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Diversity and abundance of benthic foraminifera in nearshore sediments of Iligan City, Northern Mindanao, Philippines

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Abstract. Live benthic foraminiferan composition, diversity, abundance and their relationship with the water quality parameters, organic matter and heavy metal contents, size of the sediments were determined and compared. A total of 14 foraminiferan species belonging to 12 genera and 11 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) were quite low in the coastal areas of Iligan City. One to four species tend to dominate most of the living foraminiferal assemblages in these three study areas. Data further revealed different sensitivity to pollutants may have existed among the different species of foraminifera, with *Ammonia beccarii* and *Triloculina trigonula* being tolerant to copper, high concentrations of total organic matter and bottom water temperature as revealed by the results of the Canonical Correspondence Analysis. Although trace element concentrations were below the ER-L values set by the USEPA, the possible influenced of copper, lead and chromium to the foraminiferal assemblage as revealed in the Canonical Correspondence Analysis may imply that these three study sites, though still able to harbour and host few foraminiferan species, may have a strong potential to progress into a highly polluted environment if conservation measures and biomonitoring will not be strictly implemented. The present findings further confirmed the capacity of *A. beccarii* and *T. trigonula* to tolerate the presence of pollutants 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, diversity and abundance, Iligan City, Philippines.

Introduction. Foraminifera are a group of heterotrophic, single-celled amoeboid protozoans that build a test or shell (Gooday et al 1992) which is made of secreted minerals (calcite, aragonite or silica) or of agglutinated particles. This test consists of a hollow chamber (single) or chambers (successive or multiple) that is interconnected by an orifice (foramen) or several orifices (foramina, where they get their name). Most benthic foraminifers are omnivores, scavengers, herbivores or carnivores. Since they inhabit on or in the sediment, their food items ranges from dissolved organic molecules, detritus, bacteria, single-celled phytoplankton, plant and fungal fragments to small animals such as protozoans, copepods, small sea urchins and other foraminifers. In turn, they are preyed upon (during deposit feeding and grazing) by large echinoderms (*i.e.* holothurians, echinoids, asteroids and crinoids), crustaceans (*i.e.* copepods, shrimps and crabs), molluscs (*i.e.* gastropods, bivalves and nudibranchs), worms (*i.e.* flatworms and polychaetes), tunicates and coral reef fish (Lipps & Valentine 1970; Lipps 1983; Gooday et al 1992). Considering the position these organisms occupy in the food chain, they therefore represent an important link between low (sediments and phytodetritus) and high (benthic metazoans) trophic levels (Nomaki et al 2008) and are vital in the turnover of benthic organic matters. Thus, their contribution in the bottom community would mean that their potential importance in the food webs cannot be ignored. Aside from the vital role that benthic foraminifers play in the marine food webs, they are also being used as environmental indicators, specifically as bio-indicators, since foraminifers can be applied in monitoring the health of the environment and act as an early warning indicator. In particular, heavy metal pollution in marine ecosystems affects survival, growth and reproduction of organisms in areas where heavy industry and mines, and in environments where riverine input is high. Each species of foraminifera has its own threshold of sensitivity to different environmental parameters and to different types of pollution. Benthic foraminifera respond to elevated concentrations of certain heavy metals by changes in their test morphology, size and structure (Alve 1991, 1995a; Sharifi et al 1991; Yanko et al 1994, 1998, 1999; Jayaraju & Reddy 1996; Coccioni 2000; Geslin et al 2000, 2002; Samir 2000; Samir & El-Din 2001; Elberling et al 2003; Armynot du Châtelet et al 2004; Coccioni et al 2003, 2005, 2009; Coccioni & Marsili 2005; Ferraro et al 2006; Jayaraju et al 2008, 2011; Frontalini & Coccioni 2008; Frontalini et al 2009, 2011). 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).

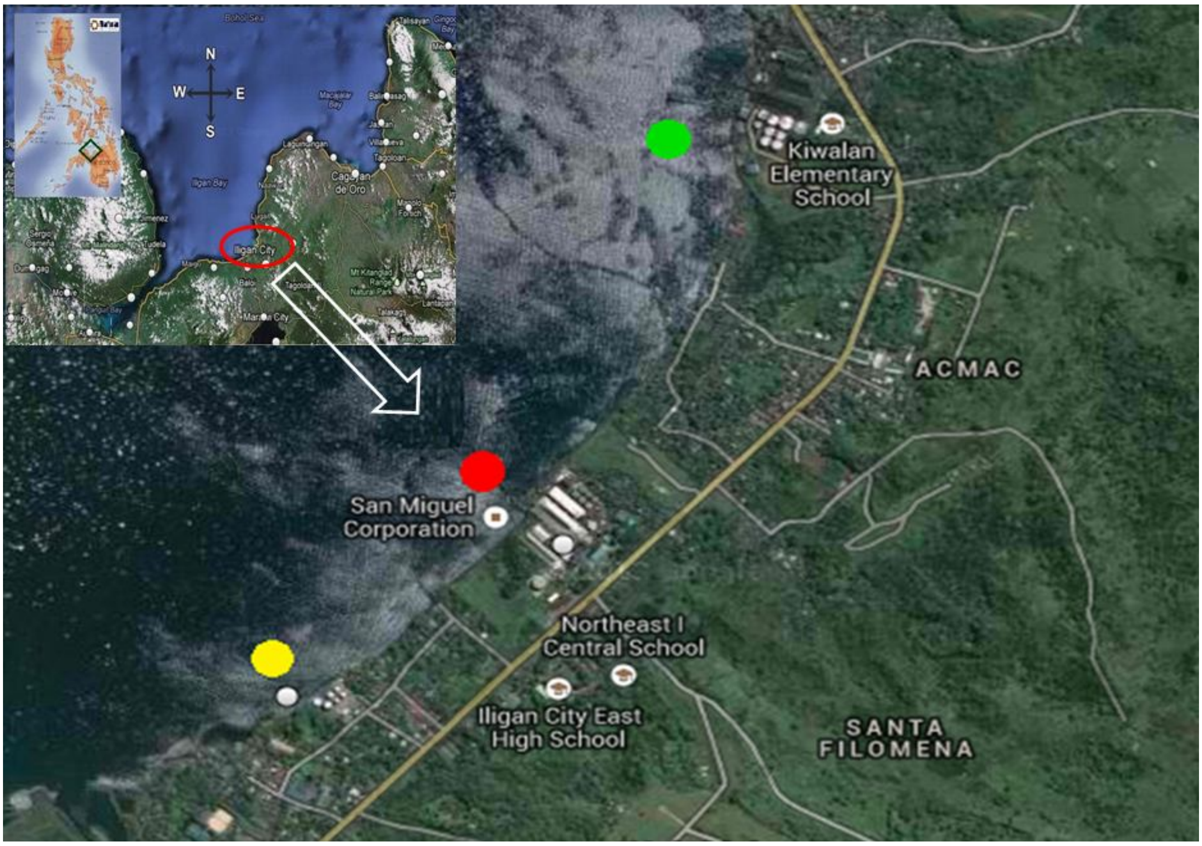

Figure 1. Geographical location of the three sampling stations where foraminifera were collected. Inset is Iligan Bay enclosed in a red circle. Legend: ● Station 1 - Granex Manufacturing Corporation; ● Station 2 - San Miguel Corporation-ILICOCO; ● Station 3 - REGS Caltex.

On the south western part Iligan Bay it connects with Panguil Bay 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 established near the coastline with a depth of 7 - 10 m (Figure 1). Station 1 was situated in front of Granexport Manufacturing Corporation which is located in Barangay Kiwalan and is 9.0 km from the city proper. This industry produces crude coconut oil and pellet. Station 2 was established facing San Miguel Corporation – Iligan Coconut Oil (formerly ILICOCO) which is located in Barangay Sta. Filomena and is 7.8 km away from the city proper. It is one of the two copra solvent extraction plants in the city and was established in 1975. Station 3 was located in front of REGS Caltex, which is a fuel depot and is situated in Barangay Sta. Filomena.

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 tapwater 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 deternine 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 14 species belonging to 12 genera and 11 families were identified in the living benthic foraminiferal assemblage in the three sampling stations in Iligan Bay (Table 1).

Table 1

Species composition of live foraminiferan in the three sampling stations in Iligan Bay

Foraminiferal species	*Stations*		
	1	*2*	*3*
Rotaliidae			
Ammonia beccarii	+	+	+
Cibicididae			
Cibicides cushmani	-	+	-
Elphidiidae			
Elphidium sagram	+	+	+
Vaginulinidae			
Lenticulina sp.	-	-	+
Lenticulina denticulifera	+	-	-
Rzehakinidae			
Miliammina fusca	-	-	+
Nonionidae			
Nonionella turgida	+	+	+
Peneroplidae			
Euthymonachapolita	-	+	-
Peneroplis carinatus	+	+	+
Planorbulinidae			
Planorbulina difformis	-	-	+
Hauerinidae			
Quinqueloculina laevigata	-	+	-
Quinqueloculina parkeri	-	-	+
Soritidae			
Sorites marginalis	-	-	+
Miliolidae			
Triloculina trigonula	+	+	+
Total number of species	6	8	10

+ presence, - absence.

The foraminiferan species in the study area is characterized by medium in size, extremely well-preserved and undeformed specimens implying that the species are free from all signatures of pollution effects on their test morphology. Bradshaw (1957) reported a mean maximum test diameter range of 266 - 365 μm for *Ammonia tepida*, while Colburn & Baskin (1998) reported a much larger mean diameter of 482 - 505 μm. The level of diversity of foraminiferal species in the three sampling stations is presented in Table 2. The living assemblages in these three areas are poorly diversified, with fewer numbers of living individuals, *viz*. 6, 8, 10, being recorded in stations 1, 2, and 3, respectively. Generally, a much lower Shannon index (H') values (0.4631, 1.77 and

1.867) were noted in all stations, with station 1 showing the lowest Shannon index and equitability values but high dominance value.

Table 2

Diversity profiles of the three sampling stations for live foraminiferan species

Diversity index	*Stations*		
	1	*2*	*3*
Taxa (S)	6	8	10
Individuals	63	75	57
Dominance (D)	0.8206	0.2014	0.1807
Simpson (1-D)	0.1794	0.7986	0.8193
Shannon (H)	0.4631	1.77	1.867
Evenness (e^H/S)	0.2648	0.7338	0.6467
Brillouin	0.3797	1.613	1.649
Menhinick	0.7559	0.9238	1.325
Margalef	1.207	1.621	2.226
Equitability (J)	0.2585	0.8512	0.8107
Fisher alpha	1.631	2.267	3.513
Berger-Parker	0.9048	0.28	0.2281
Chao-1	9	8	20

In particular, the species *T. trigonula* dominated the major bulk (90.48 %) of the living assemblage in station 1 and are therefore largely responsible for the high dominance value in the said station (Figure 2). However, their densities are quite low (4.52/10 cm^3). On the other side, the living assemblage in station 2 constituted of 8 species, with both *A. beccarii* and *T. trigonula* (28 %) dominating the community, but still with very low densities (1.67/10 cm^3), much lower when compared to station 1. Conversely, the living assemblage in station 3 is much better diversified (10) when compared to stations 1 (6) and 2 (8), although the living individuals recognized in station 3 were still fewer 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). Nonetheless, the foraminiferal assemblage in station 3 are dominated by the following 4 species, albeit very low densities: *viz*., *Elphidium sagram* (22.81 % or 1.03/10 cm^3), *Peneroplis carinatus*, *T. trigonula* (21.05 % or 0.95/10 cm^3) and *Quinqueloculina parkeri* (17.54 % or 0.79/10 cm^3). It should be noted that the high equitability value (0.8107) in station 3 further justifies its more or less high Shannon (H': 1.867) and low dominance (0.1807) values when compared to stations 1 and 2. This high equitability in station 3 is reflected in more foraminiferans (4 species mentioned above) dominating the said station as compared to those in stations 1 and 2 where only 1 - 2 species tend to dominate the living foraminiferal assemblage.

In general, low diversity indices with high dominance of few species but having very low densities are expected in all three sampling stations since these areas directly receive effluents and oil wastes from the nearby industries (*viz.* Granexport manufacturing Corp., San Miguel Corp-Iligan Coconut oil, Regs Caltex Depot) and therefore can be categorized as polluted environments. It has been reported that low diversity fauna are not expected under oligotrophic stress-free conditions (Kouwenhover 2000; Drinia et al 2004) but rather the lowering of species richness (S), density, equitability (J) on benthic foraminiferal communities and the high dominance of stress-tolerant species are commonly observed in polluted areas (Lacuna et al 2013; Foster et al 2012; Martins et al 2011; Frontalini et al 2010; Carboni et al 2009; Jayaraju et al

2008, 2011; Ferrano et al 2006; Yanko et al 1998) and can therefore be viewed as a measure of environmental stress to the said organisms caused by pollution.

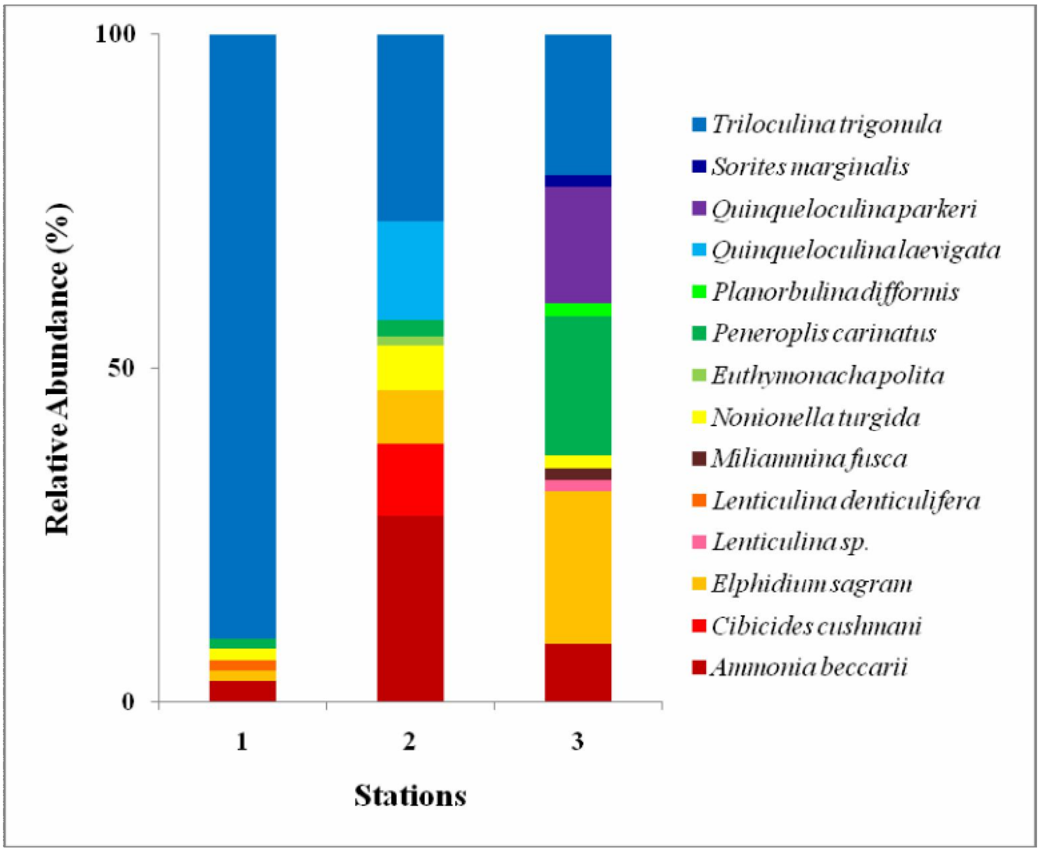

Figure 2. Relative abundance (%) of all live foraminiferan species in three sampling stations in the Iligan Bay.

Studies of pollution effects include different types of pollutants, such as oil, agrochemicals and heavy metals (Samir 2000; Samir & El-Din 2001; Ernst et al 2006), of which heavy metals have a strong adverse influence on benthic foraminiferal assemblages (Le Cadre & Debanay 2006). Although, the effects of heavy metals on foraminiferans are yet poorly understood (Samir & El-Din 2001; Le Cadre & Debanay 2006), several reports suggested that heavy metal contamination may lead to the development of abnormal (teratological) tests as well as changes in foraminiferal abundance and taxonomic composition, size variation, and structural modification (Alve 1991, 1995a; Sharifi et al 1991; Yanko et al 1994, 1998, 1999; Jayaraju & Reddy 1996; Coccioni 2000; Geslin et al 2000, 2002; Samir 2000; Samir & El-Din 2001; Elberling et al 2003; Armynot du Châtelet et al 2004; Coccioni et al 2003, 2005, 2009; Coccioni & Marsili 2005; Ferraro et al 2006; Jayaraju et al 2007, 2011; Frontalini & Coccioni 2008; Frontalini et al 2009, 2011).

Hence, foraminífera may respond to environmental changes in terms of reproduction rates that may lead to population decrease and eventually to their disappearance under strongly unfavourable environmental conditions such as greater concentrations of trace elements and other chemical discharges (Samir 2000; Ferraro et al 2006). The dominance of *T. trigonula*, *A. beccarii*, *Elphidium sagram, Peneroplis carinatus* and *Quinqueloculina parkeri* observed in most of the sampling stations is assumed to be associated with the discharges coming from these industries. It has been reported that *Triloculina* spp. and *Ammonia* spp. (*A. beccarii*), to occur in lagoons which is severely influenced by industrial discharges and trace elements. Moreover, Frontalini & Coccioni (2008) stressed out the increase abundance of *A. tepida* in response to increasing heavy metal contents and concluded the capacity of this species to tolerate increasing heavy metal concentration. This species has also been known for its great tolerance to chemical and thermal pollution, fertilizing products, hydrocarbons (Setty & Nigam 1982; Coccioni 2000; Lacuna et al 2013) and even capable of supporting very polluted environments and high concentrations of trace elements (Ferraro et al 2006; Frontalini et al 2009, 2010). Burone & Pires-Vanin (2006) suggested that the sole dominance of *A. tepida* may be an indicative of unstable conditions caused by both natural and anthropogenic effects. 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). They 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 *T. trigonula, A. beccarii*, *E. sagram, P. carinatus* and *Q. parkeri* recognized in the present study areas may appear to be related to the stress conditions occurring there. Images of these 5 dominant foraminiferans are shown in Figures 3 - 7.

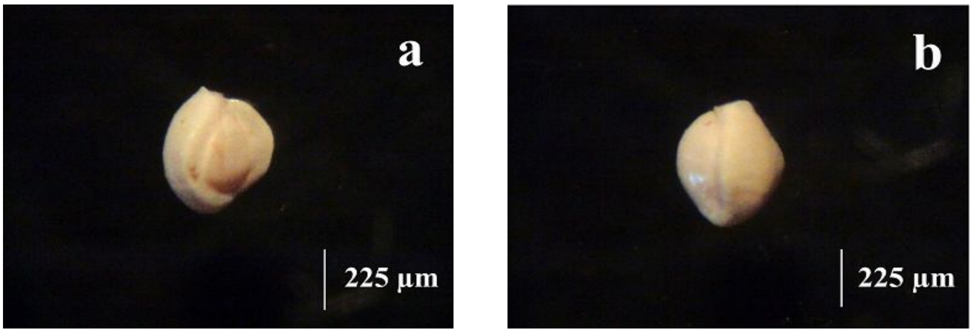

Figure 3. Dorsal (a) and ventral (b) view of *Triloculina trigonula.*

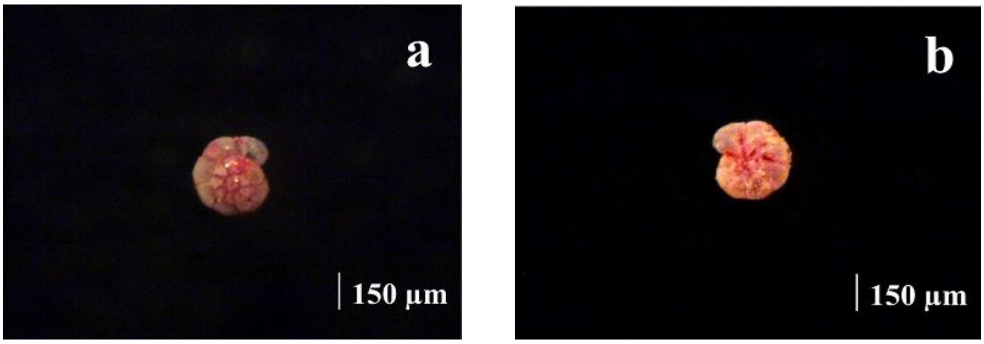

Figure 4. Dorsal (a) and ventral (b) view of *Ammonia beccarii*.

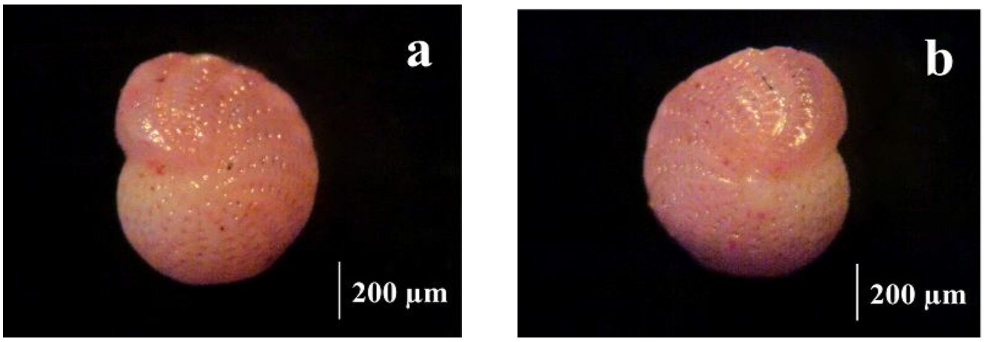

Figure 5. Dorsal (a) and ventral (b) view of *Elphidium sagram.*

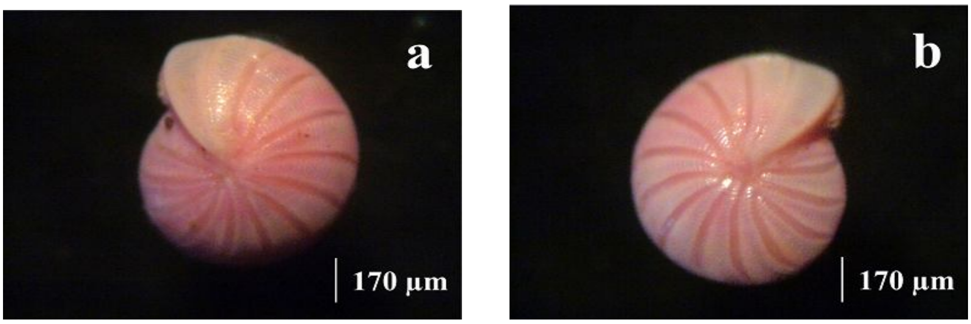

Figure 6. Dorsal (a) and ventral (b) view of *Peneroplis carinatus.*

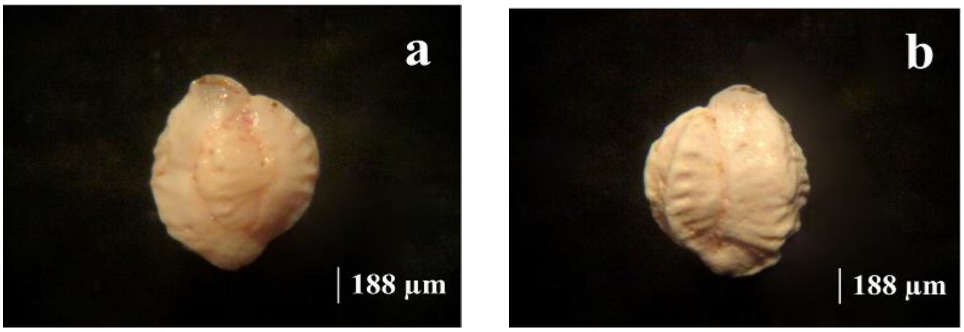

Figure 7. Dorsal (a) and ventral (b) view of *Quinqueloculina parkeri.*

The mean values of the physical and chemical parameters of the bottom waters, the organic matter and heavy metal contents of the sediments, and grain size in the three sampling sites is shown in Table 3.

All bottom water quality parameter values such as temperature, pH (Price 1976), salinity and DO in all three sampling stations are within the range for any marine faunistic assemblage to thrive and be fairly abundant (DENR - DAO 34 1990). However, the mean values reflected variations between the three sampling stations and might be responsible for differences in the foraminiferal assemblage. For instance, bottom water temperature value in station 1 was higher (30.25 °C) when compared to the two sampling stations. Conversely, the pH value in station 1 was lowest (7.84) among the three sampling stations. In the marine biome, pH plays only a minor role for benthic microfauna since the slightly alkaline seawater (pH: 7.5 - 8.5) is well buffered against pH fluctuation (Lacuna et al 2013). The pH of the area is an important indicator of chemical conditions of the depositional environment. It is a critical environmental factor which influences the production of calcareous microfauna. Hydrogen ion concentrations are expected to affect the production of calcareous tests of foraminiferans at pH approximately <7, where they may not be able to survive (Phleger 1960). Salinity content in the three sampling stations did not exhibit any fluctuations and is within the values recorded for a marine environment. Dissolved oxygen is one of the most important environmental gradients in the system and is frequently impacted by human activity (Bouchet et al 2012). The DO values recorded in all three sampling stations did not show maximum differences and were within the standard limits set by the Philippines Department of Environment and Natural Resources (DENR) (DAO 34 1990). On the other hand, the organic matter contents of the sediment (*i.e.* $CaCO_3$, TOM, Chlorophyll *a*) were highest in station 1 but lowest in station 3. In terms of grain size, the sedimentary structures of the benthic zone in the three sampling stations are predominantly made up of fine to very fine grain sands. The Sediment Quality Guidelines (SQG) of the USEPA (United States Environmental Protection Agency) introduced the Effects Range-Low (ER-L) and Effects Range-Median (ER-M) values for chemical concentrations in marine and estuarine sediments. These values represent potential for occasional detrimental effects to the aquatic environment. For instance, ER-L value represents the concentrations below which adverse effects rarely occur, whereas ER-M 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 lead, copper, zinc and chromium were below the ER-L values. Although the concentrations recorded for these trace elements were not high, it may still have some influenced in the species composition and the foraminiferal assemblage dominating in each sampling stations. Copper, for instance, was high (27.3 mg kg^{-1}) in station 2 and lowest (24.8 mg kg^{-1}) in station 3. Lead and chromium registered the highest concentrations in station 3 but lowest in station 1, whereas zinc values were highest in stations 1 and 2.

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 in Iligan Bay

Environmental parameters	*Stations*		
	1	*2*	*3*
Temperature (°C)	30.25	29.25	28.65
pH	7.84	8.25	8.195
Salinity (ppt)	34	35	35
DO (mg L^{-1})	5.42	5.65	5.3
CaCO3 (%)	52.38	42.19	30.185
TOM (%)	13.36	7.18	4.725
Chlorophyll_a (mg L^{-1})	0.87	0.45	0.3
Lead (mg kg^{-1})	12.1	12.4	14.7
Copper (mg kg^{-1})	25.8	27.3	24.8
Zinc (mg kg^{-1})	47.6	47.4	40.6
Chromium (mg kg^{-1})	18.2	19.8	27.4
Gravel (%)	0.28	2.16	0.93
Coarse sand (%)	13.42	6.82	3.04
Medium sand (%)	9.08	4.53	8.41
Fine sand (%)	15.86	23	29.56
Very fine sand (%)	44.54	41.42	49.6
Silt/Mud (%)	9.76	18.6	4.8
Clay (%)	7.07	3.47	3.65
Sediment type	Very fine sand	Fine – very fine sand	Fine – very fine sand

Standard value for marine and coastal waters: Water temperature minimum rise of 3°C; pH range from 6.0 to 8.5;DO >5mgL^{-1}; Salinity 34 to 45ppt (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).

In order to distinguished benthic foraminiferal assemblages in the study area, hierarchial cluster analysis was employed. The dendrogram revealed the following assemblages (Figure 8): *T. trigonula* - *A. beccarii* dominated the bottom sediments in station 1 among the total assemblages. *T. trigonula* occurs with the highest abundance (>80 %), while *A. beccarii* showed abundance of around 11 %; *A. beccarii* - *T. trigonula* assemblage still represents station 2 having abundances of >25 % for both species; and *P. carinatus* - *E. sagram* - *T. trigonula* - *Q. parkeri* assemblage represents station 3 with abundances of >15 %, with *P. carinatus* and *E. sagram* garnering the highest abundance of >20 %. The results reflected in the cluster diagram (Figure 8) are supported by the results of the Canonical Correspondence Analysis (Figure 9). The CCA showed the plot of the sampling stations across the first two canonical axes.

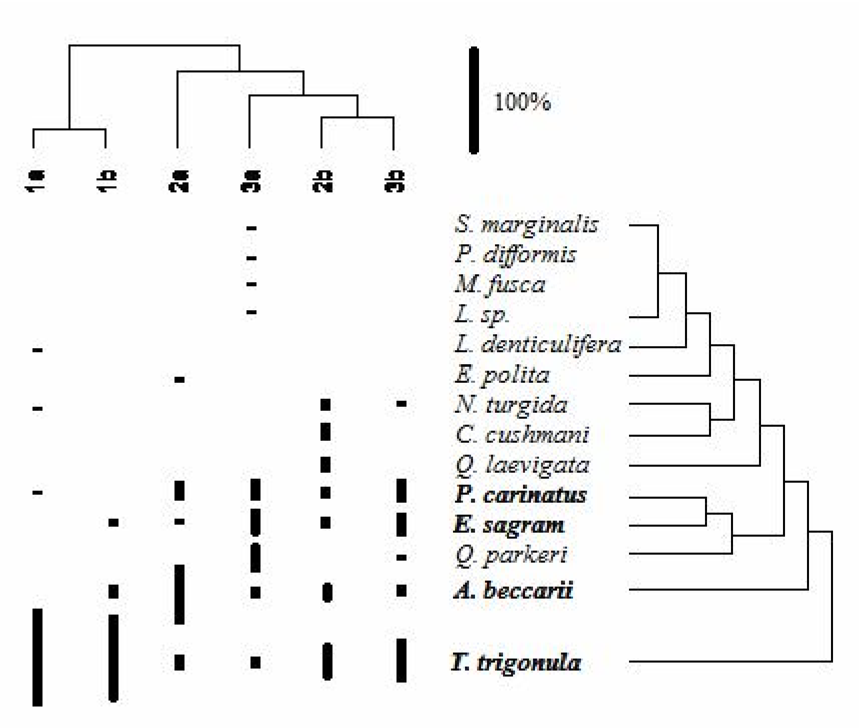

Figure 8. Two-way cluster analysis showing the top four live foraminiferan species that dominates in the three sampling stations in the Iligan Bay.

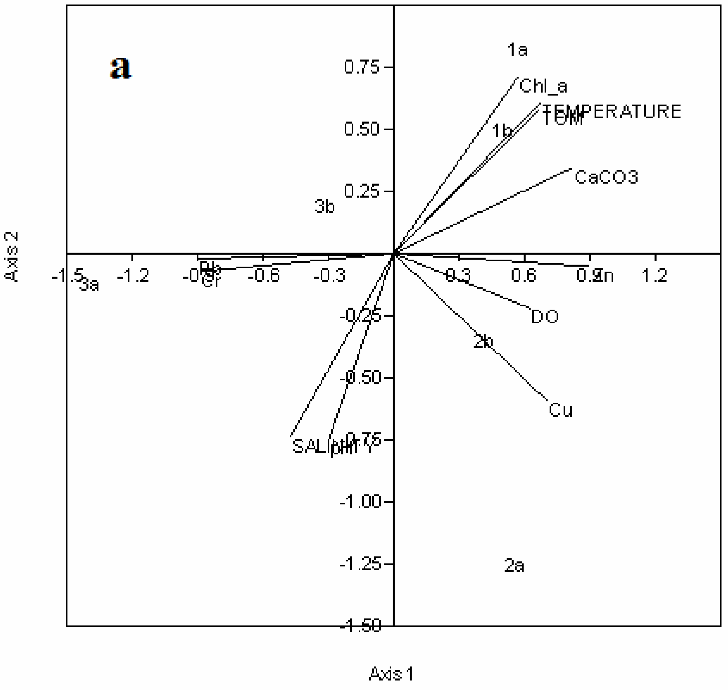

Figure 9. Results of the Canonical Correspondence Analysis – Biplot showing the distance among the sampling stations and the physico-chemical factors that influence the distribution and abundance of live foraminiferan.

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 9 showed that the sparse abundance of foraminiferal assemblage in station 1, which was dominated by *T. trigonula* and *A. beccarri* but in very low densities, might be affected by an increase in TOM, chlorophyll-*a* and temperature.

Alve (1995a), who reviewed studieson the responses of benthic foraminifera to several sources of pollution, reported that excess supply of organic material can lead to the following effects: (1) a collapse of the benthic community (Pearson & Rosenberg 1978); (2) extremely reduced abundance (Bandy et al 1965); (3) and reduced number of species (Resig 1960; Bandy et al 1964, 1965; Bates & Spencer 1979; Schafer 1973; Schafer & Cole 1974). Moreover, Martins et al (2010) observed that one source of stress among benthic foraminiferal assemblage is related with the high content of organic matter. They pointed out that the influence of this parameter is expressed in the dominance of certain foraminiferal assemblage such as *Ammonia, Elphidium, Bolivina* and *Haynesina germanica*. According to Sundara Raja Reddy et al (2012) organic matter increases as the sediments becomes finer and finer. This is an account of the absorption of the organic matter by finer sediments (Sundara Raja Reddy et al 2012) and also by the similarity in the settling velocity (Trask 1939). It should be noted that the sediments in station 1 are made up of very fine grains of sand (<73 µm) and it is probable that such sedimentary structure may have received more concentrations of total organic matter as a result of cumulative effects of several factors *viz.* effluents from the nearby industry (Granex) and from domestic sewage and river run-offs that may carry with it organic compounds from uplands and agricultural activities whereby discharging these into the bay.

Aside from high TOM concentration, other factors such as increase bottom water temperature and chlorophyll-*a* might have contributed to the low foraminiferal community in station 1. It has been pointed out by Lacuna et al (2013) that the dumping of sediments into the sea as terrigenous contribution might have influenced increased bottom water temperature in the area where rapid reconstruction of an international airport was undergoing. They suggested that such parameter may influence low foraminiferal abundance. The high total organic matter concentration in station 1 in the present study which may be due to the contributions coming from the cumulative effects of several factors as mentioned above, would seemed to have lead to the high temperature of bottom water as a result of organic degradation caused by bacterial actions. On the other side, 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 favoured 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.

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 1992; Lesen 2005; Nomaki et al 2008). Despite earlier documents showing the positive effect of chlorophyll-*a* to foraminiferal community, the present study particularly in station 1, is not in agreement with these earlier reports, instead increased chlorophyll-*a* may have influenced low foraminiferal assemblage. This may imply that other factors may control the benthic foraminifera community structure rather than the presence of high food sources (*viz*. organic matter and chlorophyll-*a*) in that station.

Moreover, results reflected in Figure 9 showed trace elements to have an effect on the foraminiferal community structure in stations 2 and 3. In particular, the presence of copper concentration seems to have an influence on the dominance of the foraminiferal assemblage "*A. beccari - T. trigonula*" in station 2. 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; Sundara Raja Reddy et al 2012). Lauren (1986) reported that toxicity of copper in its free ion form is more prevalent at pH more than 7. The copper concentration in station 2 is below the ER-L (Effects Range-Low) value set by USEPA (Cu: ER-L = 34 ppm or mgKg^{-1}), which represents the concentrations below which adverse effects may rarely occur. However, the high alkalinity concentration of the water (pH: 8.25) may have rendered copper to exert its toxic effect thereby causing low abundance of foraminiferal population but dominance of certain un-deformed species, such as *A. beccari* and *T. trigonula*. 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. 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. The present finding thereby documented poor foraminifera population, with dominance of *A. beccarii* and *T. trigonula* but in very low densities even under lower concentrations of copper. This may confirm the potential of *A. beccarii* and *T. trigonula* to tolerate the presence of copper and therefore can be considered as tolerant species in moderately polluted environment. Their responses to the negative effects of trace element were manifested in the form of low species number, diversity and abundance but without any deformities in their shell morphology. Cosentino et al (2013) documented poor foraminifera population characterized by low values of species richness and densities under lower concentrations of trace elements in moderately polluted sectors of the Gulf of Milazzo, Sicily.

Although the results of CCA manifested in Figure 9 showed an influenced of lead (Pb) and chromium (Cr) to the abundance of foraminifera in station 3, the concentrations of these 2 trace elements were below the ER-L values (Pb: 46.7 ppm, Cr: 81 ppm) set by USEPA. Lead and chromium are also common contaminants that exert strong toxicity to marine organisms in industrialized coastal areas. Inputs of these trace elements into natural water come from different sources including paints, mining, smelting, petroleum refining, alloys, pulps and paper (Frontalini & Coccioni 2012; Sundara Raja Reddy et al 2012), with an additional sources of fuel combustion, pipes, sheets, plastics and batteries for lead (Sundara Raja Reddy et al 2012). It should be noted that the foraminiferal assemblage in this station, although in low abundance, diversity and species richness, consisted this time of 4 dominant species (*P. carinatus, E. sagram, T. trigonula,* and *Q. parkeri*). Despite the much lower concentrations of Pb and Cr in station 3 when compared to the 2 stations, the data may further imply that station 3 is a moderately polluted environment and that it can still harbour and cater more foraminiferan species but in low densities. Although, the presence of more dominant foraminifera is being highlighted here, their low densities and relation with Pb and Cr as shown in Figure 9, could indicate that station 3 has strong possibilities to progress into a highly polluted environment if conservation measures and biomonitoring will not be strictly followed. Hence, the present result showed that benthic foraminiferans are suitable indicators of early warning signs of probable anthropogenic pollution of the marine environment as suggested by Kramer & Botterweg (1991).

Conclusions. In general, values for foraminifera abundance, density, diversity and equitability (eveness) are quite low in the coastal areas of Iligan City where nearby industries are located. One to four species tend to dominate most of the living foraminiferal assemblages in these three study areas. Data further revealed different sensitivity to pollutants may have existed among the different species of foraminifera, with *A. beccarii* and *T. trigonula* being tolerant to copper, high concentrations of total organic matter and bottom water temperature as revealed by the results of the Canonical

Correspondence Analysis. Although trace element concentrations are below the ER-L values set by the USEPA, the possible influenced of copper, lead and chromium to the foraminiferal assemblage as revealed in the Canonical Correspondence Analysis may imply that these three study sites, though still able to harbour and host few foraminiferan species, may have a strong potential to progress into a highly polluted environment if conservation measures and biomonitoring will not be strictly implemented. The present findings further confirmed the capacity of *A. beccarii* and *T. trigonula* to tolerate the presence of pollutants thereby making benthic foraminifera as suitable device/tool for *in situ* continuous monitoring of anthropogenic pollution in coastal marine ecosystems.

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