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# Carbon and nitrogen isotopic composition of suspended particulate organic matter in Zuari Estuary, west coast of India

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ABSTRACT

The spatio-temporal variations of the $\delta^{13}C$ and $\delta^{15}N$ of suspended particulate organic matter (SPOM), along with ancillary chemical and hydrographic parameters, have been examined monthly for one year (October 2010 to September 2011) at a total of seven stations to refine the understanding of SPOM sources and biogeochemical pathways in the tropical Zuari Estuary, west coast of India. The dynamic nature of C and N cycling in estuaries is reflected in the isotopic variation of SPOM as a function of space and time. The results exhibit marked seasonality, with the autochthonous component and the terrestrial component being the major SPOM sources during periods of low and high river discharges, respectively. Spatially, enrichments of $\delta^{13}C$ and $\delta^{15}N$ from the head ($\delta^{13}C = -29.6‰$, $\delta^{15}N = 1.78‰$, C/N = 7.09) to the mouth ($\delta^{13}C = -20.9‰$, $\delta^{15}N = 5.77‰$, C/N = 6.12) of the estuary indicate downstream reduction of terrigenous influence. The mean C:N ratios varied between 4 and 9 over the study period with low values during the monsoon, in spite of large terrestrial input, which can be attributed to microbial modification of terrestrial SPOM. A significant positive correlation of $\delta^{13}C$ with salinity suggests the reliability of $\delta^{13}C$ as a biogeochemical tracer for organic matter provenance. Carbon: chlorophyll plots reveal suppressed autochthonous production during the southwest monsoon which may be attributed to the rapid flushing time, light-limitation due to cloud cover and high water-column turbidity.



## 1. Introduction

Located at the confluence of freshwater and marine ecosystems, estuaries receive organic matter from multiple sources. Allochthonous sources comprise both marine and terrestrial inputs, with the latter including land runoff, domestic and industrial wastes, while the autochthonous supply comes through pelagic and benthic photosynthesis and chemoautotrophic production. Microzooplankton plays a crucial role in transferring organic carbon from heterotrophic bacteria to higher trophic levels via the microbial loop. Alteration of particulate organic matter (POM) by the microbial community plays an important role in estuaries having long residence times. The estuarine POM serves as a significant source of nutrients to the adjacent coastal ecosystems (Mayer et al., 1998; Rabalais et al., 1996).

It is estimated that by 2025, about three-fourth the world's population will reside in coastal regions (Hinrichsen, 1997), making coastal ecosystems more vulnerable to human induced changes than they are today. It is essential to understand the origin and transformation pathways of organic matter in various estuarine and coastal systems in order to assess the current state of these ecosystems globally and predict the vulnerability of the coastal ocean to various potential scenarios of growth of anthropogenic drivers. Estuaries located in tropical regions with high human population density are expected to be most severely affected by human-induced changes. Despite their high vulnerability, relatively few studies have been conducted so far to understand the sources and transformation pathways of organic matter in such systems (Andrews et al., 1998; Cifuentes et al., 1996; Maya et al., 2011).

The continental shelf off western India is known to experience depletion of dissolved oxygen (DO) in the water column seasonally during the southwest (SW) monsoon when the low-oxygen subsurface waters are brought up through upwelling (Banse, 1959; Carruthers et al., 1959). It has been suggested that this natural oxygen deficiency has intensified in the past few decades, possibly due to enhanced loading of nutrients and organic matter from land (Naqvi et al., 2000, 2006). This loading is largely through numerous small rivers that originate in the Western Ghats. The Zuari is one such river that forms one of the largest estuaries along the Indian west coast. This tide-dominated estuary is extensively used for transportation of iron and manganese ores for overseas export from the Mormugao port, located at the mouth of the estuary, throughout the year. There are 129 industries and 10 large mines located in the river basin. Each mine discharges 1000–4000 tonnes of rejects per day which eventually end up in the river.

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In addition, the estuary also receives large quantities of, mostly untreated, sewage from municipal sources (http://www.indiawaterportal.org/articles/mining-havoc-impact-mining-water-resources-goa-article-dams-rivers-and-people). Mining rejects act as a significant source of nitrate to the estuary (Desousa, 1999). Fishing is another important activity that goes on uninterrupted throughout the year, especially during the SW monsoon when fishing in the sea is temporarily suspended. Thus the estuary is subjected to considerable anthropogenic impact that is expected to alter the ecology and biogeochemical cycling in this water body.

Although several studies have been undertaken dealing with the biogeochemistry of the Zuari Estuary (Shetye et al., 2007), a detailed study on the sources of organic matter is lacking so far. Suspended sediment dynamics and geochemistry has been studied by Rao et al. (2011) and Kessarkar et al. (2013) respectively in the Zuari and the neighboring Mandovi estuaries, with the latter study focusing solely on the SW Monsoon season. In this paper, we examine the stable carbon and nitrogen isotopic composition of POM using the data collected for one year (from October 2010 to September 2011) in order to gain insights into sources of organic matter and intrinsic cycling of carbon and nitrogen in the Zuari Estuary.

## 2. Materials and methods

### 2.1. Study area

The Zuari Estuary is located in Goa between latitudes 15°20′N and 15°30′N, and longitudes 73°45′E and 74°10′E (Fig. 1). The Zuari River originates in the Western Ghats and flows nearly 70 km before meeting the Arabian Sea. The estuary is ~5.5 km wide at its mouth, rapidly narrowing down to ~0.5 km upstream. It is a shallow estuary, the depth varying from ~10 m at the mouth to ~3 m upstream. As a result, the estuary, which is under the influence of semi-diurnal tides (tidal range 1.5 m–2.3 m), is vertically well-mixed during the dry season (October–May). During the SW Monsoon (June–September), the large freshwater influx due to heavy rainfall and land runoff (catchment area = 550 km$^2$) results in partial stratification of the estuary which is more pronounced near the mouth.

As part of the Sustained Indian Ocean Biogeochemistry & Ecosystem Research (SIBER)-India program, sampling was carried out at seven stations located along the length of the estuary (Fig. 1). Based on the salinity, we have classified the 7 stations into three zones. Moving upstream from the mouth, the first two stations were located in nearly marine Zone-I; the next two stations having intermediate salinity comprise Zone-II; and finally, the last three stations experiencing the lowest salinities form Zone-III.

### 2.2. Sampling and ancillary measurements

The observational period extended from October 2010 to September 2011. Sampling at the above mentioned stations was carried out once a month for the following measurements: water temperature and salinity, DO, nutrients (nitrate), chlorophyll-*a* and suspended particulate organic matter (SPOM) including its isotopic compositions ($\delta^{13}$C and $\delta^{15}$N). Salinity and temperature data were acquired using a portable Sea-Bird Electronics CTD (conductivity–temperature–depth) system.

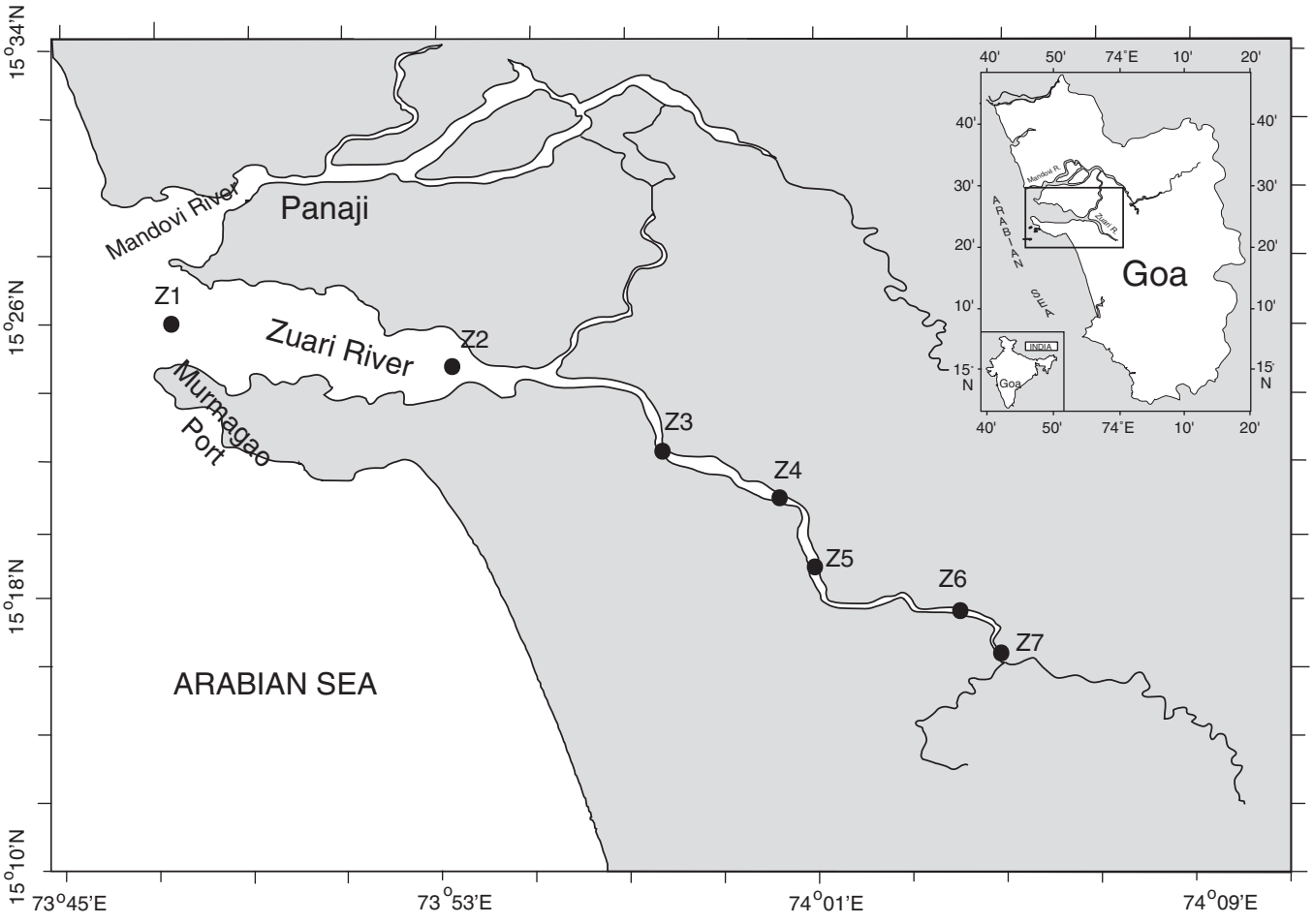


**Fig. 1.** Location of sampling sites in the Zuari Estuary, Goa, India.