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Mudbank off Alleppey, India: A bane for foraminifera but not so for carbon burial

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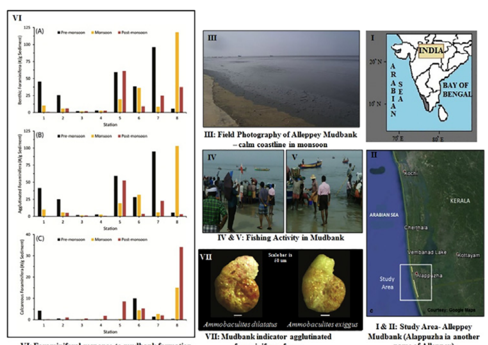
HIGHLIGHTS

- Poor abundance of living benthic foraminifera suggests that Alleppey mudbank represents a stressed marginal marine environment
- Dominance of living agglutinated foraminifera indicate freshwater influence in the region
- *Ammobaculites dilatatus* and *Ammobaculites exiggus* are indicator species of the mudbank region.
- The reduced calcareous benthic foraminiferal abundance, however, does not affect the overall carbon burial in the mudbank.

GRAPHICAL ABSTRACT



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ABSTRACT

Calm conditions and extensive fishing, during monsoon season in the mudbank off Alleppey (Kerala), India creates a unique environment, associated with high suspended particulate matter. The effect of processes associated with mudbank formation, on benthic foraminifera, however, has not been documented. We have studied, seasonal foraminiferal distribution, to understand foraminiferal response to physico-chemical changes associated with the mudbank formation. Additionally, seasonal changes in total carbon, calcium carbonate ($CaCO_3$), organic carbon (C_{org}) and C_{org}/nitrogen (C_{org}/N) were also measured to understand the effect of mudbank formation on carbon burial. We report a low foraminiferal abundance in the mudbank. Benthic foraminiferal diversity is also low in the mudbank, during both pre-monsoon and monsoon season, clearly suggesting a stressed environment. Agglutinated foraminifera dominate the living benthic foraminiferal population in the mudbank, suggesting that the area is carbonate undersaturated and under fresh-water influence. *Ammobaculites dilatatus* and *Ammobaculites exiguus* are the dominant agglutinated species abundant in the mudbank and thus can be used to reconstruct past changes in the mudbank. The $CaCO_3$ is consistently low during all seasons, at one of the core mudbank stations. The %C_{org} is, however, higher in the core mudbank as well as the northern peripheral region. The C_{org}/N is consistently uniform at all the stations indicating a similar source of organic matter in all the seasons. The higher %C_{org} and constant C_{org}/N suggest, that food availability and its source is not a major factor affecting benthic foraminifera in the mudbank. Instead, increased turbidity and low bottom water salinity are the main cause of seasonally stressed environment in the mudbank. Additionally, C_{org} degradation coupled with fresh water influx induced drop in bottom water pH is responsible for low foraminiferal population in mudbank region, in all the seasons. The reduced calcareous benthic foraminiferal abundance, however, does not affect the carbon burial in the mudbank, due to higher %C_{org}.

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1. Introduction

The huge sediment influx and characteristic hydrodynamic conditions near river mouth regions, result in the formation of mudbanks. The mudbanks have been reported from several regions and the processes leading to the mudbank formation vary. The mudbank off the coast of French Guiana at Kaw river mouth, forms due to the combined effect of sediment supply from the Amazon River and hydrodynamics of coastal currents (Lefebvre et al., 2004). The combined effect of currents, tides and waves also result in the formation of a mudbank plume off Brazil (Chevalier et al., 2008). The low-energy environment mudbanks are also reported from Florida Bay and are contrary to the high-energy environment mudbanks described from the nearshore areas around the Amazon River mouth (Taylor and Purkis, 2012). The coastal water of southeastern Arabian Sea, off Alleppey, Kerala, also becomes characteristically calm during the otherwise turbulent monsoon season. This calm coastal zone forms within 15 m water depth and is known as mudbank. It is distinctly associated with high suspended particulate matter in the water column (Shynu et al., 2017). The re-suspension of bottom mud is supposed to be the cause of very high turbidity in the mudbank (Kurup, 1977; Mallik et al., 1988; Tatavarti and Narayana, 2006). Along the southwest coast of India, other than Alleppey, mudbanks have been reported from a coastal area off Kozhikode near Beypore river mouth and off Narakkal (near Kochi) at Periyar river mouth (Rao, 1967). Of these mudbank occurrences, only the Alleppey mudbank continues to be persistent during the southwest monsoon season since the 1900s. Apart from its continued occurrence, Alleppey mudbank is different from the rest as it forms in nearshore setting away from river mouth (CMFRI, 1984). The characteristic calmness along the shoreline (CMFRI, 1984; Murty et al., 1984; Jiang and Mehta, 1996; Narayana et al., 2008) makes the Alleppey mudbank area important for fisheries. The mudbank shoreline becomes the avenue of extensive fishing when the rest of the coastline is highly unsafe to venture into the sea (Gopinathan and Qasim, 1974; Ragunathan et al., 1984; Aswathy and Sathiadhas, 2006; Shyam et al., 2016). The high socio-economic implications of mudbank, require a proper understanding of the mudbank dynamics, especially the changes in its spatial and temporal extent.

The unique marine environment of the mudbank and extensive anthropogenic activities invariably affect the marine organisms living in mudbank area, resulting in a characteristic distribution pattern (Damodaran and Hridyaanathan, 1966). The seasonal disturbance of bottom mud would certainly affect the dominant unicellular benthic protozoan, foraminifera, as it lives in the top few centimeters of the substrate (Singh et al., 2017). The species-specific response of foraminifera is due to the sensitivity of these organisms to the changes in their inhabiting environment (Boltovskoy and Wright, 1976; Sen Gupta, 1999; Murray, 2006; Bouchet et al., 2012). Even the short-term anthropogenic (Bouchet et al., 2007) or ecological stressors (Kurtarkar et al., 2011) leave a traceable signature in benthic foraminiferal population. Therefore, the objective of this work was to understand the effect of processes associated with mudbank formation, and other anthropogenic activities in the area, on benthic foraminifera. Additionally, as the calcareous benthic foraminifera are responsible for sequestering a large part of the carbon, efforts are also made to understand the effect of mudbank formation and anthropogenic activities on carbon burial. Benthic foraminiferal distribution from the eastern Arabian Sea, including off Kerala, has been extensively documented. The pioneering foraminifera related work dealt with detailed bathymetric distribution, zonal abundance and correlating faunal response to environmental parameters (Sethulekshmi, 1958; Antony, 1968; Seibold, 1975; Seibold and Seibold, 1981; Nisha and Singh, 2012). Our effort to document foraminiferal distribution from the mudbank off Alleppey is, however, different from the previous works, in being a seasonal study of faunal abundance. Moreover, the foraminifera response is studied specifically concerning the onset and offset of mudbank phenomenon in the area. The study of specific foraminiferal response will help to understand mudbank migration and intensity in the past and its influence on carbon burial.

2. Study area

The areal extent of mudbank off Alleppey, Kerala is approximately 32 km^2. It extends for ~3–4 km along the shore and ~8–10 km perpendicular to the shore (Gopinathan and Qasim, 1974; Manojkumar et al., 1998; Balachnadran, 2004; Narayana et al., 2008). The mudbank forms during every monsoon season at Punnapra, with historical record available since 1885 (Damodaran and Hridyaanathan, 1966(Fig. 1). The study area is devoid of any rivers/streams. The only source of freshwater near the mudbank is the Vembanad Lake which is approximately 40 km inland from the coastal site of mudbank formation (National Wetland Atlas Kerala, 2010; Soman, 2013). The average annual rainfall in the study area is 2826 mm (http://www.imd.gov.in/section/climate/extreme/alappuzha2.htm), and the larger part of the precipitation is during the summer monsoon season. The seasonal coastal currents in the area remain southerly during the pre-monsoon season. The coastal currents remain weak and significantly nullified during the mudbank season. As the mudbank subsides during the post-monsoon, the currents change direction towards the north (Mathew et al., 1984; Gopinathan and Qasim, 1974).

The primary productivity in the mudbank area off Alleppey, decreases during monsoon season (June–September), unlike the rest of the west coast of India. The productivity in the mudbank during pre-monsoon season (February–May) was 19.77 to 277.00 mg $C/m^3/h$. The productivity decreased during monsoon season to 0.52 to 41.40 mg $C/m^3/h$ and was also low during the post-monsoon season (1.31 to 17.40 mg $C/m^3/h$) (Nair et al., 1984). The drop in productivity was attributed to the reduction in the euphotic zone at the time of mudbank formation (Nair et al., 1984).

3. Materials and methods

The core mudbank area, as well as both the north and south peripheral regions, were sampled, by using a grab sediment sampler, operated from a fishing trawler *Santa Cruz*. The sampling area falls within 9.48–9.36°N latitude and 76.32–76.28°E longitude. The sampling was done along four transects. Each transect had a couple of stations, one between 5 and 10 m water depth and another between 10 and 15 m water depth. Transect I has two stations, i.e. station numbers 1 and 2, and falls within the northern periphery of the core mudbank area. The stations 1 and 2 are henceforth referred as Northern Stations (NS). Transect II had station numbers 3 and 4, that fall within the mudbank area, and are referred as Core Mudbank Stations (CMS). Transects III and IV had station numbers 5, 6 and 7, 8, respectively, and constitute the Southern Stations (SS) (Fig. 1). The sampling was carried out during pre-monsoon (May 2015), monsoon (August 2015) and post-monsoon season (February 2016). The sampling time was decided by the presence and absence of the mudbank and does not exactly coincide with the meteorologically defined average monsoon seasons. The total area covered was 53.28 km^2. Immediately after sampling, approximately top 5 cm of the sediment, collected by grab sampler, was stained by using ethanol rose-Bengal solution to distinguish living benthic foraminifera. The top 5 cm of the sediments were stained as the studies suggest that the living benthic foraminifera are confined to this depth in the southeastern Arabian Sea (Singh et al., 2017). The sediments were processed following the standard procedure for foraminiferal study, after a minimum staining period of two weeks (Manasa et al., 2016).

A minimum of 300 living (stained) benthic foraminifera were picked from weighed aliquots of coarse fraction (>63 μm) of each sample. In a few cases, where sufficient specimens were not available, the entire coarse fraction was used to pick all the living specimens. To be sure of the stained status, the specimens were transferred to a petri-dish filled