Continental Shelf Research 78 (2014) 16–28

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Research papers

Influence of upwelling on distribution of chaetognath (zooplankton) in the oxygen deficient zone of the eastern Arabian Sea

K.K. Kusum *, G. Vineetha, T.V. Raveendran, K.R. Muraleedharan, A. Biju [1], C.T. Achuthankutty [2]

CSIR, National Institute of Oceanography, Salim Ali Road, Kochi 18, Kerala, India

ARTICLE INFO

Article history:
Received 10 August 2013
Received in revised form
18 December 2013
Accepted 8 January 2014
Available online 4 February 2014

Keywords:
Chaetognaths
Upwelling
Oxygen minimum zone
Indicator species
Eastern Arabian Sea

ABSTRACT

The study addresses the coupled spatial scales in the physico-chemical variables and chaetognaths in the upwelling system of the eastern Arabian Sea during the 2005 summer monsoon. We studied the taxon between 0 and 1000 m depth along seven zonal sections between 8°N and 19°N and especially observed the vertical stratification of the animals. In the upwelling regions, higher chaetognath abundance was observed resulted by the local population growth and advection of the upwelling preferred epipelagic species. Abundance weight (*Aw*) value further helped to understand the mode of distribution of the chaetognath community around the upwelling locations. The variation in the depth-weighted average values of different species between the upwelling and non-upwelling sites helped to identify the dissimilarity in their coupling with the abiotic components. As this eastern boundary current region further draws research interest as one of the major natural oxygen deficient system in the global ocean, the role of this hypoxia was shelved separately from the influence of upwelling in the heterogeneity of distribution of chaetognaths. In our study, two mesopelagic species *Eukrohnia fowleri* and *Eukrohnia minuta* were identified as the indicator species of this upwelling process. Our observation suggests that the temporal physical event (upwelling) plays a decisive role in the heterogeneity of the spatial abundance, community composition and diversity of chaetognaths in this least studied eastern boundary current system.

1. Introduction

The eastern boundary current systems (EBCs) in the oceans are well known for their close association with upwelling, and plays a vital role in the spatial variability of physico-chemical variables and biological components (Escribano and Morales, 2012; Hidalgo et al., 2012). Upwelling regions have immense global significance (Peterson et al., 1988; Botsford et al., 2003) as they form biologically the richest parts of the oceans and in turn produce about half of the world's fish supply (Ryther, 1969). The eastern Arabian Sea (EAS) is one of the major EBCs in the Indian Ocean, which experiences intense upwelling induced by the westerly-northwesterly monsoonal winds during summer monsoon (Banse, 1959; Mathew, 1983; Mohankumar et al., 1995; Smitha et al., 2008). This temporal phenomenon has persisted for millions of years (Sirocko et al., 1991) and has a strong impact on the biological production of the Arabian Sea (Curry et al., 1992; Rostek et al., 1997). Zooplankton plays a pivotal role in the pelagic food web as they transfer the energy from primary producers to higher trophic levels (Banse, 1995). Chaetognaths, a major carnivorous taxon, form an important component of the food web in the upwelling regions (Giesecke and González, 2004; Ulloa et al., 2004) and often are taken as valuable indicators of different hydrographic conditions as well as water masses (Bieri, 1959; Sund and Renner, 1959; Nagai et al., 2006). Recently, the variability in the abiotic and biotic components in the EBCs of Pacific and Atlantic Oceans has been an important area of study (Cornejo and Farías, 2012; Correa-Ramírez et al., 2012; Morales and Anabalón, 2012; Roura et al., 2012). Among zooplankton, several comprehensive studies have been carried out on the copepod community of the upwelling systems (Boyd et al., 1980; Hidalgo and Escribano, 2007; Hidalgo et al., 2010, 2012) and groups like euphausiid, fish and decapod larvae have also received wide attention (Lindsey and Batchelder, 2011; Riquelme-Bugueño et al., 2012; Parada et al., 2012; Soto-Mendoza et al., 2012; Yannicelli et al., 2012), whereas studies on chaetognaths are scanty (Giesecke and González, 2004; Ulloa et al., 2004). In EBCs of the Indian Ocean, earlier studies on chaetognath community were mostly limited to the geographic (Nair, 1972; Nair and Rao, 1973) and vertical distribution (Nair, 1978; Balamurugan et al., 2011; Kusum et al., 2011).

* Corresponding author. Tel.: +91 484 2390814; fax: +91 484 2390618.
E-mail addresses: kusum.kk1@gmail.com, karatik@nio.org (K.K. Kusum).
[1] Present address: St. Stephens College, Kerala University, Kerala, India.
[2] Present address: National Centre for Antarctic and Ocean Research, Vasco-da-gama, Goa 403804, India.

http://dx.doi.org/10.1016/j.csr.2014.01.005
0278-4343

Earlier, Srinivasan (1974) studied the chaetogntha community of this upwelling region and suggested the possibility of using *Sagitta decipiens* as an indicator of upwelling process from the total 14 species identified. Though the work gave an account of the distributional pattern of chaetognaths and their preferences between shelf and oceanic region, the coupling between chaetognaths and the physico-chemical variables associated with upwelling process was mostly overlooked. Later, Nair (1977) while describing the cheatognath community of the Indian Ocean mentioned the association of mesopelagic species *Eukrohnia fowleri* with upwelling event. Though these earlier observations gave an account of the cheatognath community in this region, the modulating processes for the heterogeneity in their distribution remained poorly understood.

The EAS also forms an area of immense ecological interest as one of the prominent natural oxygen deficient systems in the global ocean (Vinogradov and Voronina, 1962; Morrison et al., 1999; Naqvi et al., 2006, 2009). The northern part of EAS in particular has greater significance as the oxygen minimum zone (OMZ, <0.5 mL L^{-1}) of this region is the thickest ($\sim$1 km) among the world oceans (Naqvi et al., 2009). The ecological impact of the OMZ is the shrinking of the available habitats, and only a few species can tolerate the extreme oxygen deficient condition (Prince and Goodyear, 2006; Bertrand et al., 2010; Kusum et al., 2011). Thus to have a better understanding on the ecology of this dynamic system, the need to understand the critical role of the oxygen deficient waters along with the influence of upwelling on zooplankton distribution is a prerequisite.

In the present study, our aim was to identify the active upwelling zones and to assess the influence of this physical process on the abundance and diversity pattern of chaetognath community in this oxygen deficient system. We intended to identify this process along both surface and subsurface layers to verify whether any fine scale coupling occur in the biotic and abiotic components of this environment. As the earlier studies had dissimilar views on the indicator species in this upwelling region (Srinivasan, 1974; Nair, 1977), an attempt was also made to reevaluate this aspect. The present study depicting the responses of an important zooplankton taxon to the upwelling phenomenon will provide vital information regarding the ecology and dynamics of this important upwelling zone in the Indian Ocean.

2. Method

2.1. Sampling

Sampling locations in the EAS are shown in Fig. 1. Starting from near the coast, sampling was carried out during 26 May–24 June 2005 (summer monsoon) on board FORV *Sagar Sampada* (cruise 235) on seven zonal transects along 8°N–19°N (Fig. 1). Stations were spaced by 1° of longitude. For diurnal observation, one coastal and one offshore station were monitored along each transect (only one diurnal station at 10°N, 15°N and 19°N) and the sampling was done at 6-h intervals for 24-h. The day and night was determined based on the local times of sunrise and sunset during the cruise.

Vertical profiles of temperature and salinity were obtained by a SBE Seabird 911 plus CTD. It was operated from the sea surface to close to the bottom in coastal stations, and down to 1000 m in offshore stations. For expressing the salinity value, the practical salinity scale was used which has no physical unit (UNESCO, 1985). The potential density (σt) was computed from the temperature, salinity and pressure obtained from the CTD. To estimate dissolved oxygen (DO) water samples were collected using a CTD Rosette sampler, fitted with 1.8 L Niskin bottles, from standard depths down to 1000 m (surface, 10, 20, 30, 50, 75, 100, 150, 200, 300,

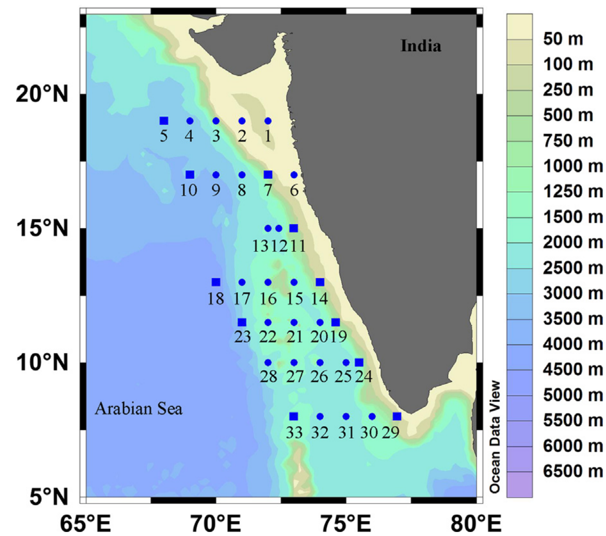

Fig. 1. Sampling locations in the EAS. The squares denote diurnal stations and circles denote regular stations. In the regular stations only one sampling was done for each depth layers.

500, 750, 1000 m), and were analyzed using Winkler's method (Grasshoff, 1983) with visual endpoint detection.

A multiple plankton net (Hydrobios, Germany) with a mouth area of 0.25 m^2 and a mesh area of 200 μM, with an electronic depth sensor was operated vertically to sample mesozooplankton. As each net is opened and closed independently, contamination is apt to be negligible (Weikert and John, 1981). One disadvantage of similar net system i.e. MOCNESS is that the slow speed of vertical hauling can lead to avoidance of some of the larger zooplankton (www.whoi.edu/instruments/viewInstrument.do?id=10008). Hence, to avoid this problem we maintained a towing speed of 1 m s^{-1}. We sampled at five depth strata: mixed layer (MLD), top to base of thermocline (TC), base of thermocline (BT) to 300 m, 300–500 m and 500–1000 m based on temperature and density characteristics (see Table 1). MLD was fixed as the depth at which a temperature decrease of 0.5 °C occurred from the sea surface temperature, and BT was taken as the depth where temperature fell to 15 °C. Chaetognaths were counted by species in the whole sample or from an aliquot (50%) using a Folsom splitter. The volume strained was figured from the distance towed (m) × 0.25 m^2, and the abundance expressed as ind/1000 m^3. To have a better understanding on the influence of upwelling on chaetognaths, the upwelling regions were categorized as i.e. (i) surface upwelling site, where deep water had been uplifted into the mixed layer, (ii) upper subsurface upwelling site, where upwelling was prominent in TC layer and (iii) lower subsurface upwelling site, where upwelling was most evident at BT–300 m layer.

2.2. Statistical analysis

Multivariate statistics, principal components analysis (PCA) was carried out for the abiotic (physicochemical variables) and biotic component (chaetognath abundance) as it helped in the reduction and interpretation of large multivariate data sets with some underlying linear structure. For plotting and clustering, the important aspect of this analysis is the simple reduction of the data set to only two most important components. The mean values of the abiotic parameters for the particular depth stratum at each station were considered for the analysis. As all the variables are measured in different units, they were normalized and analysis was done based on the correlation matrix using the statistical program PAST