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Dominance of coastal upwelling over Mud Bank in shaping the mesozooplankton along the southwest coast of India during the Southwest Monsoon

L. Jagadeesan, R. Jyothibabu *, N. Arunpandi, C. Karnan, K.K. Balachandran

CSIR- National Institute of Oceanography, Regional Centre, Kochi 682018, India

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ABSTRACT

Mud Banks are littoral zones along the Kerala (southwest) coast of India with increased suspended sediments during the Southwest Monsoon (SWM), which facilitate remarkable damping of incident waves creating a localized calm sea environment conducive for fishing activities. In this paper, we used the response of mesozooplankton community as a whole and copepod species in particular as a tool to characterize the relative importance of Coastal Upwelling and Mud Bank in shaping the biological manifestations along the southwest coast of India. The geographical area studied was off Alappuzha (Kerala coast) and altogether 18 field samplings (weekly/fortnightly) were carried out in three locations in the region (M1, M2 and M3) from the Pre-SWM to the Late-SWM of 2014. M1 was a reference location at the same depth contour (6 m) and 10 km north of location M2 that represented the region where the Mud Bank forms during the SWM. Location M3 was situated beyond the offshore boundary of the Mud Bank zone (12 m depth), perpendicular to location M2. The physical characteristics of the Mud Bank, such as relatively high suspended sediments and calm sea conditions, existed at M2 by mid-June and before that all the three locations had comparable physical characteristics in the water column. Coastal Upwelling was prevalent over all the three locations by early-June, characterized by cool and less oxygenated waters, more so in the subsurface waters. The mesozooplankton community in the study domain was composed of 15 heterogeneous groups; their biomass and abundance were high during the Peak- (av. 6.02 ± 5.19 ml m^{-3} and av. 7285 ± 3248 No m^{-3}) and Late-SWM (av. 4.91 ± 4.35 ml m^{-3} and av. 6802 ± 2727 No m^{-3}) compared to the Pre-SWM (av. 0.63 ± 0.55 ml m^{-3} and av. 3045 ± 1584 No m^{-3}) and Early-SWM (av. 0.58 ± 0.46 ml m^{-3} and av. 2047 ± 1675 No m^{-3}). Mesozooplankton abundance was dominated by copepods (>70%) and the number of larger zooplankton carnivores (medusae, siphonophores and chaetognaths) was found to be low (<5%). Altogether, 43 species of copepods were recorded from the present study. Based on the abundance and species distribution of copepods in all three locations, cluster and SIMPROF analyses delineated four environmental conditions (clusters) typical of Pre-SWM (cluster 1), Early-SWM (cluster 2), Peak-SWM (cluster 3) and Late-SWM (cluster 4). SIMPER analysis demarcated the discriminating species of copepods in the environmental clusters delineated by cluster/SIMPROF. The discriminating copepods were composed of *Acartia danae*, *A. erythraea*, *Centropages orsini* (cluster1); *Temora turbinata* (the upwelling indicator) (cluster 2); *Oithona similis* (cluster 3); *Temora turbinata*, *Pseudodiaptomus serricaudatus*, *Centropages tenuremis* (cluster 4). The dominance and distribution pattern of copepods observed in all three study locations were very similar and the detailed Multivariate Redundancy analysis confirmed the dominant influence of Coastal Upwelling and not the Mud Bank in structuring the mesozooplankton/copepod community in the study domain. The present study provides the first in-depth information on the mesozooplankton (especially copepods) from a Coastal Upwelling - Mud Bank system along the southwest coast of India, evidencing the dominant role of Coastal Upwelling in shaping the zooplankton community during the SWM.

1. Introduction

Mud Bank (Chakara) is a well-known but, enigmatic coastal feature that occurs annually during the Southwest Monsoon

* Corresponding author.
E-mail address: rjyothibabu@nio.org (R. Jyothibabu).

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(June - September) in fragmented stretches of the Kerala coast (Southwest coast of India). It is a unique feature attracting scientific and public interest from time immemorial principally due to the rich fishery associated with the event (Bristow, 1938; Du cane et al., 1938; Damodaran, 1973; Gopinathan and Qasim, 1974; Silas, 1984). Essentially, Mud Banks are semicircular patches of calm littoral waters carrying a relatively high load of suspended sediments. Their seaward extent typically occurs along the 10 m depth contour and their alongshore dimension is about 3–6 km (Kurup, 1977; Silas, 1984). The thick fluid muddy layer that exists close to the sea bottom during the Mud Bank facilitates damping of waves, making the environment conducive for fishing activities at a time that the rest of the region experiences strong monsoonal sea conditions unsuitable for fishing (Damodaran, 1973; Gopinathan and Qasim, 1974; Silas, 1984; Mallik et al., 1988). Even though Mud Banks occur in several places along the Kerala coast (Damodaran, 1973; Silas, 1984), the one that forms off Alappuzha receives special attention due to (a) its consistent occurrence every year and (b) large fisheries associated with it (Damodaran, 1973; Silas, 1984; NIO Report, 2008). Although a dozen hypotheses are in place to explain the formation of Mud Bank along the Kerala coast (Ramasastry and Myrland, 1959; Silas, 1984; Mathew et al., 1995; Manojkumar et al., 1998; Tatavarti et al., 1999; Narayana et al., 2001; Balachandran, 2004), all of them leave uncertainty in explaining one or the other characteristics of the Mud Bank that occurs along the Kerala coast. Nonetheless, it is a fact that large landings of fishes are associated with the Alappuzha Mud Bank event every year during the Southwest Monsoon period (Regunathan et al., 1984a,b). The Mud Bank region, due to its calm environment, serves predominantly as a launching and landing place for fishing vessels rather than an actual fishing ground itself (Regunathan et al., 1984a,b).

Upwelling in the nearshore waters along the Southwest coast of India begins by the onset of the Southwest Monsoon (June) and gets intensified during July - August (Madhupratap et al., 1996; Nair et al., 1992; Jyothibabu et al., 2008). Its presence during the Southwest Monsoon is indicated by the advection of cool, nutrient-rich, hypoxic subsurface waters towards the coast, leading to significantly high plankton biomass and production (Madhupratap et al., 1996, 2001; Smith and Madhupratap, 2005; Jyothibabu et al., 2006, 2008). Recent studies showed that both local wind stress and remote forcing contribute to the formation of coastal upwelling along the southwest coast of India (Gupta et al., 2016 and references therein). Certainly, the coastal upwelling areas possess immense socio-economic significance as they represent the regions of high fishery resources (Banse, 1959, 1968; Cury et al., 2000). World over, upwelling systems that occupy only 0.1% of the total oceanic area contribute around 20% of the world fish production (Cury et al., 2000). It is evident in the above description that coastal upwelling along the southwest (Kerala) coast of India during the Southwest Monsoon facilitate significant enhancement in plankton biomass.

Zooplankton are good indicators of hydrographical transformations in marine systems, as they respond to even subtle changes in the physical, chemical and biological properties in their surroundings (Queiroga and Blanton, 2004; Jagadeesan et al., 2013). Among around 15 zooplankton groups that normally occur in Indian seas, copepods generally contribute numerically 60–90% of the community and play a significant role in the planktonic food web (Jagadeesan et al., 2013). Their community/species response is considered to be a true indication of the prevailing hydrographical settings (Madhupratap et al., 1996; Jagadeesan et al., 2013). The current understanding is that the plankton biomass (both phyto - and zooplankton) in the inshore waters along the Southwest coast of India increases noticeably during the Southwest Monsoon period associated with intense coastal upwelling (NIO Report, 2008; Jyothibabu et al., 2008, 2010; Asha Devi et al., 2010). Similar is the case of the Alappuzha Mud Bank (present study area), wherein the water column becomes highly productive during the Southwest Monsoon (Mathew et al., 1977, 1984; Nair et al., 1984). As coastal upwelling and Mud Bank formation occurs during the same period (Southwest Monsoon), their specific role to enhance the plankton biomass is rather unclear. Therefore, in this study, we investigated the response of the mesozooplankton community as a whole and copepod species in particular to understand the specific biophysical roles of Mud Bank and coastal upwelling along the southwest coast of India during the Southwest Monsoon period.

The following aspects of the mesozooplankton community in the study region were considered with respect to the hydrographical settings; (a) temporal and spatial changes in biomass, abundance and composition of mesozooplankton (b) delineating the dominant and discriminating species of copepods during the different phases of hydrographical transformations associated with Mud Bank and coastal upwelling events, (c) the relative importance of coastal upwelling and the Mud Bank in shaping the copepod community (d) to verify whether there is a specialized zooplankton community adapted to the relatively turbid environment of the Mud Bank region.

2. Materials and methods

2.1. Environment and sampling

The Mud Bank area studied is located south of Alappuzha in Kerala, along the Southwest coast of India, between 9.25 to 9.43°N and 76.3–76.4°E. Baseline information on the biological characteristics of the Alappuzha Mud Bank is available in some of the historical studies on plankton (Mathew et al., 1977, 1984; Nair et al., 1984), benthos (Damodaran, 1973; Regunathan et al., 1984a) and fisheries (Regunathan et al., 1981, 1984b). In general, diatoms dominate throughout the Mud Bank phase, while dinoflagellates (especially *Noctiluca* sp.) occur abundantly and sporadically during the peak and late phases of the Mud Bank (Subrahmanyan et al., 1975; Nair et al., 1984). A review of the literature indicates that the phytoplankton successional pattern in the Mud Bank area is not very different from what exists all along the southwest coast of India during the Southwest Monsoon period governed by coastal upwelling (Subrahmanyan, 1959; Nair et al., 1992; Madhupratap and Parulekar, 1993; Naqvi et al., 1998; Sahayak et al., 2005). Compared to the phytoplankton community, studies on the mesozooplankton community from the Alappuzha Mud Bank is more generic in nature and basically deal with group level information (Mathew et al., 1977, 1984).

As a part of a focused study on the Mud Bank of Alappuzha in 2014 [Alappuzha Mud Bank Process Studies (AMPS)], 18 field samplings were carried out in three different locations (M1, M2 and M3) in the study domain off Alappuzha, southwest coast of India Fig. 1. Location M1 was a reference (non-Mud Bank) point at the same depth contour (6 m) but 10 km northward from M2 (Mud Bank location). Location M3 was situated beyond the offshore boundary of the Mud Bank (12 m depth) and perpendicular to the Mud Bank location M2. Field sampling at these three locations were carried out from April (Pre-Southwest Monsoon) to September 2014 (Late Southwest Monsoon) including 15 weekly samplings (April 22nd to 2nd August) and 3 biweekly samplings (16th August to 20th September). In total, four sampling phases were considered: Pre-Southwest Monsoon (Pre-SWM), Early-Southwest Monsoon (Early-SWM), Peak-Southwest Monsoon (Peak-SWM) and Late-Southwest Monsoon (Late-SWM).