery in *Diploria strigosa* (Dana). Mar. Ecol. 7: 23-42.

Yamazato, K., Sato, M. and Yamashiro, H. 1981. Reproductive biology of an alcyonacean coral, Lobophytum crassum Marenzeller. Proceedings of the 4th International Coral Reef Symposium, Manila. 2: 671-678.