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CURRENT STATUS OF MODERN FORAMINIFERAL RESEARCH IN PENINSULAR AND EAST MALAYSIA

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Abstract: Many studies have successfully utilised modern foraminiferal distribution as indicators of pollution and proxies of paleoecological, paleoclimatological and sea-level reconstructions. In spite of growing interests in this unicellular organism, certain countries still lack the data of modern foraminifera. Within the last 50 years, there have been less than twenty publications of modern foraminifera in Malaysia. This paper reviews previous research, summarises the status of ongoing research, identifies research gaps and suggests directions for future research of modern foraminifera in Malaysia. Several significant grey literatures are also mentioned in this review. Most of the publications concentrated on the ecology with very few attempts made for application of modern foraminifera (e.g. sea-level reconstruction and pollution monitoring).

KEYWORDS: Foraminifera, tropical waters, South China Sea, bioindicator, micropaleontology

Introduction

Benthic foraminifera occupy all marine habitats, including marginal environments (e.g. lagoons, coastal lakes, estuaries, mangroves and salt marshes), coastal waters and deep sea (Scott *et al.,* 2001; Sen Gupta, 2003). Despite their widespread distribution, foraminifera are sensitive to environmental gradients and require specific ecological requirements for their distribution (Scott *et al.,* 2001; Fontanier *et al.,* 2002; Murray, 2006). The presence of test on foraminifera allows fossilisation which at the same time translates the environmental condition of which the assemblage was found at that particular time. Hence foraminifera are good ecological indicators in various marine and transitional marine environments (Alve, 1995; Culver & Buzas, 2003; Murray, 2006). Ecological work on foraminifera started in 1935 by Rhumber (Murray, 2006). Research in foraminiferal ecology have been intensified ever since due to their ability in providing clues to the understanding of geological changes in the past (Sen Gupta, 2003). Distribution of foraminifera in relation to the elevation of mangroves and salt marshes make them useful indicators of sea-level reconstruction (Scott *et al.,* 2001; Horton & Edwards, 2006). Distinct requirements in the distribution of symbiont-bearing, agglutinated and stress tolerant taxa make foraminifera as potential indicators of reef monitoring (Hallock *et al.,* 2003; Carnahan, 2005; Hallock, 2012).

Despite the intense studies and publications of foraminifera elsewhere, Malaysia has only limited numbers of published literature. Many of the earliest studies of foraminifera in Malaysia have focused on fossil foraminifera and their application in oil and gas exploration. In the late 70s, several studies have utilised the foraminfera microfacies to determine the age of limestone outcrops (Coo & Smit, 1975; Grazdzicki & Smit, 1977; Whittaker & Hodgkinson, 1979). Meanwhile in the late 90s, many of the published manuscripts were on fossil planktonic forams (Jasin & Ahmad, 1995; Jasin *et al.,* 1995; Jasin, 2002). The studies on recent benthic foraminifera

and their ecological preferences however started much later (Ibrahim, 2001; Saelan, 2011). This review aims to summarize the status of ongoing research, identify gaps and suggest direction for future studies in Malaysia.

Results and Discussion

Previous Research

A salient observation was made on all published and available grey literatures of foraminiferal research in Malaysia. Grey literatures refer to foraminifera studies that are available in form of abstract and are not published in indexed journal database. Altogether there were 14 published manuscripts, two published proceedings and six grey literatures that have reviewed. These literatures are summarized in Tables 1 and 2 according to the year of publications. Six out of fourteen manuscripts were published in international journals with impact factor, four in the *Journal of Foraminiferal Research* and one published in the *Marine Geology.* Table 1 summarises and highlight the studies on recent foraminifera between 1960 to 2014, which have been published in indexed journals. The name of the author, year of publication, study locations and the important findings were provided in Table 1. Table 2 highlights the grey literatures on foraminifera studies that are not published in indexed journal and are only partially available in form of abstracts.

Table 1: Summary and remarks on published literatures on modern nearshore foraminifera in Malaysian waters.

No.	Author	Year	Area	Remarks
1.	Keiji	1963	Offshore Sabah and Brunei	Distribution of planktonic foraminifera in relation to depth was studied along Brunei and Sabah shelf. The abundance of planktonic foraminifera increases with increasing depth.
2.	Dhillon	1969	Labuk Estuary, Sabah.	A taxonomic paper which recognised three new species of agglutinated foraminifera, namely *Arenoparrella malaysiana, Haplophragmoides labukensis* and *Haplophragmoides sabahensis.*
3.	Bronnimann & Keiji	1986	Brunei and Sabah	This manuscript discussed the distribution of agglutinated foraminifera from the brackish waters of Brunei and Sabah.
5.	Hughes	2007	Sedili River, Johor	The study recognised the significance of biofacies application to determine the paleoenvironment. In areas where there is normal marine influence, the distribution of foraminifera consisted of mixed calcareous assemblages. The lower estuarine area supports a diverse agglutinated foraminiferal assemblage. Meanwhile the upper estuarine supports lower diversity of agglutinated foraminifera.
6.	Hawkes *et al.*	2007	Sungai Burong, Penang and Kuala Teriang, Langkawi, Kedah	The study analysed the foraminiferal assemblages in characterizing the pre-tsunami and tsunami sediments along the Malaysia–Thailand Peninsula. The foraminiferal zones provide estimates of sediment source and wave characteristics.
7.	Husain *et al.*	2007	Kapar and Matang, Perak	Study on the vertical distribution of foraminifera in short cores near coastal plain mangroves in Kapar and estuarine mangroves in Matang.
8.	Husain *et al.*	2008	Kapar mangrove, Perak	Distribution of benthic foraminifera from coastal plain mangroves in Kapar was investigated in this study. Soil salinity and percentage of clay were concluded to have significant influence on foraminiferal distribution in Kapar.

Table 1 continued

No.	Author	Year	Area	Remarks
9.	Hasan *et al.*	2012	Kelang Delta, Selangor, Pahang Delta, Pahang and Sedili Besar Rivers, Johor	The authors analysed the distribution of *Miliammina fusca* in brackish water. This study indicated that *M. fusca* is highly related to salinity and sedimentary facies.
10.	Culver *et al.*	2012	Setiu estuary and lagoon, Terengganu	This manuscript discussed the foraminifera and environment relationship in estuary-lagoon setting. Five biofacies were recognized which pertained to salinity.
11.	Culver *et al.*	2013	Setiu Wetland, Terengganu	The study observed the downcore distribution of dead foraminifera in mangrove of Setiu Wetland, with application to sea-level reconstruction.
12.	Culver *et al.*	2015	Terengganu coast	This is the first high-resolution foraminiferal-based sea-level study from the Sunda Shelf. This study demonstrated the application of benthic foraminifera in sea-level reconstruction from 1800 years ago.
13.	Minhat *et al.*	2013	Northwestern Penang Island	The study observed the distribution of shallow coastal water foraminiferal assemblages. The assemblages were mixture of calcareous and agglutinated foraminifera. Salinity and other environmental gradients had little variation along the transects. Hence they do not influence the foraminiferal assemblages.
14.	Minhat *et al.*	2014	Northwestern Penang Island	This study recognized the potential use of subtidal foraminifera as pollution indicator. The spatial distribution of foraminifera indicated the sedimentary characteristic and changes were due to anthropogenic activities.
15.	Minhat *et al.*	2016	Southeast Peninsular Malaysia.	Shifts in subtidal foraminiferla distribution in relation to water depth was observed here. This study tested the performance of transfer function and concluded that the foraminiferal assemblages have the potential to be used in sea-level reconstruction.
16.	Husain *et al.*	2014	Kapar and Matang, Perak	The study compares the modern foraminiferal distribution from two mangroves locality. The abundance and distribution of benthic foraminifera at Matang and Kapar show significant different in response to soil salinity, pH, grain size and total organic carbon.
17.	Ellis *et al.*	2014	Setiu estuary and lagoon, Terengganu	This study indicated that the spatial distribution of foraminifera is affected by the aquaculture activity in Setiu estuary and lagoon area.
18.	Thornberg *et al.*	2014	Setiu estuary and lagoon, Terengganu	The temporal influenced of aquaculture on modern foraminiferal distribution was from Setiu estuary and lagoon was investigated. The research indicated that overtime, fish-cage aquaculture affected the sediment characteristic and organic matter which in turn changes the distribution of foraminiferal assemblages.

Overall, the modern foraminiferal study in Malaysia is very scarce and focused mainly on their ecological distribution. Detailed analysis of published literature on modern foraminiferal studies along the west and east Malaysian water are summarised in Table 1. There are all together fifteen published studies in the coastal waters of Peninsular Malaysia and three published literatures of modern foraminifera from the coastal area of Sabah. In Peninsular Malaysia, many of the studies have been carried out in mangroves and estuarine environments with limited studies on the subtidal distribution. Both published and grey literatures are discussed in this review to obtain a complete picture on the status of modern foraminifera study in Malaysia. Below we summarise the foraminiferal studies in Malaysia according to their implication.

Taxonomy of Modern Foraminifera

Most of the studies emphasised on the ecological distribution rather than taxonomic aspect. An early taxonomic study by Dhillion (1969) discovered three new brackish water species from Labuk Estuary, Sabah, East Malaysia. The three species were identified as *Arenoparella malaysiana, Haplophragmoides labukensis* and *Haplophragmoides sabahkensis.* After the work of Dhillion (1969), there has not been any published manuscript on taxonomic work of modern foraminifera in Malaysia. Despite being one of the hotspot of diversity, less interest was paid to taxonomic study of modern foraminifera.

Ecology of Modern Foraminifera

The ecological study in East Malaysia is scarce with only two published literatures on modern foraminifera. One of the manuscripts focused on the distribution of modern planktonic foraminifera in Sabah waters (Keiji, 1963). Keiji (1963) concluded that the relative abundance of planktonic foraminifera increased with depth. The other published manuscript from Sabah discussed on the distribution of agglutinated foraminifera in brackish waters of Brunei and Sabah (Bronnimann & Keiji, 1986). Relatively more work has been done around the Malaysia peninsular waters. The Malaysia peninsula is characterized by the South China Sea on the east coast and Malacca Straits on the west coasts. There are four ecological studies published on modern benthic foraminifera along the South China Sea (Mohamed *et al.,* 2008; Culver *et al.,* 2012; Hasan *et al.,* 2012; Culver *et al.,* 2013) and five more from the Malacca straits (Husain *et al.,* 2007; Husain *et al.,* 2008; Hasan *et al.,* 2012; Minhat *et al.,* 2014; Satyanarayana *et al.,* 2014). Study on the southeastern coast by Mohamed *et al.* (2008) discussed the trend of agglutinated foraminifera distributions along Sedili Besar Rivers, Johor that open up to a well – developed estuary facing the South China Sea. The study indicated that the foraminiferal assemblages from the Sedili Besar River, Johor and the adjacent offshore area can be divided into five distinctive zones namely the upper intertidal, lower intertidal, estuary mouth, nearshore and shallow marine depositional settings. Another study at the intertidal area by Culver et al. (2012) recognized the association of foraminiferal assemblages distribution with salinity gradient. They observed both dead and live foraminifera along the estuary and lagoon of Setiu wetland, Terengganu and discovered that in area with low salinity, the assemblage is characterized by low diversity and high number of agglutinated foraminifera. The calcareous group on the other hand shows a trend of increase abundance and diversity with increased salinity.

Meanwhile on the west coast of Peninsular Malaysia, Husain *et al.* (2007), Husain *et al.* (2008) and Satyanarayana *et al.* (2014) observed the foraminiferal assemblages in the Matang estuary mangrove and Kapar coastal plain mangrove, Perak. Husain *et al.* (2007) collected short cores from Matang and Kapar and studied the vertical distribution of foraminifera in two different mangrove settings. The foraminiferal assemblage distribution along the core varied between Kapar and Matang samples. In Kapar, the top 4 cm was dominated by agglutinated group, which correlated with the presences of higher silt and clay percentage. The calcareous group increased down the core due to the increase percentage of sand. In Matang, a mixture

of agglutinated and calcareous foraminifera dominates the upper 40 cm and no species were found beyond this zone.

Another study by Husain *et al.* (2008) in Kapar mangrove investigates the spatial distribution of foraminifera. They observed that salinity and sediment characteristic have significant influence on the foraminiferal distribution. This study concluded that the density and diversity of foraminifera are higher at the middle and upper mangrove area where lower salinity and higher silt and clay percentage are observed. Subsequent study from Matang and Kapar, Perak by Satyanaraya *et al.* (2014) compared the spatial distribution of modern foraminifera from Kapar and Matang. The foraminiferal distributions differ between Matang and Kapar as they were locally influenced by two different environmental settings that prevail at Kapar and Matang.

With regards to grey literature from Table 2, Suriadi (2011) and Saelan (2011) provided a general distribution and ecological correlation of foraminifera assemblages collected from mangrove area. Saelan (2011) indicated that the assemblages in Larut Matang, Perak correlates with the sediment grain size distribution, while Suriadi (2011) indicated that the assemblages in Kemaman mangroves, Terengganu are mostly influenced by the salinity rather than grain size distribution. In another study, Hasan *et al.* (2012) compared the distribution of *Miliammina fusca* from three different deltas namely Sungai Pahang, Pahang, Sungai Kelang, Selangor and Sedili Besar, Johor. This study showed that the distribution of *Miliammina fusca* is closely related to salinity. A supportive gray literature on biofacies assemblages in Klang-Langat Delta, Selangor indicate that foraminiferal distribution can be divided into six distinctive zones (i.e. freshwater, upper brackish intertidal, lower brackish intertidal, channel banks, tidal channel and tidal flat) (Hasan *et al.,* 2010). However in their abstract, the authors do not state any fauna-environment relationship nor any dominant species found. The distribution of biofacies was probably effected by salinity, similar to the other studies. A study by Minhat *et al.* (2013) looked at the distribution of sub-tidal foraminifera around the coastal waters of Penang island. The shallow marine foraminifera assemblages are characterised by mixture between calcareous and agglutinated forms with high abundance of *Ammonia* sp., *Bigenerina* sp. and *Elphidium* sp. (Minhat *et al.,* 2013). This study also indicated that water nutrients do not have significant influence on the distribution of foraminifera in Penang coastal waters.

Application of Modern Foraminifera

The assessment of modern formainiferal application in paleo study only emphasises on the Peninsular Malaysia coastal area, and no data incorporated Sabah or Sarawak area to date. Along the east coast of Peninsular Malaysia, Hughes (2007) assessed the foraminiferal biofacies along the Sedili River in Johor. The foraminiferal distribution from upper to lower estuary show a discrete distributional pattern which can be directly correlated with salinity variations (Hughes, 2007). Hughes (2007) concludes that the foraminiferal biofacies are useful in paleoenvironment interpretation where sedimentological data alone cannot provide such refined interpretation. A different study by Culver *et al.* (2013) looked at the potential use of down core mangrove foraminifera assemblages in sea-level study. The authors collected four short cores along the mangrove swamp in Setiu, Terengganu. Three of the cores (two from high swamp and one from mid swamp) taken show no significant impact of tophonomic loss or bioturbation. This study suggests the possibility of using mangrove foraminifera as a sea-level signal. Suriadi *et al.* (2013) however indicated on the west coast of Peninsular Malaysia that not all foraminifera species are suitable in interpreting the paleo sea level. The presences of living infauna *Miliammina fusca* at 40-50 cm depth suggest that this species is a weak indicator for sea level interpretation.

Meanwhile a study by Hawkes *et al.* (2007) at the northern part of west of coast

Peninsular Malaysia observed the pre and post tsunami impact on foraminiferal assemblages. They had collected samples from two islands (i.e. Langkawi, Kedah and Penang) that have been hit by the 2004 Indian Ocean tsunami. The foraminifera assemblages observed in this study changes between pre and post tsunami event. The study confirms that foraminifer is a good indicator to mark the tsunami event where no lithological changes are evident. This study also recognised the potential use of foraminifera to estimate sediment source and wave characteristic. A study by Minhat *et al.* (2014) on the west coast of Peninsular Malaysia acknowledged the potential use of sub-tidal foraminifera assemblage in addressing the pollution impact. This study addresses the anthropogenic pollution by looking at the foraminiferal densities, assemblages, *Ammonia-Elphidium* Index values and the FoRAM indices. The results indicate that foraminifera can be utilised as an early warning bioindicator in areas where the physical and chemical parameters has no significant changes. Meanwhile in the east coast, two studies from the Setiu estuary and lagoon, Terengganu utilised the distribution of foraminifera to investigate the influence of aquaculture activities on the health of the estuary and lagoon. Ellis *et al.* (2014) discussed the effect of aquaculture on spatial distribution of foraminiferal diversity and density. The foraminiferal assemblages at the fish-cage complexes were strongly affected by the salinity and pH. Changes in distributional patterns and diversity as well as increase in the number of living specimen surrounding the active aquaculture area were concluded to be caused by the pollution from the fish-cage culture activity. A complementary study by Thornberg *et al.* (2014) assessed the temporal influence of aquaculture activity in Setiu estuary and lagoon. Thornberg *et al.* (2014) investigated the core samples collected from the Setiu estuary and lagoon, Terengganu. The study indicated that over the years, the presence of aquaculture activity has increased the flux of organic matter to the estuarine and lagoonal environment. Hence both studies in Setiu, Terengganu have proven the usefulness of foraminiferal assemblages as bioindicator in monitoring the health of marine environment.

The growing interest in modern foraminiferal study in recent years is important as these studies provide a baseline data for future research. Nonetheless, more research is required especially on the coast of Sabah and Sarawak to fill the gaps in Malaysian formainiferal research. Based on the current status of foraminiferal study, we outlined several recommendations for future foraminiferal research

Recommendations for Future Research

So far no effort of compiling the illustration and taxonomic identification of foraminifera taxa in Malaysian water has been attempted. The most similar taxonomic references to this region which is up to date is Loeblich and Tappan (1994) on foraminifera classification in the Sahul Shelf. Nevertheless the references available so far are not complete, with several missing genera that are endemic to our region (e.g. *Asterorotalia puchella*). We recommend a compilation of proper illustration and identification of Malaysian foraminifera. This effort will certainly serve as an important reference for future study. As for the application in paleoenvironmental study, we observed that attempts have been made to assess the usefulness of modern foraminifera in paleo studies. Nevertheless, none has attempted to apply them to interpret the paleoenvironment. The study of cores from Malaysian waters could establish better understanding of the past environment.

Since Malaysia is situated on the far-field site and less active tectonic plate, the data collected from Malaysian waters are important to determine the rise and fall of the world sea-level. Hence, we recommend that the application of foraminifera in paleo study should be intensified. The reconstruction of past monsoon patterns, sea level changes and coastal evolution using foraminifera will benefits many stakeholders in planning future flood mitigation strategies. Malaysia is also blessed by the high diversity

and distribution of coral reef. However, no attempt is made to understand the foraminiferal distribution in such environment. Therefore we suggest that ecological study should be carried out in coral reef area and offshore area. Such study will not only serve as baseline data on modern foraminifera distribution but also useful to the paleoenvironmental study. Extended data on modern foraminifera distribution will serve as indicator of past environment and the condition from the past will be the key to unlock the future events.

Conclusion

It is obvious that despite the potential application of foraminifera in various fields, adequate attention has not been given to the foraminiferal studies in Malaysia. The attempt by several authors may have set the stepping stone to many other possible studies on foraminifera. Hence it is recommended that study of foraminifera application as indicator to changes should be intensified in the near future. This is important, especially in sea level research as Malaysia is believed to be at a geologically stable region and at the far-field site, the most suitable site for sea level interpretation.

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