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Benthic foraminifera in moderately polluted coasts of Iligan City, Philippines: Diversity and abundance

Shiela M. Ganaway, Maria L. D. G. Lacuna

Department of Biological Sciences, College of Science and Mathematics, Mindanao State University-Iligan Institute of Technology, Andres Bonifacio Avenue, Iligan City, Philippines. Corresponding author: M. L. D. G. Lacuna, mileskung@yahoo.com

Abstract. Composition, diversity, abundance of living benthic foraminifera and their relationship with the environmental parameter, *viz*. water quality, organic matter and heavy metal contents, size of the sediments, were determined. A total of 29 foraminiferan species belonging to 20 genera under 16 families were identified in the living foraminiferal assemblage in the three sampling stations where nearby industries are located. Values for foraminifera abundance, density, diversity and equitability (eveness) clearly showed variations between the three sampling areas in Iligan City where nearby industries are located. In particular, the living foraminiferal assemblages in stations 2 and 3 were quite diversified whereas station 1 was poorly diversified, with less number of living individuals being recorded. The low species diversity and equitability but high dominance values observed in station 1 further revealed the sole dominance of one species, *Quinqueloculina bicostata*, in the foraminiferal community structure. Conversely, the high diversity and equitability but low dominance values recorded in station 3 further justified the even distribution of foraminiferan species in terms of their abundance in this particular area. The present data reflected in the Canonical Correspondence Analysis did not show any direct influenced of the heavy metals in the sediments to the foraminiferal assemblage in the three sampling areas. Although the copper concentration in station 3 is above the ERL (Effects Range-Low) value set by USEPA (Cu: ERL = 228.9 ppm or $mgKg^{-1}$), such value may not be enough to cause decreased diversity of the living foraminiferal assemblage nor high dominance of opportunistic species. Instead, high foraminiferal diversity, as manifested in the high H' and J values, observed in station 3 may be influenced by high chlorophyll *a* in the particular station. Although heavy metals did not seemed to influenced the different responses of benthic foraminiferal structure, the mere presence of these trace elements, even below or above ER-L levels, and the dominance of one species may imply the strong potential of the areas to progress from being moderately polluted ones into highly polluted environments if conservation measures and biomonitoring will not be strictly implemented. Moreover, the present findings further confirm the potential of *Q. bicostata* as good candidate for biological indicator in moderately to highly polluted environments thereby making benthic foraminifera as suitable device/tool for in situ continuous monitoring of anthropogenic pollution in coastal marine ecosystems.

Key Words: Tropical benthic foraminiferans, foraminiferal assemblage, environmental parameter, *Q. bicostata*.

Introduction. Coastal marine to brackish water environment have served as the ultimate destination of virtually all terrestrial runoffs and a recipients for various kinds of anthropogenic wastes. Population growth resulting to acceleration of domestic, municipal, industrial, agricultural and recreational activity were the primary causes of these pollution in the marine realm. These activities have, in many cases, severely affects the local biota and the shallow near shore marine environment are particularly subject to frequent and extensive industrial and municipal pollution. Being one of the most common and naturally-occurring meiofaunal benthic components in these areas, foraminifera play a significant role and can be considered as an excellent tool to characterize both abiotic conditions and environmental quality of marine ecosystems (Alve 1995a; Kravchuk 2006; Aloulou et al 2012). Foraminifera are single-celled, heterotrophic, amoeboid marine protozoa which are characterized by the presence of pseudopodia (a cylindrical extensions of the cytoplasm, radiating away from the test surface and the apertural face) and a test or a shell (Gooday et al 1992). Most foraminifers are herbivores, carnivores, omnivores, or scavengers although cannibalism, parasitism, mixtophy and osmotrophy have recently been demonstrated in some shallow-water species (Lipps 1983). Benthic foraminifera that are active herbivores graze on algae and bacteria while they move on their substrate. On the other hand, passive herbivores capture their food (diatoms) around the site where they are fixed. The carnivorous type however, preys on small arthropods and other foraminifera. The majority of the foraminifera living in the fine sediment under the photic zone consume detritus and bacteria. They pre-dominate in the uppermost levels (1 - 2 cm) of the sediment. Most benthic foraminifera are opportunistic omnivores but many large forms have symbiotic algae that aid in supplying energy. Sequentially, they become a food source by other organisms like worms, gastropods, crustaceans, echinoderms, fishes and other larger organisms. In the concept of “eat and be eaten”, foraminifera are very important in the marine food chain. They feed on dissolved organic matter (DOM), total organic carbon (TOC), total organic nitrogen (TON) and amino acid in which larger organisms in higher trophic level cannot utilize but prey on the foraminifera instead, making them a vital link between trophic levels (Lipps & Valentine 1970; Gooday et al 1992). Foraminifera also play a significant role in global biogeochemical cycles of inorganic and organic compounds, making them one of the most important animal groups on earth (Kravchuk 2006). Benthic foraminifera caught the attention of many researchers not just because of their importance and contribution to the marine food chain but because of their relevance in the marine environment especially to polluted areas. The concept of anthropogenic impact is extremely important to be considered while analyzing the ecology of coast and shelf zones. For centuries, these zones have been the epicenters for various human activities including urbanization, construction of sea ports and harbors, development of natural reservoirs (including oil production and fishing) marine aquaculture, shipping, recreation and many others (Jayaraju et al 2011). These huge amounts of pollutants actually results in changing the normal hydrographic conditions of these environments since these changes maybe significant in disturbing the natural ecosystem (Abou-Ouf & El-shater 1991). Because of their abundance, diversity and high preservation potential (Alve 1991; Yanko et al 1994), benthic foraminifera are used as bio-indicators in these polluted areas to assess environmental conditions and monitor the polluted coastal marine environment due to their rapid response to contaminants and changes in sediment composition (Yanko et al 1994; Samir & El-Din 2001; Mojtahid et al 2008).

Despite the increased numbers in the studies of benthic foraminiferal ecology in developed countries, works done in Iligan Bay were limited to those of Lacuna et al (2013) and other preliminary studies done by students of the Mindanao State University-Iligan Institute of Technology. In order to address this gap, this study was carried out to investigate the composition, diversity and abundance of foraminiferan species and to get a general view of the water quality conditions of the bottom water as well as the sediment contents and structure of the areas. The data generated from this study will show the health condition of the coastal waters where nearby industries are located and confirm benthic foraminifera as suitable device/tool for *in situ* continuous monitoring of anthropogenic pollution in coastal marine ecosystems.

Material and Method. Iligan Bay is located in Mindanao (Figure 1), with a latitude of 8.42 (8° 25' 0 N) and a longitude of 124.08 (124° 4' 60 E). It has an estimated coastline of 170 km with surface area of about 2,390 km^3. It connects with Panguil Bay on the south western part and opens to Bohol Sea in the north (Quiñones et al 2002). A total of 27 rivers and 42 minor tributaries are identified which carry freshwater and transport nutrients and sediments into the bay. Iligan Bay is recognized by the Philippine Bureau of Fisheries and Aquatic Resources (BFAR) as a major fishing ground for its rich in fishery resources such as fish, algae and mollusks and serves as an important food producer and as a living space for wildlife assemblages. Within the coastal waters in Iligan City, the study was carried out in September 2012 in the three sampling stations where nearby industries are present. These sampling stations were established near the coastline with a depth of 7 - 10 m (Figure 1). Station 1 was established in front of Shell-Iligan Depot located at Barangay Tominobo that supplied petroleum products since 1975.

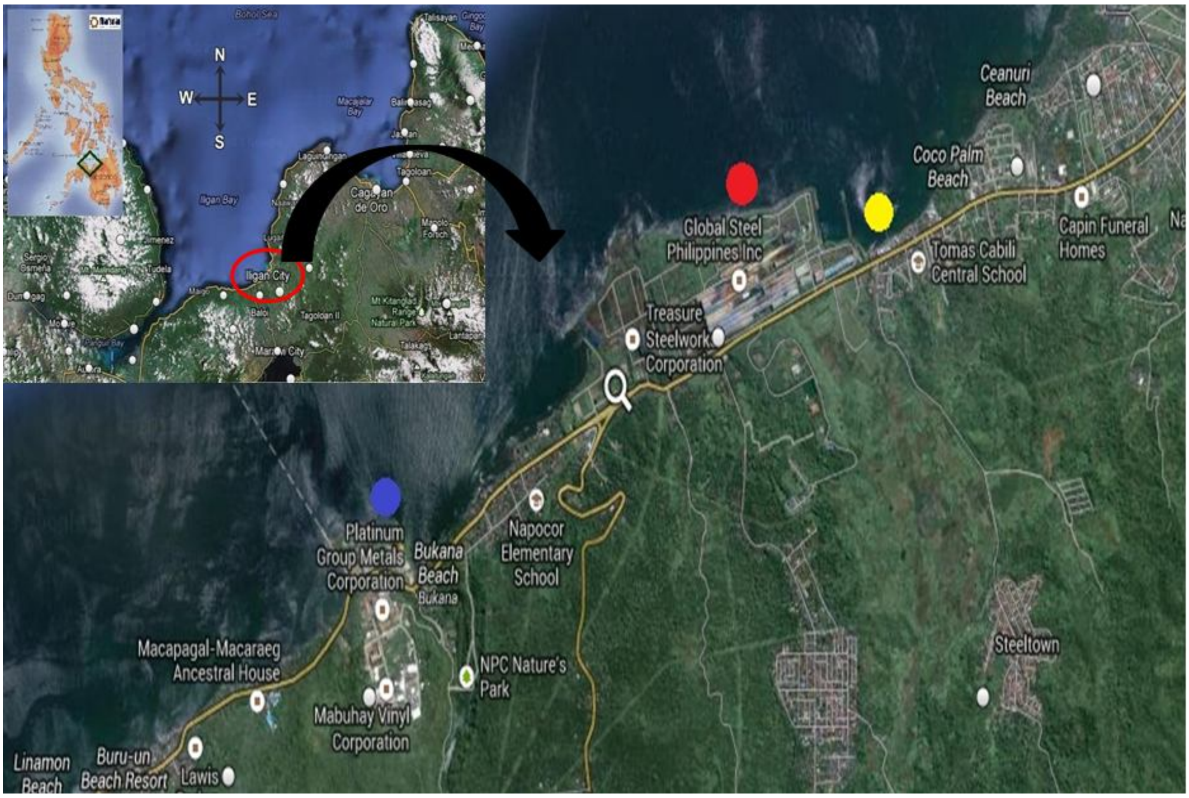

Figure 1. Geographical location of the three sampling stations where foraminifera were collected. Inset is Iligan Bay with Iligan City enclosed in a red circle. Legend: ● Station 1 - Shell-Iligan City Depot; ● Station 2 - Global Steel Inc.; ● Station 3 - PGMC.

Station 2 was situated in the front of the Global Steel Inc., which has become one of the largest steel manufacturers in ASEAN and was established in 1962. At present, it has four main operating mills, hot mills, billet plant and thinning line at Barangay Suarez, Iligan City. Station 3 was established facing the Platinum Group Metals Corporation (PGMC) formerly known as Maria Cristina Chemical Industries Inc. (MCCI), a ferro-nickel smelting plant located at Barangay Maria Cristina, Iligan City.

Methods for the field collections and laboratory analyses employed in the present study were patterned from those of Lacuna et al (2013). Field data like bottom water temperature, pH, salinity and dissolved oxygen were measured *in situ* in each of the three sampling stations using portable pH meter (Eutech Instruments), handheld refractometer (ATAGO) and DO meter (Eutech Instruments Ecosan DO6), respectively.

Likewise, sediments for organic matter content (such as calcium carbonate, total organic matter and chlorophyll *a*) determination were collected using a syringe with its tip being cut off (4 cm inner diameter, 10 cm length). Employing the aid of a diver, the corer was pushed into the top 1 - 2 cm of the sediment. Calcium carbonate and total organic matter concentration were measured following the method described by Moghaddasi et al (2009).

Chlorophyll *a* was extracted in acetone following the method described by Liu et al (2007) and read on a spectrophotometer. Grain size was collected from each sampling station using a grab sampler and was analyzed by sieving 100 g oven-dried sediment using a series of sieves of 2.00 mm, 0.841 mm, 0.595 mm, 0.31 mm, 0.149 mm, and 0.074 and 0.053 mm mesh opening. The remaining soil particles in each sieve were carefully removed and weighed separately. The percentage of each particle fraction was calculated and classified based on the Wentworth grade classification of particle size. Separate core samples from the top 1 cm of the sediment were also collected in the three sampling stations for foraminiferan analysis. The sample was placed into a properly labeled bottle and preserved and stained with a solution of 10 % formalin (buffered with sodium borate) already added with Rose Bengal stain to a concentration of 2.0 g/L. Rose

Bengal stain was used in order to determine the presence of live foraminifera during the time of collection. The stained sediment samples were gently mixed so that the foraminiferans within the interstitial spaces of the sediments were properly preserved and stained. Since foraminiferas exhibited spatial patchiness, core sediment samples were deployed twice in each sampling station in order to avoid bias in information on abundance (Murray & Alve 2000). The entire wet volume of sediment collected for the analysis of foraminifera in each core sample was 12.56 cm^3. The sediment samples for foraminifera analysis were stored for 3 - 4 weeks to allow effective staining with Rose Bengal. Each foraminiferal sample were gently washed with tap water through a 1000 μm sieve in order to remove pebbles and then washed through a 150 μm sieve. The fraction of sediments remaining on the 150 μm sieve were transferred to a petri dish, allowed to air dry and were weighed afterwards. All individuals were hand-picked using an artists' brush (Sakura, tip size 3/0) moistened with distilled water, under a dissecting microscope (Optech). Live (stained) and dead (unstained) individuals were separated, identified and counted to species level. Foraminiferal data were represented as relative abundance.

Identification of foraminifera were done using the illustration guides of Javaux & Scott (2003), Murray (2003), Riveiros & Patterson (2007), Patterson et al (2010), Scott et al (2000), Clark & Patterson (1993), Montaggioni & Vénec-Peyré (1993) and the illustrated foraminifera gallery (http://www.foraminifera.eu). All encountered species were documented using a digital camera (Sony Cyber-Shot, 16 MP) and measured using an eyepiece micrometer whose scale division appears together with the image of the foraminifera to be measured.

Diversity indices were computed using Shannon-Weaver Index, Margalef Index and Menhinick index. Cluster analysis using Ward's method was employed to determine the major groupings of foraminiferans present between the three sites. Canonical Correspondence Analysis (CCA) was employed to determine the physico-chemical parameters and sediment contents that influenced the relative abundance of foraminiferans. All statistical analyses were done using the software PAST version 2.17 (http://folk.uio.no/ohammer/past/) (Hammer et al 2001).

Results and Discussion. A total of 29 foraminiferan species belonging to 20 genera under 16 families were identified in the living benthic foraminiferal assemblage in the three sampling stations in Iligan Bay (Table 1). The level of diversity of foraminiferal species in the three sampling stations is presented in Table 2. The living assemblages in stations 2 and 3 were quite diversified, with 26 and 20 living individuals being recorded in stations 2 and 3, respectively. Conversely, data showed that station 1 was poorly diversified, with less number of living individuals, *viz*. 8, being recorded. Results further revealed a much higher Shannon index (H') and equitability (J) values in station 3 followed in decreasing trend by station 2 and then station 1 having the lowest values. Although station 2 recorded the highest number of living individuals (26), it did not have the highest H' and J values. Instead, station 3, with 20 living individuals, showed the highest H' and J values but with the lowest dominance value (0.09238) (Table 2). This is further justified by the even distribution in the abundance or density among the 20 foraminiferan species in station 3 as reflected in figure 2. The present result did not seem to agree with those reported by Lacuna et al (2013), who assessed foraminiferal assemblage in the same area/station, where the ferro-nickel smelting plant is located, in the year 2011. Their results showed one foraminiferan species, *viz*. *Ammonia beccarii* (55 %), solely dominating the living foraminiferal assemblage. The difference in the diversity and dominance of foraminiferans in this specific sampling station between the year 2011 as reported by Lacuna et al (2013) and the present study (which was conducted in 2012) might be attributed to the organisms' being patchy in distribution as well as the different degrees of sensitivity of the foraminiferans to spatial and temporal changes in their environment. According to Buzas et al (2002), no two stations showed the same degree of abundance of individuals because foraminifers are sensitive to even a very slight ecologic difference (Stubbs 1940).

Table 1

Species composition of live foraminiferan in the three sampling stations where nearby industries are present

Foraminiferal species	*Stations*		
	1	*2*	*3*
Rotaliidae			
Ammonia beccarii	-	-	+
Neorotalia calcar	+	+	+
Pararotalia sp.	+	+	+
Soritidae			
Amphisorus sp.	+	-	-
Amphisteginidae			
Amphistegina sp.	-	+	-
Peneroplidae			
Coscinospira arietina	+	+	-
Peneroplis carinatus	-	+	+
Peneroplispertusis	+	+	+
Bagginidae			
Baggina bradyi	-	+	+
Bolivinidae			
Bolivina sp.	-	+	+
Calcarinidae			
Calcarina spengleri	+	+	+
Elphidiidae			
Elphidium hanzawai	-	+	+
Elphidium taiwanum	+	+	-
Elphidium kusiroense	-	+	-
Ophthalmidiidae			
Edentostomina cultrate	-	+	+
Eponididae			
Eponides repandus	-	+	-
Hauerinidae			
Cribromiliolinella subvalvularis	-	+	-
Massilina granulo costata	-	+	+
Quinqueloculina sp.	-	+	+
Quinqueloculina bicostata	+	+	+
Quinqueloculina kerimbatica	-	+	+
Quinqueloculina parkeri	-	+	+
Quinqueloculina poeyana	-	+	+
Quinqueloculina sternberg	-	+	-
Nubeculariidae			
Nodobaculariella sp.	-	-	+
Nonionidae			
Pseudononion japonicum	-	+	-
Nummulitidae			
Operculina ammonoides	-	+	+
Spiroloculinidae			
Spiroloculina angulata	-	+	+
Miliolidae			
Triloculina trigonula	-	+	+
Total number of species	8	26	20

+ presence, – absence.

Table 2

Diversity profiles of live foraminiferan species in the three sampling stations where nearby industries are located

Diversity index	*Stations*		
	1	*2*	*3*
Taxa (S)	8	26	20
Individuals	96	432	296
Dominance (D)	0.668	0.2012	0.09238
Simpson (1-D)	0.332	0.7988	0.9076
Shannon (H)	0.7998	2.234	2.607
Evenness (e^H/S)	0.2781	0.3593	0.6777
Brillouin	0.7053	2.131	2.481
Menhinick	0.8165	1.251	1.162
Margalef	1.534	4.12	3.339
Equitability (J)	0.3846	0.6858	0.8702
Fisher alpha	2.075	6.078	4.844
Berger-Parker	0.8125	0.3866	0.1486
Chao-1	9	29	20

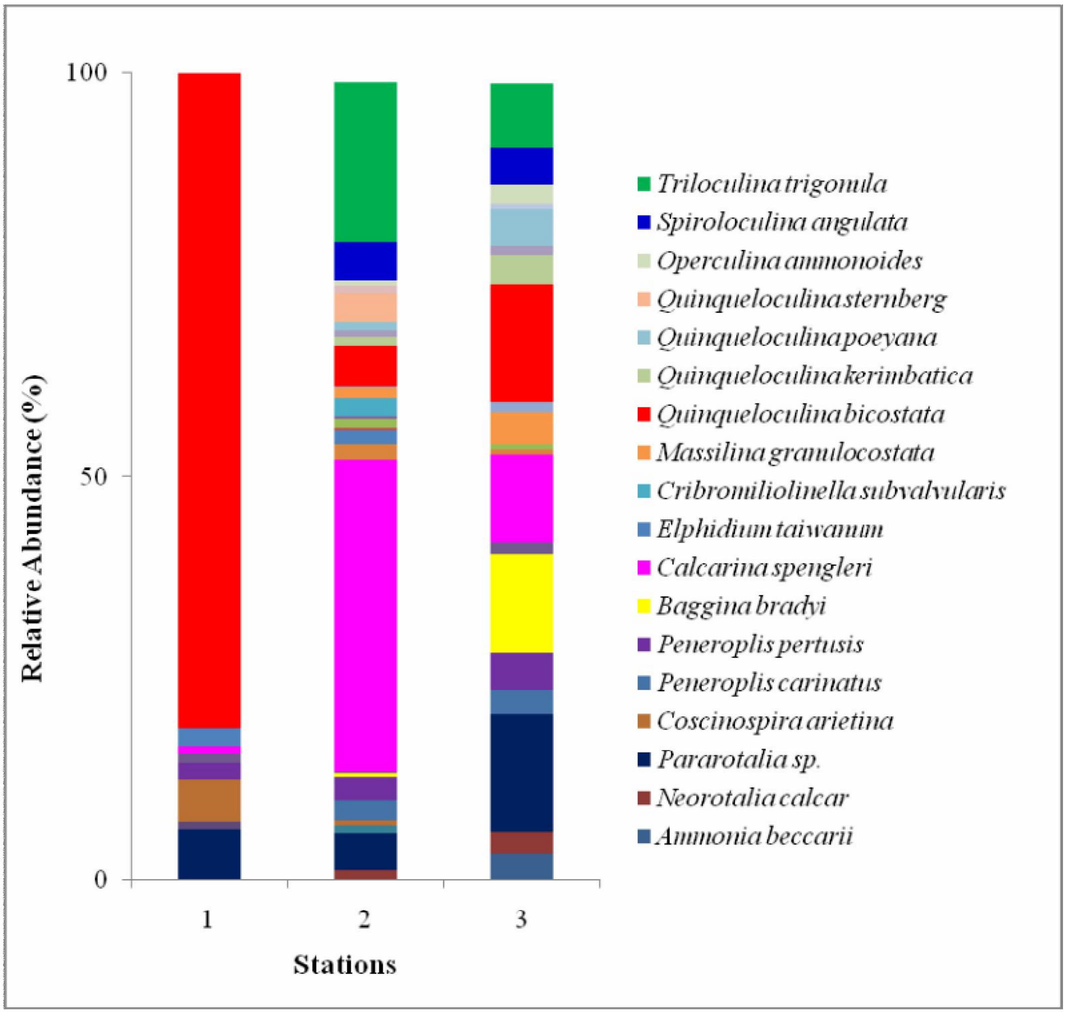

Figure 2. Relative abundance (%) of all live foraminiferan species in three sampling stations where nearby industries are present.

Further, several studies documented patchiness occurring between the two dominant species (*Ammonia tepida* and *Haynesina germanica*) at a scale of decimeter and even

>50 meters (Duijnstee et al 2007) and to a scale of a few centimeters in monthly samplings in an intertidal zone (Murray & Alve 2000). It is argued that the patchiness (*i.e.* organisms distributed unevenly or aggregated) in the spatial distribution and abundances of benthic foraminifera may be due to factors like grazing and predation aside from local changes in the environment (Valiela 1995). It is therefore assumed that the arguments suggested by these studies might be responsible to the differences in the diversity and abundance of foraminiferans when comparing the years 2011 and 2012 in the same sampling area. On the other side, station 2, despite having more living individuals and with high H' and J values, the dominance value (0.2012) seemed to be slightly high. The reason for the slightly high dominance value in station 2 can be observed in the high relative abundance of two species, namely *Calcarina spengleri* (38.66%) and *Triloculina trigonula* (19.91%) that solely dominated the living foraminiferal assemblage (Figure 2). It is quite clear that the density of *C. splengeri* was relatively high (13.25 per 10 cm^3) than those of *T. trigonula* (6.83 per 10 cm^3). Kumar & Manivannan (2001) considered *T. trigonula* among the 8 identified living taxa in Palk Bay, India to be widely distributed and abundant since they were found in living condition in more than 75 % of the samples collected. The other dominant foraminifera in station 2, *C. splengeri*, showed no records of being abundant in polluted waters. Instead, Hansen (1981) documented the findings of Lorentz Splenger, a curator of the Royal Collection of Art, Crafts and Rarities of Nature, Denesmark in 1771 - 1807, describing this species to occur in large quantities in coral and shell gravels. Several studies further reported *C. splengeri* to be quite common and widely distributed on the Great Barrier Reef (Lobegeier 2002; Schueth & Frank 2008) and in the Western Indo-Pacific regions (Lobegeier 2002) specifically in tropical, shallow waters and coral reef flat areas. It is probable that the high dominance and density of *C. splengeri* might be associated with the presence of corals since all foraminiferan samples were collected in shallow waters having a depth between 7 - 10 m and the fact that some patches and scattered living assemblage of corals as well as coral rubbles were observed in station 2. In contrast, station 1, which exhibited the lowest number of individuals, had the lowest H' and J values but with the highest dominance value, indicating that the abundance is not that evenly distributed among all the species. In particular, the species *Quinqueloculina bicostata* (81.25 %) dominated the major bulk of the living assemblage in station 2 and are therefore largely responsible for the high dominance value in the said station (Figure 2). Despite relatively high abundance of *Q. bicostata*, their densities are still quite low (6.19 per 10 cm^3). Foster et al (2012) observed the relative abundance of *Q. bicostata* to increase in the most polluted areas and proposed that this taxon may be used as an indicator of heavy metal pollution. Since *Q. bicostata* obviously dominated in station 1, it is likely that they are good candidate for biological indicator of pollution in these sites as suggested by Foster et al (2012). The dominance of *Q. bicostata, T. trigonula* and *C. splengeri* observed in stations 1 and 2 is assumed to be associated with the present condition of their environment. In particular, the presence of the nearby industries, *viz*. Shell Depot and Global Steel in stations 1 and 2, respectively, and the discharges or effluents coming from these industries may have influence the structure and composition of live foraminiferan assemblage. It has been reported that *Triloculina* spp. and *Ammonia* spp. (*A. beccarri* and *A. tepida*) are opportunistic species in coastal regions that were constantly exposed by anthropogenic pollution (Kfouri et al 2005). In fact, Lacuna & Alviro (2014) reported the capacity of *A. beccarii* and *T. trigonula* in tolerating the presence of pollutants in moderately stressed coastal environment. Several studies also showed foraminiferal assemblages in the vicinity of sewage outfalls to be characterized by a large number of specimens and low diversity (Alve 1995b; Thomas et al 2000). It has been stressed out that human-induced organic material caused oxygen depletion and bottom water hypoxia which has led to a negative effect on foraminiferal diversity but a positive one on the population of opportunistic species (Alve 2000). Jorissen et al (1992) reported differences in the foraminiferal composition based on the flux of organic matter and oxygen levels and concluded that areas with high organic matter are characterized by opportunistic species. Hence, the dominance of *Q. bicostata*, *T. Trigonula* and *C. splengeri* recognized in the present study areas may appear to be related to the stress

conditions occurring there. Moreover, the results would imply that the living assemblage in stations 2 (26) and 3 (20) are more diversified when compared to station 1. In fact, stations 2 and 3 were even better diversified than those reported in the sediments near a ferro-nickel smelting plant (*S*:15) and a cement factory (*S*:21) in Iligan Bay, Philippines (Lacuna et al 2013). Images of these 3 dominant foraminiferans are shown in figures 3 - 5.

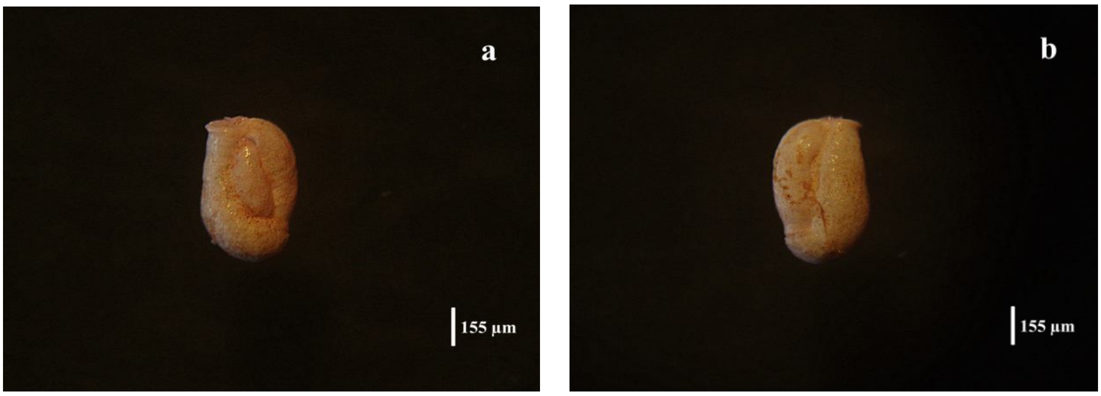

Figure 3. Dorsal (a) and ventral (b) view of *Quinqueloculina bicostata*.

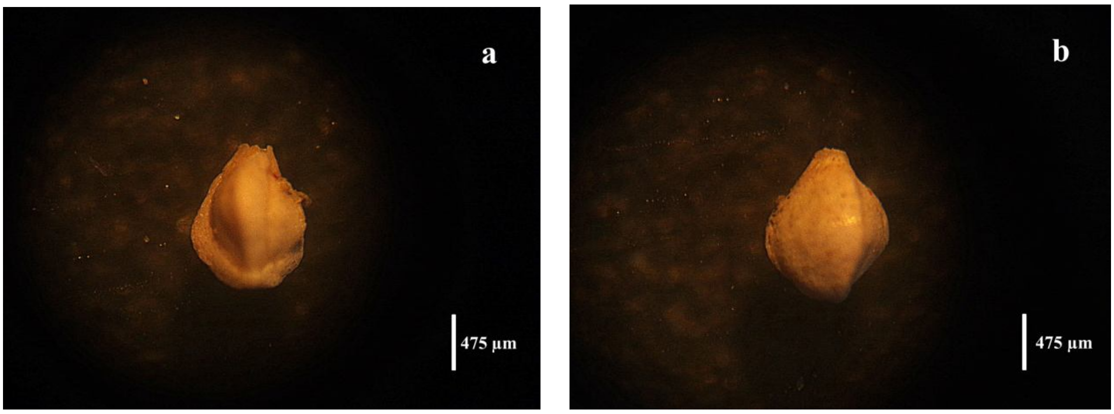

Figure 4. Dorsal (a) and ventral (b) view of *Triloculina trigonula*.

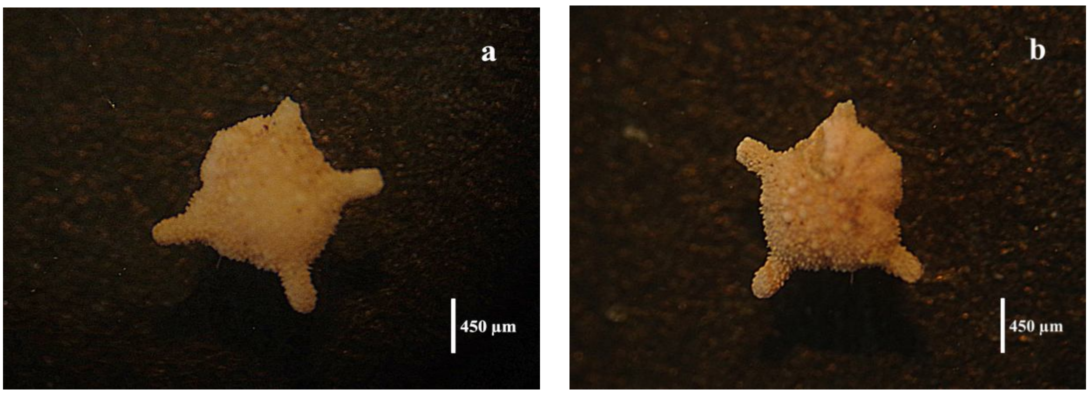

Figure 5. Dorsal (a) and ventral (b) view of *Calcarina spengleri*.

The mean values of the physical and chemical parameters of the bottom waters, the organic matter, chlorophyll *a*, selected and heavy metal and grain size of the sediments in the three selected sites in Iligan Bay is presented in table 3. In the three sampling stations, difference in the mean values of the environmental parameters was observed. For bottom water temperature, station 1 (26.5 °C) was lowest, whereas station 3 (30.1 °C) had the highest value recorded. Although temperature is an important factor in coastal environments (Culver & Buzas 1999), it is relatively uniform and if not, within the range of standard value in most parts of the ocean and therefore probably not a major parameter for foraminifera, at least in modern oceans (Gooday & Jorissen 2012). For pH, the lowest (6.74) and highest (7.75) values were recorded in stations 1 and 3, respectively. This parameter plays a minor role for benthic microfauna since the slightly alkaline seawater (pH 7.5 - 8.5) is well buffered against pH fluctuations (Lacuna et al 2013). For salinity, the values recorded were uniform in all the sampling stations (35 ppt). For DO, the values recorded in stations 2 (5.25 mgL^{-1}) and 3 (5.31 mgL^{-1}) were within the range for any marine organisms to thrive, however, station 1 (4.76 mgL^{-1}) showed value that was lower than those set by DENR. In general, all bottom water environmental parameters recorded in the three sampling stations are within the standard limits set by DENR (DAO 34 1990) except for the DO value in station 1 (4.76 mg L^{-1}). The grain size analysis of the sediments showed that the sedimentary structure of the benthic zone in the three sampling stations are predominantly made up of sands but in varying degrees of sizes. Station 1 consisted of fine sands to very fine sands, stations 2 was made up of coarse to very fine sands while station 3 was made up of medium to very fine sands. Based on the results, it showed that the sediment structure in station 2 was made of a combination of larger and very fine grains of sand as compared to the much finer grains of sand in the two sampling stations.

Table 3

Mean values of environmental parameters of the bottom waters, organic matter and heavy metal contents and size of sediments in the three sampling stations where nearby industries are present

Environmental parameters	*Stations*		
	1	*2*	*3*
Temperature (ºC)	26.5	29.9	30.1
pH	6.74	7.28	7.75
Salinity (ppt)	35	35	35
DO (mg L^{-1})	4.76	5.25	5.31
CaCO3 (%)	64.04	46.6	50.19
TOM (%)	15.43	10.07	8.2
Chlorophyll_*a* (mg L^{-1})	0.167	0.0795	0.199
Lead (mg kg^{-1})	10.6	18.3	28.3
Copper (mg kg^{-1})	32.7	38.4	228.9
Zinc (mg kg^{-1})	15.5	21.5	29.2
Chromium (mg kg^{-1})	51.8	82.6	161.4
Gravel (%)	0.05	0.01	0.47
Coarse sand (%)	19.86	30.29	3.18
Medium sand (%)	12.4	15.93	25.84
Fine sand (%)	25.3	11.43	4.9
Very fine sand (%)	43.94	39.76	66.86
Silt/Mud (%)	0.28	1.95	0.81
Clay (%)	0.05	0.13	0.08
Sediment type	Fine - very fine sand	Coarse - very fine sand	Medium - very fine sand

Standard value for marine and coastal waters: Water temperature minimum rise of 3 ºC; pH range from 6.0 to 8.5; DO > 5m gL^{-1}; Salinity 34 to 45 ppt (Philippine water standard values from DENR-DAO 1990); ER-L (Effect range low in mg kg^{-1}) and ER-M (Effect range median in mg kg^{-1}) values reported for the marine sediment quality standards of the USEPA: Lead (ER-L = 46.7; ER-M = 218), Copper (ER-L = 34; ER-M = 270), Zinc (ER-L = 150; ER-M = 410) and Chromium (ER-L = 81; ER-M =370) by Long et al (1995).

Since the Philippines had no established sediment quality guidelines, the Sediment Quality Guidelines (SQG) of the USEPA (United States Environmental Protection Agency) were instead used as basis in assessing whether the concentrations of heavy metal in the sediments could have adverse biological impacts. The SQG of the USEPA introduced the Effects Range-Low (ERL) and Effects Range-Median (ERM) values for chemical concentrations in marine and estuarine sediments. These values represent potential for occasional detrimental effects to the aquatic environment. For instance, ERL value represents the concentrations below which adverse effects rarely occur; whereas ERM value represents the concentrations above which such effects frequently occur (Long et al 1995). For the heavy metal contents of the sediment in the three sampling stations, results showed that the sediments in stations 2 and 3 contained copper and chromium that were above the ER-L values; however lead and zinc were below ER-L values. On the other side, all trace elements or heavy metals in the sediment in station 1 were below ER-L values. Although the concentrations recorded for lead and zinc were not high, it may still have some influenced in the species composition and the foraminiferal assemblage dominating in each sampling stations.

In order to distinguish benthic foraminiferal assemblages in the study area, hierarchial cluster analysis was employed. The dendrogram revealed the following assemblages (Figure 6): *Q. bicostata* solely dominated the total foraminiferal assemblage of the bottom sediments in station 1 having an abundance of 81.25 %; *C. splengeri* - *T. trigonula* assemblage represents station 2, with *C. splengeri* being most abundant (38.66 %), while *T. trigonula* constituted 19.91 % of the total living assemblage; and *Q. bicostata* - *Pararotalia* sp - *C. splengeri* assemblage represents station 3 with *Q. bicostata* and *Pararotalia* sp. garnering the highest abundance of 14.57 %, while *C. splengeri* constituted 10.93 % of the total foraminifera assemblage. The results reflected in the cluster diagram (Figure 6) are supported by the results of the Canonical Correspondence Analysis (Figure 7). The CCA showed the plot of the sampling stations across the first two canonical axes. The plot includes a vector plot that could be used to pinpoint important variables that can explain the differences in the community structures of live foraminiferans between the three stations. Results in figure 7 showed that the low abundance of foraminiferal assemblage in station 1 (12 %), which was solely dominated by *Q. bicostata* but in very low densities, might be influenced by an increase in calcium carbonate. Although it is expected that high amount of $CaCO_3$ in the sediment maybe attributed to high numbers of foraminiferan shells as reported by Sadough et al (2012), it is not the case in the present study. Instead, the high concentration of $CaCO_3$ in the sediment might be due to the presence of appreciable broken gastropod shells and coral fragments which were observed to be mixed up in the collected sediment samples in station 1. It is suggested that the presence of a nearby river might have brought in these mixtures by dumping into the sea more sediments containing broken shell and coral debris as terrigenous contributions. The present data is in accordance with Lacuna et al (2013) and Suresh Gandhi (2004) who argued that the high $CaCO_3$ content in the bottom sediments of Laguindingan, Northern Mindanao, Philippines and in Palk Strait, India, respectively, were probably due to the accumulation of high order broken shell debris dumped through the sea and creek as a result of the dispersal of terrigenous sediment. Moreover, results reflected in figure 7 showed copper and chlorophyll *a* to have an influence on the foraminiferal community structure in station 3. Copper plays a biologically essential role in the growth and life of most aquatic organisms. However, above threshold level, this trace element may potentially become toxic to marine organisms (Kennish 1992). Copper is a common contaminant with a high toxicity to marine organisms in coastal areas, particularly in industrialized bays, lagoons and estuaries. Inputs of copper into natural water come from different sources including mining, smelting, domestic and industrial activities (Frontalini & Coccioni 2012; Reddy et al 2012). Martinez-Colon & Hallock (2010) documented foraminiferal assemblages to be strongly dominated by *Ammonia* spp and *Quinqueloculina rhodiensis* under the influence of anthropogenic pollutants including copper. Further, Alve & Olsgard (1999) showed that high concentrations of copper in sediment have a detrimental effect on benthic foraminifera such as reduced abundance and diversity but without the occurrence of abnormal specimens.

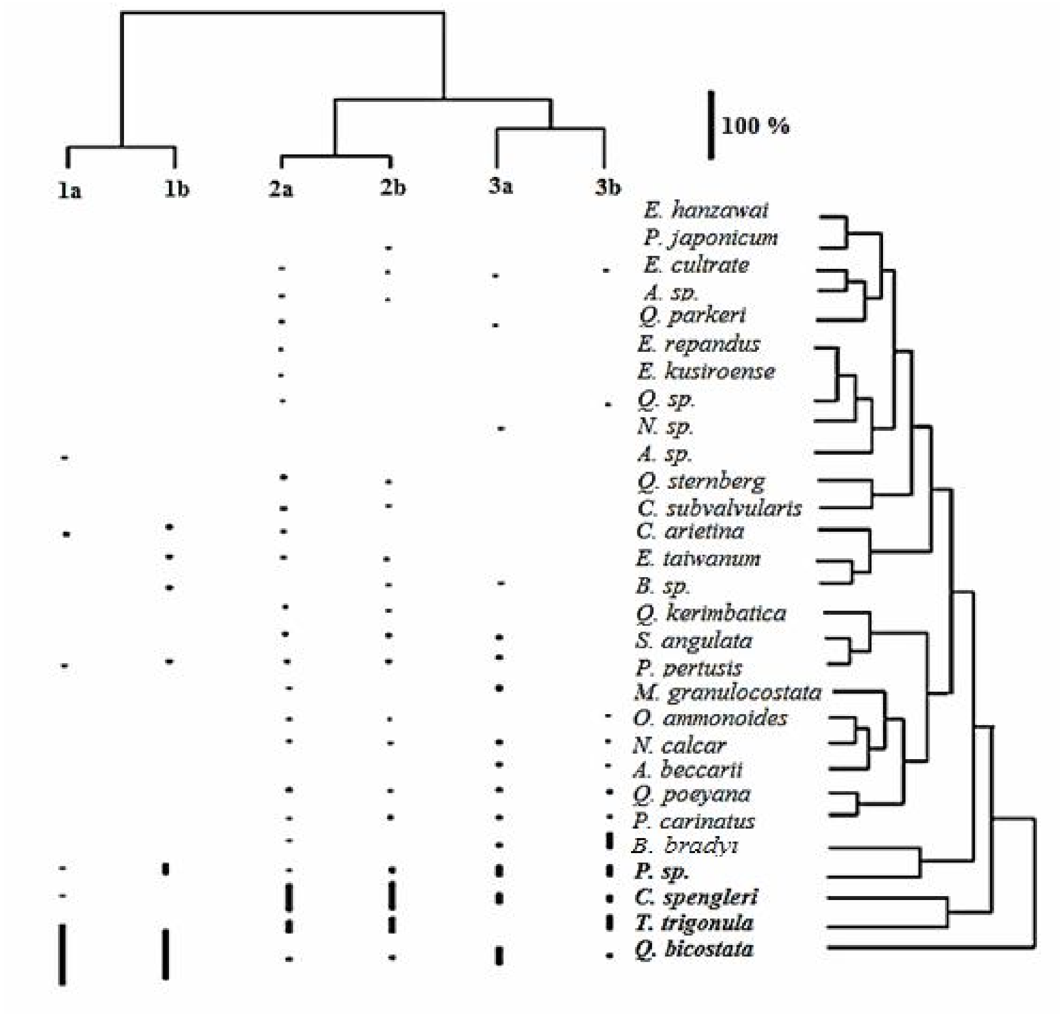

Figure 6. Two-way cluster analysis showing the top three live foraminiferan species that dominates in the three sampling stations where nearby industries are present.

Mikulic et al (2008) observed specimens of *A. beccarii* in low abundance but did not show any deformities despite high copper concentrations. Le Cadre & Debenay (2006) reported reduction in growth and reproduction of *A. beccarii* and *A. tepida* under increased copper concentrations. Although the copper concentration in station 3 is above the ERL (Effects Range-Low) value set by USEPA (Cu: ERL = 228.9 ppm or $mgKg^{-1}$), such value may not be enough to cause decreased diversity of the living foraminiferal assemblage nor high dominance of opportunistic species as reported by the above-mentioned studies. Instead, high foraminiferal diversity, as manifested in the high H' and J values, were observed in this particular station. The present finding clearly showed that the foraminiferal assemblage was not affected by the presence of copper despite its value above the ERL level. In addition, the high foraminiferal diversity observed in this particular station could be attributed to the high chlorophyll *a* recorded in this station. Foraminiferal biomass and standing stocks are directly related to the amount of food available and many workers have suggested that measuring sediment chlorophyll may be the best proxy for food supply or as a measure of food availability (Erskian & Lipps 1987; Murray & Alve 2000). In general, foraminifera mostly favored pennate diatoms, small chlorophytes and certain bacteria (Gooday et al 1992). Lesen (2005) have shown that total foraminiferal standing crop was positively correlated with water column chlorophyll and suggests that all the chlorophyll *a* in the sediments is the result of sedimentation from the water column following phytoplankton bloom rather than *in situ* production by benthic microalgae.

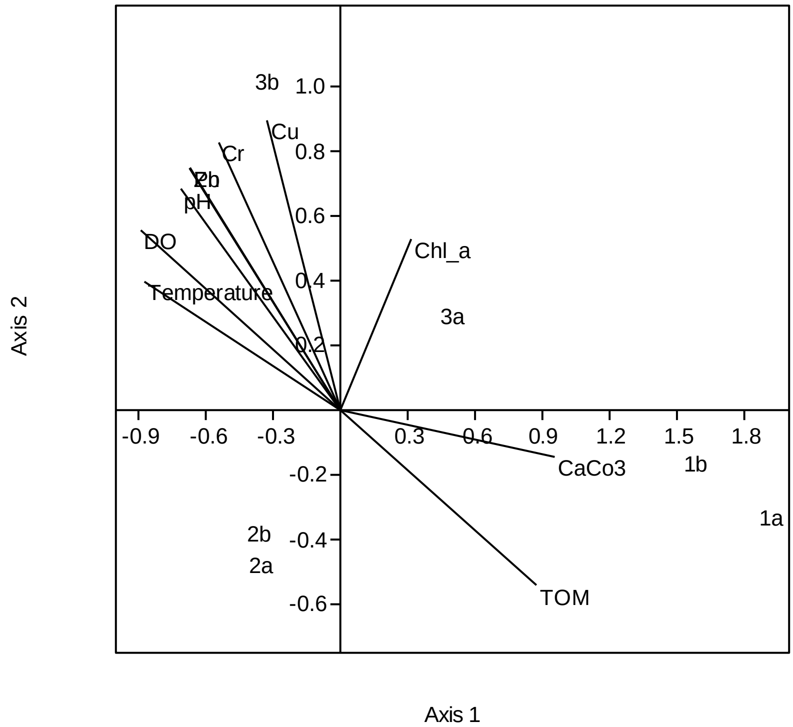

Figure 7. Results of the Canonical Correspondence Analysis showing the distance among the sampling stations and the physico-chemical factors that influence the distribution and abundance of live foraminiferans.

Previous studies have documented links between benthic foraminiferal populations and levels of organic matter and have found evidence that the said organisms utilized surface sediments or particulate organic matter as their food sources (Alve & Murray 1994; Ohga & Kitazato 1997; Altenbach & Struck 2001; Lesen 2005; Nomaki et al 2008). The present result would imply that high foraminiferal diversity and equitability in station 3 might be due to abundance of food sources, such as in the form of chlorophyll *a*, as suggested by these authors.

Conclusions. In general, values for foraminifera abundance, density, diversity and equitability (evenness) clearly showed variations between the three sampling areas in Iligan City where nearby industries are located. In particular, the living foraminiferal assemblages in stations 2 and 3 were quite diversified whereas station 1 was poorly diversified, with less number of living individuals being recorded. The low species diversity and equitability but high dominance values observed in station 1 further revealed the sole dominance of one species, *Q. bicostata*, in the foraminiferal community structure. Conversely, the high diversity and equitability but low dominance values recorded in station 3 further justified the even distribution of foraminiferan species in terms of their abundance in this particular area. The present data reflected in the Canonical Correspondence Analysis did not show any direct influenced of the heavy metals in the sediments to the foraminiferal assemblage in the three sampling areas. Although the copper concentration in station 3 is above the ERL (Effects Range-Low) value set by USEPA (Cu: ERL = 228.9 ppm or $mgKg^{-1}$), such value may not be enough to cause decreased diversity of the living foraminiferal assemblage nor high dominance of opportunistic species. Instead, high foraminiferal diversity, as manifested in the high H’ and J values, observed in station 3 may be influenced by high chlorophyll *a* in the particular station. Although heavy metals did not seemed to influenced the different responses of benthic foraminiferal structure, the mere presence of these trace elements, even below or above ER-L levels, and the dominance of one species may imply the strong potential of the areas to progress into highly polluted environments if conservation measures and biomonitoring will not be strictly implemented. Moreover, the present findings further confirm the potential of *Q. bicostata* as good candidate for biological indicator in moderately to highly polluted environments thereby making benthic foraminifera as suitable device/tool for *in situ* continuous monitoring of anthropogenic pollution in coastal marine ecosystems.

References

Abou-Ouf M., EL-Shater A., 1991 The relationship between the environmental conditions of Jeddah coast, Red Sea, and benthic foraminifera. Journal of King Abdulaziz University, Marine Sciences 2:49-64.

Aloulou F., Elleuch B., Kallel M., 2012 Benthic foraminiferal assemblages as pollution proxies in the northern coast of Gabes Gulf, Tunisia. Environ Monit Assess 184(2): 777-795.

Altenbach A. V., Struck U., 2001 On the coherence of organic carbon flux and benthic foraminiferal biomass. J Foraminiferal Res 31:79–85.

Alve E., 1991 Benthic foraminifera in sediment cores reflecting heavy metal pollution in Sorfjord, Western Norway. J Foraminiferal Res 21(1):1-19.

Alve E., 1995a Benthic foraminiferal responses to estuarine pollution: A review. J Foraminiferal Res 25(3):190-203.

Alve E., 1995b Benthic foraminiferal distribution and recolonization of formerly anoxic environments in Drammensfjord, southern Norway. Mar Micropaleontol 25:169-186.

Alve E., Murray J. W., 1994 Ecology and taphonomy of benthic foraminifera in a temperate mesotidal inlet. J Foraminiferal Res 24:18–27.

Alve E., Olsgard F., 1999 Benthic foraminiferal colonization in experiments with copper-contaminated sediments. J Foraminiferal Res 29(3):186-195.

Alve E., 2000 A case study reconstructing bottom water oxygen conditions in Frierfjord, Norway, over the past five centuries. Environmental statigraphy. In: Environmental micropaleontology. Martin R. E. (ed), vol. 15 of Topics in Geobiology.

Buzas M. A., Hayek L. C., Reed S. A., Jett J. A., 2002 Foraminiferal densities over five years in the Indian River Lagoon, Florida: A model of pulsating patches. J Foraminiferal Res 32:68-93.

Clark F. E., Patterson T., 1993 An illustrated key to the identification of unilocular genera of calcareous foraminifera. J Paleontol 67(1):20-28.

Culver S. J., Buzas M. A., 1999 Biogeography of Neritic benthic foraminifera. In: Modern foraminifera. Sen Gupta B. K. (ed), pp. 93-102, Kluwer Academic Publishers, The Netherlands.

DENR - Administrative Order No. 34., 1990 Revised Water Usage and Classification of Water Quality Criteria Amending Section Nos. 68 and 69, Chapter III of the 1978 Rules and Regulations. Manila.

Duijnstee I. A. P., Bergman M. J. N., van Der Zwaan G. J., 2007 The ecology of benthic foraminifera across the Frisian Front (Southern North Sea). In: Shallow-water benthic foraminifera as proxy for natural versus human-induced environmental change. De Nooijer L. J. (ed), pp. 33-48, Geologica Ultraiectina, Ubbergen. Retrieved from http://igitur-archive.library.uu.nl/dissertations/2007-0201-202220/c4.pdf

Erskian M. G., Lipps J. H., 1987 Population dynamics of the foraminiferan Glabratella ornatissima (Cushman) in northern California. J Foraminiferal Res 17:240–256.

Foster W. J., Armynot du Châtelet E., Rogerson M., 2012 Testing benthic foraminiferal distributions as a contemporary quantitative approach to biomonitoring estuarine heavy metal pollution. Mar Pollut Bull 65(5):1039-1048.

Frontalini F., Coccioni R., 2012 The response of benthic foraminiferal assemblages to copper exposure: A pilot mesocosm investigation. J Environ Prot 3:342-352.
Gooday A. J., Jorissen F. J., 2012 Benthic foraminiferal biogeography: Controls on global distribution patterns in deep-water settings. Ann Rev Mar Sci 4:237-62.
Gooday A. J., Levin L. A., Linke P., Heeger T., 1992 The role of benthic foraminífera in deep sea food webs and carbon cycling. In: Deep-sea food chains and the global carbon cycle. Rowe G. T., Pariente V. (eds), pp. 63-91, Kluwer Academic Publishers, The Netherlands.
Hammer O., Harper D. A. T., Ryan P. D. 2001. PAST: paleontological statistics software package for education and data analysis. Palaeontol Electronica 4:1-9.
Hansen H. J., 1981 On Lorentz Spengler and a neotype for the foraminifer Calcarina spengleri. Bulletin of the Geological Society of Denmark 29:191-201.
Javaux E. J., Scott D. B., 2003 Illustration of modern benthic foraminifera from Bermuda and remarks on distribution in other subtropical/tropical areas. Palaeontol Electronica 6(4):1-29.
Jayaraju N., Sundara B. C., Reddy R., Reddy K. R., 2011 Anthropogenic impact on Andaman coast monitoring with benthic foraminifera, Andaman Sea, India. Environ Earth Sci 62(4):821-829.
Jorissen F. J., Barmavidjaja D. M., Puskaric S., Van Der Zwaan G. J., 1992 Vertical distribution of benthic foraminifera in the northern Adriatic Sea: The relation with the organic flux. Mar Micropaleontol 19:131-146.
Kennish M. J., 1992 Ecology of estuaries: anthropogenic effects. CRC Press Inc., Boca Raton.
Kfouri P. B. P., Figueira R. C. L., Figueiredo A. M. G., Souza S. H. M., Eichler B. B., 2005 Metal levels and foraminifera occurrence in sediment cores from Guanabara Bay, Rio de Janiero, Brazil. Journal of Radioanalytical and Nuclear Chemestry 265(3):459-466.
Kravchuk A., 2006 Benthic foraminifera as indicators of pollution in the north-western shallow part of the Black Sea. Geophysical Research Abstracts 8.
Kumar V., Manivannan V., 2001 Benthic foraminiferal responses to bottom wáter characteristics in the Palk Bay, off Rameswaram, southeast coast of India. Indian J Mar Sci 30:173-179.
Lacuna M. L. D. G., Masangcay S. I. G., Orbita M. L. S., Torres M. A. J., 2013 Foraminiferal assemblage in Southeast coast of Iligan Bay, Mindanao, Philippines. AACL Bioflux 6(4):303-319.
Lacuna M. L. D. G., Alviro M. P., 2014 Diversity and abundance of benthic foraminifera in nearshore sediments of Iligan City, Northern Mindanao, Philippines. ABAH Bioflux 6(1):10-26.
Le Cadre V., Debenay J. P., 2006 Morphological and cytological responses of Ammonia (foraminifera) to copper contamination: Implication for the use of foraminifera as bioindicators of pollution. Environ Pollut 143(2):304-317.
Lesen A. E., 2005 Relationship between benthic foraminifera and food resources in South San Francisco Bay, California, USA. Mar Ecol Prog Ser 297:131–145.
Lipps J. H., 1983 Biotic interactions in benthic foraminifera. In: Biotic interactions in recent and fossil benthic communities. Tevesz M. J. S., McCall P. L. (eds) pp. 331-376, Planum Press, New York.
Lipps J. H., Valentine J. W., 1970 The role of foraminifera in the trophic structure of marine communities. Lethaia 3:279-286.
Liu X. S., Zhang Z. N., Huang Y., 2007 Sublittoral meiofauna with particular reference to nematodes in the southern Yellow Sea, China. Estuar Coast Shelf Sci 71:616-628.
Lobegeier M. K., 2002 Benthic foraminifera of the family Calcarinidae from Green Island reef, Great Barrier Reef province. J Foraminiferal Res 32(3):201-216.
Long E. R., MacDonald D. D., Smith S. L., Calder F. D., 1995 Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environ Manage 19(1):81-97.
Martinez-Colon M., Hallock P., 2010 Preliminary survey on foraminiferal responses to pollutants in Torrecillas Lagoon-Puerto Rico. Caribb J Sci 46(1):106-111.

Mikulic N., Orescanin V., Elez L., Pavicic L., Pezelj D., Lovrencic I., Lulic S., 2008 Distribution of trace elements in the coastal sea sediments of Maslinica Bay, Croatia. Environ Geol 53:1413-1419.

Moghaddasi B., Nabavi S. M. B., Vosoughi G., Fatemi S. M. R., Jamili S., 2009 Abundance and distribution of benthic foraminifera in the Northern Oman Sea (Iranian Side) continental shelf sediments. Res J Environ Sci 3(2):210-217.

Mojtahid M., Jorissen F., Pearson T. H., 2008 Comparison of benthic foraminiferal and macrofaunal responses to organic pollution in the Firth of Clyde (Scotland). Mar Pollut Bull 56:42-76.

Montaggioni L. F., Vénec-Peyré M. T., 1993 Shallow-water foraminiferal tapochoenoses at site 821: Implications for the Pleistocene evolution of the central Great Barrier Reef Shelf, Northeastern Australia. In: Proceedings of the Ocean Drilling Program, Scientific Results 133:365-378.

Murray J. W., Alve E., 2000 Major aspects of foraminiferal variability (standing crop and biomass) on a monthly scale in an intertidal zone. J Foraminiferal Res 30(3):177–191.

Murray J. W., 2003 An illustrated guide to the benthic foraminifera of the Hebridean Shelf, West of Scotland, with notes on their mode of life. Palaeontol Electronica 5(1):1-31.

Nomaki H., Ogawa N. O., Ohkouchi N., Suga H., Toyofuku T., Shimanaga M., Nakatsuka T., Kitazato H., 2008 Benthic foraminifera as trophic links between phytodetritus and benthic metazoans: carbon and nitrogen isotopic evidence. Mar Ecol Prog Ser 357:153–164.

Ohga T., Kitazato H., 1997 Seasonal changes in bathyal foraminiferal populations in response to the flux of organic matter (Sagami Bay, Japan). Terra Nova 9:33–37.

Patterson R. T., Haggart J. W., Dalby A. P., 2010 A guide to late Albian-Cenomanian (Cretaceous) foraminifera from the Queen Charlotte Islands, British Columbia, Canada. Palaeontol Electronica 13(2):1-28.

Quiñones M. B., De Guzman A. B., Moleño E. P., 2002 Iligan Bay. In: Atlas of the Philippine Coral Reefs. Aliño P. et al (eds), pp. 164-166, Goodwill Trading Co., Inc, Philippines.

Reddy B. C., Jayaraju N., Reddy K. R., 2012 Anthropogenic impact on the Pulicat Lagoon monitoring with foraminifera, East coast of India. Marine Science 2(5):66-76.

Riveiros N. V., Patterson T. R., 2007 An illustrated guide to fjord foraminifera from the Seymour-belize Inlet Complex, Northern British Columbia, Canada. Palaeontol Electronica 11(1):1-45.

Sadough M., Ghane F., Manouchehri H., Moghaddasi B., Beikaee H., 2012 Identification and abundance of benthic foraminifera in the sediments from Fereidoonkenar to Babolsar of Southern Caspian Sea. Turkish J Fish Aquat Sci 12:1-2.

Samir A. M., El-Din A. B., 2001 Benthic foraminiferal assemblages and morphological abnormalities as pollution proxies in two Egyptian bays. Mar Micropaleontol 41:193–227.

Schueth J. D., Frank T. D., 2008 Reef foraminifera as bioindicators of coral reef health: Low Isles Reef, Northern Great Barrier Reef, Australia. J Foraminiferal Res 38(1): 11-22.

Scott D. B., Takayanagi Y., Hasegawa S., Saito T., 2000 Illustration and eeevaluation of affinities of Neogene foraminifera described from Japan. Palaeontol Electronica 3(2):1-41.

Stubbs S. A., 1940 Studies of foraminifera from seven stations in the vicinity of Biscayne Bay. Proceedings of the Florida Academy of Sciences for 1939 4:225-230.

Suresh Gandhi M., 2004 Distribution of certain ecological parameters and foraminiferal distribution in the depositional environment of Palk Strait, east coast of India. Indian J Mar Sci 33(3):287-295.

Thomas E., Gapotchenko T., Varekamp J. C., Mecray E. L., Buchholz ten Brink M. R., 2000 Benthic foraminifera and environmental changes in Long Island Sound. Journal of Coastal Research 16:641-655.

Valiela I., 1995 Marine ecological processes: Springer Verlag, New York, second edition, 686 pp.
Yanko V., Kronfeld J., Flexer A., 1994 Response of benthic foraminifera to various pollution sources: Implications for pollution monitoring. J Foraminiferal Res 24(1):1-17.
*** http://folk.uio.no/ohammer/past/
*** http://www.foraminifera.eu
*** http://igitur-archive.library.uu.nl/dissertations/2007-0201-202220/full.pdf

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Authors:
Shiela Mae Ganaway, Mindanao State University-Iligan Institute of Technology, College of Science and Mathematics, Department of Biological Sciences, Philippines, Iligan City 9200, Bonifacio Avenue, e-mail: shiela_babe123@yahoo.com
Maria Lourdes Dorothy Garcia Lacuna, Mindanao State University-Iligan Institute of Technology, College of Science and Mathematics, Department of Biological Sciences, Philippines, Iligan City 9200, Bonifacio Avenue, e-mail: Philippines, mileskung@yahoo.com

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