Report for 2003GU22B: Persistent Pollutants in Biotic Components of Tanapag Lagoon, Saipan, with Emphasis on Areas Impacted by Streams, Storm Water Runoff and Sewer Outfalls

There are no reported publications resulting from this project.

Report Follows

PROJECT SYNOPSIS REPORT

Project Title: Persistent Pollutants in Biotic Components of Tanapag Lagoon, Saipan, with Emphasis on Areas Impacted by Streams, Storm Water Runoff and Sewer

Problem and Research Objectives

Tanapag Lagoon borders the western shore of central Saipan. It harbors a rich diversity of marine life and supports a variety of commercial and recreational activities. Over the last quarter century, Tanapag Lagoon has become heavily impacted by the activities of man. Primary sources of anthropogenic disturbance in these waters include a power station and commercial port (Saipan Harbor), two small boat marinas, a sewer outfall, several garment factories, auto and boat repair shops, wood shops, government vehicle maintenance yards, a commercial laundry, and an acetylene gas producer. There are also a number of old military dumps and disposal sites in the area as well as a municipal dump that has served as the island's only solid waste disposal site for the last 50 years. Several streams and storm drains empty into the lagoon during the rainy season and provide a mode of transport into the ocean for any land-based contaminants. Overflows from sewer lines are also commonplace at this time of the year and the whole area is inundated by storm water runoff during periods of prolonged wet weather. The effects of these perturbations on the indigenous biota within the lagoon are largely unknown. Likewise, fundamental data describing the abundance and distribution of persistent and potentially toxic pollutants within the system is also lacking. Mindful of these shortcomings, a contaminant assessment of surface sediments within Tanapag Lagoon was recently completed.

The study reported here examined contaminants of potential concern (heavy metals, PCB, and pesticides) in biotic components of the lagoon and was seen as a logical extension of the work already completed. The primary objectives of the study were to establish a reliable contaminant database with which future findings can be compared and evaluated; identify 'hotspots' and delineate areas of contaminant enrichment within the study area, and assess the degree of biotic contamination in Tanapag Lagoon by reference to levels reported for similar and related species from clean and polluted environments in tropical regions from elsewhere in the world, including Guam. Potential health risks (if any) associated with the long-term consumption of edible resources surveyed are also being evaluated.

Methodology

The study focused on dominant organisms inhabiting the shallow nearshore waters of the lagoon with emphasis on groups with high bioindicator potential that were either sessile or are restricted in their movement e.g., algae, seagrasses, seacucumbers, bivalves and juvenile fish. Representatives of these were collected from 12 intertidal sites between Muchot Point and San Roque village in the southern and northern ends of the lagoon respectively (Fig. 1). Sites 1-9 were impacted by land-based sources of contamination of one sort or another while sites 10-12 were not and served as useful reference sites. A list of all the animals and plants collected for analysis at each site are presented in Table 1. Surface sediments (top 2 cm) were also collected for analysis from each location.

Figure 1: Map of northern Saipan showing biota sampling sites 1-12

The fish were captured by cast-net at high tide tide. All other organisms were hand picked off bottom substrates by wading through the shallows at low tide. A small aluminum rake was used to recover the bivalves from sediments in which they were buried. All samples were cleaned of conspicuous surface debris immediately upon collection. The algae, seagrasses, seacucumbers and bivalves were transported to the laboratory in clean seawater while the fish were immediately placed on ice.

In the laboratory, the algae, seagrasses and seacucumbers were processed immediately; the latter samples being separated into body wall and hemal tissue. Only the youngest portions of the algae and seagrasses were taken for analysis, as these were relatively free of epiphytic growth and adhering sediments and minimized variations in contaminant concentrations associated with growth. The bivalves were held in clean seawater for an additional 24 hours to clear their gut contents and were subsequently analyzed whole. All samples were stored at -20^{0}C until required for analysis. Those required for metal analysis were stored in acid cleaned polypropylene vials while those for PCB and pesticide analysis were individually wrapped in aluminum foil and sealed in Ziploc® bags prior to freezing.

To date, all samples have been analyzed for heavy metals. The PCB and pesticide analyses are currently underway. Analytical protocols are as previously described in Denton *et al.* (1997, 1999, 2000).

Flora and Fauna Sampled During Present Study												
Species	**Sites**											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
ALGAE:												
Acanthophora spicifera	x	x	x	x					x	x		
Dictyota bartayresiana											x	
Gracilaria salicornia					x	x		x	x			
***Padina* sp.**		x	x	x			x		x	x	x	x
Sargassum polycystum											x	
SEAGRASS:												
Enhalus uninervis	x	x		x	x	x	x	x	x			
Halodule					x				x	x	x	
SEA CUCUMBERS:												
Bohadschia argus								x				
Bohadschia mormorata			x	x	x	x						
Holothuria atra	x	x	x	x	x	x	x	x	x	x	x	x
Holothuria hilla						x						
BIVALVES:												
Asaphia violascens		x										
Atactodea striata	x						x		x	x	x	x
Ctena bella	x											
Gafrarium pectinatum		x	x		x	x						
Quidnipagus palatum		x	x		x	x						
FISH:												
Caranx sexfasciatus	x	x		x		x	x					
Gerres argyrus	x	x	x	x	x	x	x	x				
Mulloides vanicolensis	x	x	x	x		x	x	x	x	x	x	x
Valamugil engeli	x	x	x	x	x	x						

Table 1. A list of all the animals and plants sampled from Tanapag Lagoon

Principal Findings and Significance

Sediments:

Sediment analysis revealed distinct copper, lead and zinc enrichment around the SW edge of the Puerto Rico dump (site 2), the area between the Seaplane Ramps (site 4) and immediately adjacent to the power plant and DPW maintenance yard (site 5). Sediments collected near dump were also noticeably enriched with silver, cadmium, chromium, mercury and nickel (Table 2). Elevated mercury concentrations were also evident in sediments from the mouth of Saddock Dogas (site 8), a small stream south of Tanapag village that receives drainage from an old military dumpsite ~1 km inland. Metal levels at all other sites were unremarkable and indicative of relatively mild impaction from surface runoff and stream discharges in the area.

Biota:

From Table 1, it can be seen that not all species chosen for analysis were available at all sites of interest. Those that were most widely represented were the brown alga, *Padina* sp., the seagrass, *Enhalus uninervis,* the seacucumber, *Holothuria atra*, the bivalves, *Atactodea striata* (sandy shores), *Gafrarium pectinatum* and *Quidnipagus palatum* (muddy shores), and the goatfish *Mulloides vanicolensis.* Consequently, only data summaries for these organisms are presented here.

Site	Location	Concentration (µg/g dry weight)							
		Ag	Cd	Cr	Cu	Hg*	Ni	Pb	Zn
1	Micro Beach	<0.20	0.20	3.27	0.50	3.70	<0.20	0.65	2.42
2	Peurto Rico Dump (SW side)	0.75	1.69	17.5	102	74.7	11.9	158	358
3	Echo Bay (S end)	<0.21	0.31	2.56	6.76	18.1	<0.20	3.19	7.39
4	Sea Plane Ramps	<0.15	0.23	2.83	39.8	23.0	0.89	17.7	84.0
5	Power Plant (N side)	<0.16	0.32	4.61	5.34	24.2	0.94	21.3	26.4
6	Lower Base Drainage Channel	<0.1	0.24	2.43	1.34	10.9	0.46	1.78	6.00
7	Tanapag 1 (Saddock As Agatan)	<0.17	0.17	3.08	4.70	6.90	0.85	0.84	15.1
8	Tanapag 2 (Saddock Dogas)	<1.18	0.18	3.67	5.79	50.2	1.16	1.33	18.5
9	Tanapag 3 (Bobo Achugao)	<0.17	0.17	1.42	4.80	3.28	0.25	4.07	12.1
10	Plumaria Hotel Beach (N end)	<1.18	0.18	2.78	2.53	4.37	0.26	2.19	12.0
11	San Roque Cemetary (Hotel Desalin Stream)	<0.15	0.22	1.71	0.60	2.38	0.22	1.08	3.73
12	Pau Pau Beach Park	<0.18	0.27	1.52	2.70	3.31	0.44	1.16	4.49

* mercury concentrations expressed as ng/g dry weight

Table 2: Heavy metals in sediments from Tanapag Lagoon, Saipan (2003)

Table 3 summarizes the range of heavy metal concentrations found in the most common and widespread biota sampled throughout the study area. As fish generally have relatively poor bioindicator capabilities for heavy metals, other than mercury, only the latter element was examined in this group. Moreover, only fish axial muscle was analyzed since this represents the tissues most commonly consumed by man.

Specimen	Tissue	Total Sites	Concentration (µg/g dry wt.)							
			Ag	Cd	Cr	Cu	Hg*	Ni	Pb	Zn
ALGAE										
Padina	yound frond	8	<0.09 - 0.29	<0.11 - 1.72	<0.30 - 1.43	1.3 - 25.3	0.41 - 6.44	0.9 - 1.65	<0.27 - 14.7	10.6 - 107
SEAGRASS										
Enhalus uninervis	young leaf	8	all <0.20	0.15 - 0.60	<0.30 - 0.87	1.03 - 49.5	0.37 - 3.18	0.60 - 2.34	<0.22 - 2.05	20.5 -32.9
SEACUCUMBER										
Holothuria atra	body wall	12	all <0.13	all <0.12	<0.28 - 0.66	0.96 - 3.10	0.45 - 4.54	<0.12 - 0.45	<0.15 - 2.07	13.1 - 24.1
	hemal system	12	<0.7 - 0.25	<.08 - 1.3	<0.26 - 4.99	2.8 - 11.2	5.53 - 63.2	<0.12 - 0.77	<0.11 - 6.33	29.8 - 287
BIVALVE										
Atactodea stiata	whole flesh	6	<0.14 - 5.08	0.08 - 5.45	<0.52 - 6.56	7.35 - 20.2	15.3 - 23.8	2.01 - 4.76	<0.39 - 3.14	71.8 - 147
Gafrarium pectinatum	whole flesh	4	<0.14 - 0.62	0.69 - 1.79	0.58 - 1.31	6.69 - 35.3	9.91 - 23.3	10.6 - 14.1	7.97 - 54.2	42.3 - 63.2
Quidnipagus palatum	whole flesh	4	0.32 - 19.8	0.17 - 1.4	4.81 - 10.6	14.7 - 1876	44.3 - 111	7.30 - 13.1	9.01 - 148	305 - 1027
FISH										
Mulloides vanicolensis	axial muscle	11	-	-	-	-	<0.5 - 43.2	-	-	-

* all mercury data expressed as ng/g wet weight; dashes indicate no data

Table 3: Heavy metals in selected marine organisms from Tanapag Lagoon, Saipan (2003)

While the different organism displayed widely differing affinities for the various elements examined, the bivalves and seacucumbers generally mirrored the metal distribution profiles demonstrated by sediments, particularly for copper, lead and zinc. This is to be expected as these organisms derive their metal load primarily through the ingestion of sediments and suspended particulates. The algae and seagrasses, on the other hand, are unique in that they largely reflect the soluble metal fraction and, as such provide a useful means of determining the biologically available fraction of metals in the water column rather than in the sediments. Consequently metal distribution profiles portrayed by algae and seagrasses are frequently quite different than those demonstrated by sediment ingesters like bivalves and seacucumbers. Metal profiles depicted by *Padina* provide a good example of this. For example, specimens collected from Seaplane Ramps contained approximately ten times more copper, three times more lead and five times more zinc than those near the dump (site 2). Sediments, on the other hand, were appreciably higher in all three metals at the latter site. Thus, *Padina* is telling us that dissolved levels of copper, lead and zinc are relatively high in the water column around the seaplane ramps compared to with the dump. As the former area serves as a dry dock facility, it is likely that *Padina* is ‘seeing’ soluble contributions associated with boat maintenance and repair activities, and possibly antifouling paints. It is also noteworthy the same three metals were relatively enriched in *Padina* from Echo Bay (site 3) in sharp contrast to the picture presented by sediment from this area. Again, the relatively high incidence of boat maintenance and repair activities at this location is the most likely explanation for this.

Like *Padina*, the seagrass, *Halodule uninervis*, also appears to be a very sensitive indicator of dissolved copper with levels approaching 50 µg/g in samples collected from the Seaplane Ramp area compared with only ~8 µg/g near the dump. Lead levels were also marginally higher in samples from the former site (2.05 µg/g vs. 0.71 µg/g) while zinc was similar at both sites (29.0 µg/g vs. 32.6 µg/g). It is possible that seagrasses have some regulatory capability for the latter element

As expected, mercury levels in the juvenile fish examined were all very low. A project is currently underway to determine levels of this element (and other contaminants) in larger specimens popularly taken for food from further offshore in the lagoon.

Where possible, the data gathered from the current work were compared with levels found in similar and related species from tropical waters elsewhere in the world. Several examples are cited in Table 4 for specimens collected from Guam and within the Australian Great Barrier Reef province. From such comparisons, a preliminary appraisal of the degree of heavy metal contamination exhibited by the biotic resources from within Tanapag Lagoon is possible. Clearly, there is significant copper, lead and zinc enrichment in sediments from the southern portion of Tanapag Lagoon. Biologically available levels of all three metals are also notably increased in this region. Copper is probably the element of greatest concern followed by lead and then zinc.

Species	Location	Ag	Cd	Cr	Cu	Ni	Pb	Zn	Hg[a]	Reference
BROWN ALGAE:										
Padina australis	Gt. Barrier Reef, Australia	nd	0.4-0.6	nd	2.0-3.0	1.0-1.4	<0.9-5.0	3.8-9.5	0.001-0.004	Denton & Burdon-Jones 1986a
Padina commersonni	Singapore coastal waters	nd	0.4-0.6	2.9-6.5	3.8-7.3	4.0-6.5	4.3-7.9	20.7-50.1	<0.01[b]	Bok & Keong 1976
Padina gymnospora	Puerto Rico	nd	nd	nd	nd	23.0-32.0	nd	nd	nd	Stevenson & Ufret 1966
Padina tenuis	Penang Island, Malaysia	nd	7.1	25.6	5.7	nd	17.1	45.5	1.025[b]	Sivalingam, 1978, 1980
Padina tenuis	Townsville coastal waters, Australia	<0.1-0.4	0.2-1.4	1.4-10.0	1.4-5.1	0.7-8.4	<0.3-6.2	3.7-30	nd	Burdon-Jones *et al.* 1982
Padina tetrostromatica	Goa coastal waters, India	nd	nd	nd	3.2-7.9	8.0-18.3	3.0-28.3	4.5-11.7	nd	Agadi *et al.* 1978
Padina tetrostromatica	" " " "	nd	nd	nd	8.7-20.1	nd	nd	20.2-31.5	nd	Zingde *et al.* 1976
Padina tetrostromatica	Townsville coastal waters, Australia	<0.1-0.4	0.2-1.2	1.6-8.3	2.0-9.7	0.9-4.0	1.1-4.9	5.5-25.7	nd	Burdon-Jones *et al.* 1982
Padina tetrostromatica	Townsville Harbor (lower reaches)	<0.1-0.4	0.2-0.6	2.1-9.9	4.4-11.1	0.7-5.6	2.0-10.2	67.2-166	nd	Burdon-Jones *et al.* 1982
Padina tetrostromatica	" " (upper reaches)	<0.1	<0.4	31.5	58.9	13.1	108	440	nd	Burdon-Jones et al.1975
Padina sp.	Israeli coast	nd	nd	nd	nd	nd	nd	nd	0.065[b]	Hornung *et al.* 1981
Padina sp.	Penang Island, Malaysia	nd	nd	nd	nd	nd	nd	nd	0.100[b]	Sivalingam 1980
Padina sp.	Lizard Island, Great Barrier Reef	nd	0.2	nd	2.2	1.1	<0.74	5.9	0.002	Denton & Burdon-Jones 1986a
Padina sp.	Agana Boat Basin, Guam	0.89	0.3	0.68	1.53	1.18	0.46	11	<0.002	Denton *et al.* 1999
Padina sp.	Apra Harbor, Guam	<0.1-<0.1	0.2-0.5	1.3-3.0	2.6-36.6	1.1-3.2	2.6-6.5	45.1-192	0.007-0.026	Denton *et al.* 1999
Padina sp.	Agat Marina, Guam	<0.1	<0.1	2.7	4.1	2.9	<0.25	18.7	<0.002	Denton *et al.* 1999
Padina sp.	Merizo Pier, Guam	<0.1	<0.1	14.1	27.2	2.28	8.07	78.3	0.003	Denton *et al.* 1999
SEAGRASSES:										
Halodule uninervis	Cleveland Bay, Townsville, Australia	<0.3	0.5	1.6	2.7	0.7	7	11.0	nd	Denton *et al.* 1980
Zostera capricornia	Upstart Bay, N Queensland, Australia	<0.2	0.2	0.9	3	0.6	0.4	18.0	nd	Denton *et al.* 1980
Zostera capricornia	Shoalwater Bay, N. Queensland, Australia	<0.2	0.2	1.9	2.8	1.8	0.4	14.0	nd	Denton *et al.* 1980
SEA CUCUMBERS:										
Holothuria sp. (whole)	Japanese waters	nd	nd	nd	1.9[c]	nd	14.4[c]	8.7[c]	nd	Matsumoto 1964
Holothuria sp. (whole)	Townsville coastal waters, Australia	all <0.2	<0.2	<0.3-6.3	<0.3-3.5	all <0.5	<0.4-3.8	13.9-39.4	nd	Denton, unpublished data
Holothuria atra. (muscle)	Agana Boat Basin, Guam	0.2	0.1	<0.1	1.4	<0.2	<0.4	12.6	0.008	Denton *et al.* 1999
Holothuria atra. (hemal)	" " " "	0.7	0.12	3.1	6.4	<0.4	<0.72	117	0.091	Denton *et al.* 1999
Holothuria atra. (muscle)	Apra Harbor, Guam	all <0.1	<0.1-0.1	<0.1-0.3	0.7-1.2	<0.2	all <0.3	15.5-17.9	0.007-0.008	Denton *et al.* 1999
Holothuria atra. (hemal)	" " "	4.9	0.26	8.6	5.19	<0.5	<0.8	180	0.088	Denton *et al.* 1999
Holothuria atra. (muscle)	Agat Marina, Guam	<0.2	<0.1-0.1	<0.1-<0.2	1.3-1.7	<0.2-<0.3	<0.4-<0.6	15.4-17.0	0.022-0.014	Denton *et al.* 1999
Holothuria atra. (hemal)	" " "	<0.2	0.1	0.9	3.7	<0.3	<0.5	141	0.072	Denton *et al.* 1999
Holothuria atra. (muscle)	Merizo Pier, Guam	<0.1	0.1	<0.2	2.5	<0.2	<0.4	21.2	0.008	Denton *et al.* 1999
Holothuria atra. (hemal)	" " "	<0.1	0.1	2.9	3.8	<0.2	<0.3	253	0.016	Denton *et al.* 1999
BIVALVES:										
Atactodea striata	Magnetic Island, N. Queensland, Australia	0.8	1.1	1.8	13	2.4	2.0	138	nd	Burdon-Jones et al.1975
Gafrarium tumidum	" " " "	5.7	0.3	1.6	7.1	11.9	3.1	68.8	nd	Burdon-Jones et al.1975
Gafrarium tumidum	Red Rock Bay, Townsville, Australia	5.3	0.3	0.6	7.7	14.5	5.1	26.3	nd	Burdon-Jones et al.1975
FISH (Muscle)										
50 spp.	Great Barrier Reef, Australia	nd	all <0.1	nd	0.47-2.4	all <0.5	all <0.7	4.3-41.8	<0.002-1.9	Denton & Burdon-Jones 1986c
8 spp.	Agana Boat Basin, Guam	all <0.2	all <0.1	<0.1-0.6	0.3-0.8	all <0.4	all <0.9	8.4-48.9	0.009-0.165	Denton *et al.* 1999
17 spp.	Apra Harbor, Guam	<0.1-0.2	all <0.1	all <0.5	0.5-7.8	all <0.4	all <0.8	8.3-34.2	0.012-0.660	Denton *et al.* 1999
6 spp.	Agat Marine, Guam	all <0.2	all <0.1	all <0.3	0.3-0.9	all <0.4	all <0.8	11.5-24.3	0.003-0.214	Denton *et al.* 1999
10 spp.	Merizo Pier, Guam	<0.1-0.3	all <0.1	<0.1-0.5	0.3-0.8	<0.2-<0.7	<0.4-<1.3	9.6-24.3	0.011-0.066	Denton *et al.* 1999

a = Hg determined as ug/g wet weight; b = Hg determined as ug/g dry weight; c = metal determined on a wet weight basis; nd = no data

Table 4: Heavy metals in marine organisms (μg/g dry wt.) from other parts of the world

Literature Cited

Agadi, V.V., N.B. Bhosle and A.G. Untawale (1978). Metal Concentration in Some Seaweeds of Goa (India). *Botanica Marina,* XXI: 247-250.

Bok, C.S. and W.M. Keong (1976). Heavy Metals in Marine Biota from Coastal Waters around Singapore. *Journal of the Singapore National Academy of Science.* 5: 47-53.

Burdon-Jones, C., G.R.W. Denton, G.B. Jones and K.A. McPhie (1975). Long-Term Sub-Lethal Effects of Metals on Marine Organism. Part I Baseline Survey. *Final Report to the Water Quality Council of Queensland, Australia*. 105 pp.

Burdon-Jones, C., G.R.W. Denton, G.B. Jones and K.A. McPhie (1982). Regional and Seasonal Variations of Trace Metals in Tropical Phaeophyceae from North Queensland. *Marine Environmental Research,* 7: 13-30.

Denton, G.R.W., H. R. Wood, L.P. Concepcion, H.G. Siegrist, V.S. Eflin, D.K Narcis and G.T. Pangelinan (1997). Analysis of In-Place Contaminants in Marine Sediments from Four Harbor Locations on Guam. A Pilot Study. *Water and Energy Research Institute of the Western Pacific, University of Guam, Technical Report No. 81*. 120 pp.

Denton, G.R.W., L.P. Concepcion, H.R. Wood, V.S. Eflin and G.T. Pangelinan (1999). Heavy Metals, PCBs and PAHs in Marine Organisms from Four Harbor Locations on Guam. A Pilot Study. *Water and Environmental Research Institute (WERI) of the Western Pacific Technical Report***,** No. 87, June 30, 1999. 154 pp.

Denton, G.R.W., B.G. Bearden, L.P. Concepcion, H.G. Siegrist, D.T. Vann and H. R. Wood, and (2001). Contaminant Assessment of Surface Sediments from Tanapag Lagoon, Saipan. *Water and Environmental Research Institute (WERI) of the Western Pacific Technical Report* No. 93, December 2001 110 pp plus appendices.

Denton, G.R.W. and C. Burdon-Jones (1986a). Trace Metals in Algae from the Great Barrier Reef. *Marine Pollution Bulletin,* 17: 98-107.

Denton, G.R.W. and C. Burdon-Jones (1986b). Trace Metals in Fish from the Great Barrier Reef. *Marine Pollution Bulletin,* 17: 201-209.

Denton, G.R.W., H. Marsh, G.E. Heinsohn and C. Burdon-Jones (1980). The Unusual Metal Status of the Dugong, *Dugong dugong*. *Marine Biology,* 57: 201-219.

Hornung, H., D. Ravi and B.S Trugalz (1981). The Ocurrence of Mercury in Marine Algae and Some Gastropod Molluscs of the Mediterranean Shoreline of Israel. *Marine Pollution Bulletin,* 12: 387-389.

Matsumoto, T., M. Satake, Y. Yamamoto and S. Haruna (1964). On the Microconstituent Elements in Marine Invertebrates. *Journal of the Oceanography Society of Japan*, 20: 15-19.

Sivalingam, P.M. (1978). Biodeposited Trace Metals and Mineral Content Studies of Some Tropical Marine Algae. *Botanica Marina*, XXI: 327-330.

Sivalingam, P.M. (1980). Mercury Contamination in Tropical Algal Species of the Island of Penang, Malaysia. *Marine Pollution Bulletin*, 11: 106-107.
Sivalingam, P.M. (1978). Biodeposited Trace Metals and Mineral Content Studies of Some Tropical Marine Algae. *Botanica Marina*, XXI: 327-330.

Sivalingam, P.M. (1980). Mercury Contamination in Tropical Algal Species of the Island of Penang, Malaysia. *Marine Pollution Bulletin*, 11: 106-107.
Stevenson, R.A. and Ufret, S.L. (1966). Iron, Manganese and Nickel in Skeletons and Food of the Sea Urchins *Tripneustesesculentus* and *Echinometra lucunter. Limnology and Oceanography*, 11: 11-17.

Zingde, M.D., S.Y.S. Singbal, C.F. Moraes and C.F.G. Reddy (1976). Arsenic, Copper, Zinc, and Manganese in the Marine Flora and Fauna of Coastal and Estuarine Waters around Goa. *Indian Journal of Marine Science*, 5: 212-217.