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Tracking the history of dinoflagellate cyst assemblages in sediments from the west coast of India

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ABSTRACT

In order to trace the history of dinoflagellate cyst assemblages and provide new insights in to Harmful Algal Bloom (HAB) dynamics in monsoon-influenced tropical environments, sediment cores were collected from four different coastal locations along the west coast of India. The naturally occurring radionuclide ^{210}Pb activity in the sediment samples were measured; and subsequently the sedimentation rates (SRs) and ages were modeled. The SRs ranged from 0.15 ± 0.01 to 2.80 ± 0.38 cm/yr and provided coverage of time period spanning between 21 and 145 yr. Cysts of potential harmful dinoflagellates (*Gonyaulax spinifera*, *Lingulodinium polyedrum*, *Protoceratium reticulatum* and *Scrippsiella trochoidea*) were observed to be present earlier than the 20th century. Among the four sediment cores, significant temporal variations in cyst abundance were observed in the sediment core, off Mangalore. Two of the cores from off Mangalore and Cannanore were dominated by autotrophic cyst assemblages (*Gonyaulax membranacea* and *Gonyaulax spinifera*) in the deeper sediment sections. However, the upper sediment sections were dominated by heterotrophic forms. Temporal shifts in cyst assemblages from autotrophic to heterotrophic dinoflagellates in the Mangalore core coincided with high deposition of shells; carbon analyses ($\delta^{13}C_{org}$ and C_{org}:N ratio) revealed shifts in organic matter type from terrestrial to marine source. The terrigenous input in this region, influenced by the monsoonal variations, can thus affect dinoflagellate assemblage structure and lead to changes in ecosystem functioning.

1. Introduction

Dinoflagellates are a highly diverse group of flagellates, consisting of both photosynthetic (autotrophic) and non-photosynthetic (heterotrophic) taxa in equal proportions (Taylor and Pollinger, 1987). They form an important component of phytoplankton communities, contributing to toxic and Harmful Algal Blooms (HABs) (Anderson, 1989; Hallegraeff, 1993). About 10% of the 2000 identified dinoflagellate species (Taylor and Pollinger, 1987) produce cysts (Head, 1996). These cysts, prevalent in the sediment bed, can provide basis for onset of blooms during favorable conditions.

The distribution of dinoflagellate cysts (referred further in the text as dinocysts) represents an integrated record of planktonic assemblages over time and space, and is an archive of past environmental changes. Dinocysts are composed of dinosporin (Fensome et al., 1993), a biomacromolecule that is refractory towards degradation. This resistance facilitates their high preservation potential and long sedimentary record. Dinocysts have the potential to be preserved in the sediments for a much longer time than only decades (Belmonte et al., 1995). Thus, they can provide a historical account of their past occurrence and potentially their bloom history.

With increasing awareness about the global expansion of HABs, information on dinocyst distribution in the sediment cores can provide significant insights to HAB dynamics in the region. Earlier studies have provided evidence for occurrence of harmful/toxic cyst species during a particular time period through dating of the sediment cores; for example *Pyrodinium bahamense* var. *compressum* in Manila bay (Furio et al., 1996; Siringan et al., 2008); and *Gymnodinium catenatum* in Tasmanian waters (McMinn et al., 1997) and harbors of New Zealand (Irwin et al., 2003). India being a maritime country having ~7500 km coastline reported several HAB incidents (Iyer et al., 2008; Karunasagar et al., 1984, 1998; Segar and Karunasagar, 1989; Silas et al., 1982). Reports from the recent past indicated that the coastal waters of India are also susceptible to ship-mediated bioinvasion (Anil et al., 2002). In fact, bioinvasion is recognized as one of the vectors for global expansion of HABs to other parts of the world (Blackburn et al., 2001; Hallegraeff, 1998; Marangoni et al., 2001). Apart from this, the study area is influenced by South–West (SW) monsoon and upwelling. The potential of SW monsoon to influence the dinoflagellate community and shifts in dominance has been observed in Mumbai port, west coast of India (D'Costa et al., 2008).

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Naturally occurring seasonal enrichment in nutrients has been reported along the west coast of India where upwelling during the SW monsoon results in high nutrient conditions triggering high primary production (de Sousa, et al., 1996; Naqvi et al., 2000). However, previous dinocyst studies carried out along the west coast of India have investigated only the surface sediments where dinocyst assemblages were mainly dominated by heterotrophic forms (D'Costa et al., 2008; D'Silva et al., 2011; Godhe et al., 2000; Patil, 2003).

Therefore, the present study was motivated by the lack of information on temporal/long-term changes in dinocyst assemblages from the Indian region. Sediment cores were collected from four different coastal locations (Goa, Karwar, Mangalore and Cannanore) for analyses of dinocysts. The naturally occurring radionuclide ^{210}Pb activity in sediment samples were measured; and subsequently the sedimentation rates and ages were modeled. Additionally, geochemical analysis of the organic (C_{org}) and inorganic carbon content ($CaCO_3$), isotopic nature ($\delta^{13}C_{org}$) and organic carbon: total nitrogen (C_{org}:N) ratio was also carried out to identify the origin and nature of the organic matter preserved in the sediment. The aims of the present study were to elucidate (1) the temporal variations in dinocyst assemblages and (2) the probable causes for shifts in dinocyst assemblages.

2. Materials and methods

2.1. Environmental settings and characteristics of the study area

The study area is situated on the eastern side of the Arabian Sea (refer to Fig. 1). The western continental shelf of India varies in width from 130 km in the north to 60 km in the south. The general continental drainage along the west coast of India is characterized by small rivers and streams that drain into the Arabian Sea. Rivers like Sal in Goa, Kalinadi in Karwar, Netravati in Mangalore and Valapattanam in Cannanore flow across the coastal plain, most of which are estuarine for the greater part of their length (Nair et al., 1978). Two distinct sediment types occur on the shelf, clastic clays on the inner shelf and relict sands on the outer shelf (Nair and Pylee, 1968). The surface currents along the west coast of India reverse every six months. During summer or SW monsoon (June–September), the West India Coastal Current (WICC) flows equatorward in the direction opposite to the wind. The local winds are upwelling favorable (Shetye et al., 1990); they commence from the SW coast of India during May and gradually propagate towards the north with decreasing intensity, well after the collapse of SW monsoon winds during September/October (Banse, 1968; Shetye et al., 1985). The SW monsoon coupled with upwelling brings cold, nutrient-rich waters from a few hundred meters depth to the surface and fuels biological productivity in the euphotic zone. Due to high biological productivity, the intermediate water gets depleted of oxygen creating hypoxic conditions during September–October (Naqvi et al., 2000). This region is also profoundly influenced by the SW monsoon rainfall. The heaviest rainfall occurs along the central west coast (around 13–14°N latitude) decreasing northward to <1000 mm/yr along the Gujarat coast (north of Mumbai) and more gently towards the south (~2500 mm/yr at Trivandrum). During the winter period from November to January with reversal in surface currents (WICC), this process is reversed and associated with downwelling and well-oxygenated conditions over the shelf. The west coast of India is also characterized by low nutrient conditions and higher sea surface temperatures during February to May period.

2.2. Sediment sampling

Sampling was carried out at four coastal locations along the west coast of India during cruises onboard the Coastal Research Vessel (CRV) *Sagar Sukti* (cruise numbers: SaSu–89 and SaSu–125). The sampling locations were located on the inner shelf region off Goa (G1), Karwar (K1), Mangalore (M1) and Cannanore (Cn1) (Fig. 1).

Sediment cores were collected with a gravity corer having an inner diameter of 63 mm (details of cores given in Table 1). Utmost care was taken to collect the core tops and no visible disturbance features were seen on hauling up the sediment cores. The cores were

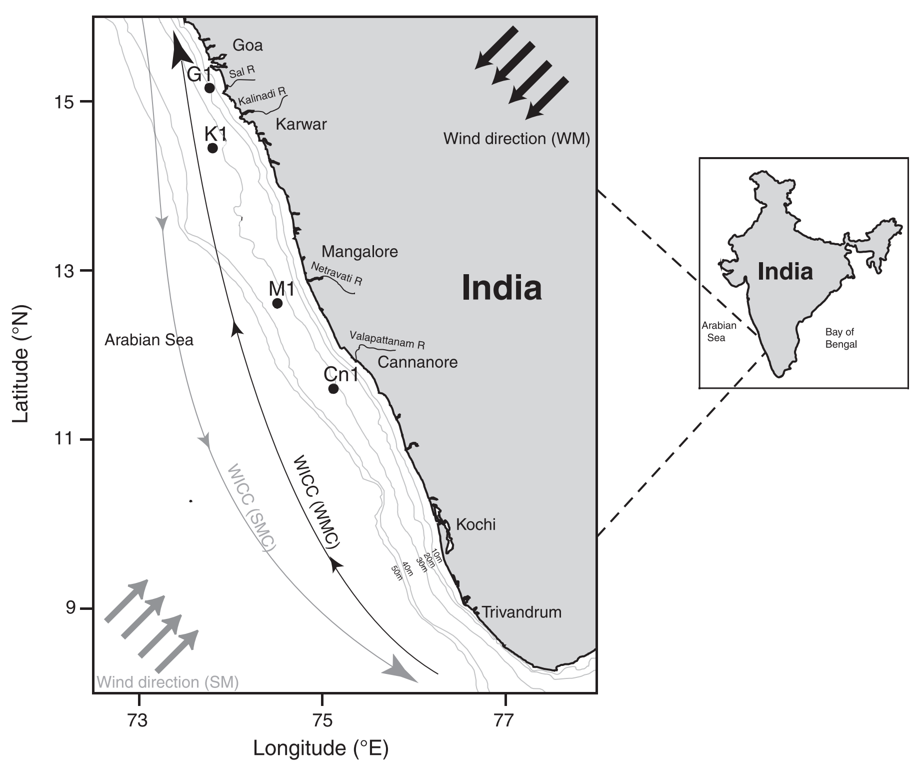

Fig. 1. Location map of sediment cores collected from the west coast of India. Map showing major features of surface circulation and wind direction during the South-West (SW) monsoon and North–East (NE) monsoon [WICC, West India Coastal Current; SMC, South-West monsoon current; NMC, North-East monsoon current; SM, summer monsoon; WM, winter monsoon].