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Interactions between trophic levels in upwelling and non-upwelling regions during summer monsoon

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ABSTRACT

Coastal upwelling is a regular phenomenon occurring along the southwest coast of India during summer monsoon (May–September). We hypothesize that there could be a shift in environmental parameters along with changes in the network of interactions between bacteria, phytoplankton, and zooplankton in upwelling and non-upwelling regions. During cruise # 267 on FORV Sagar Sampada, water samples were analysed for environmental and biological parameters from two transects, one upwelling region off Trivandrum (TVM) (8°26′N, 76°20′E–8°30′N, 76°50′E), and the other non-upwelling region off Calicut (CLT) (11°11′N, 75°30′E–11°14′N,74°54′E), about 230 nmi to the north. Meteorological, hydrological, and nutrient profiles confirmed upwelling off TVM. Bacteria, phytoplankton and zooplankton significantly responded. Primary and bacterial productivity enhanced together with increase in the percentage of viable bacteria (TVC). Pearson's correlation analysis pointed out the differences in bacterial interactions with other trophic levels at both transects. TVC played a prominent role in trophic interactions off TVM by depending on phytoplankton for substrate ($r = 0.754$). This contrasted with CLT where total counts (TC) played an important role. However, most interrelationships were less pronounced. Principal component analysis (PCA) confirmed the correlation analysis and further showed that the factor loadings of the biotic and abiotic parameters differed in strength and direction in the two regions. More importantly, the processes of mineralization by bacteria and uptake by phytoplankton are obviously more coupled off TVM as evidenced by the clustering of the related parameters in the PCA biplot. Canonical correspondence analysis also complements these findings and demonstrated that the abiotic factors influenced phytoplankton and bacteria similarly at TVM but differently at CLT. The impact on the trophic interrelationships is evident by the close association between all the variables in upwelling waters. Besides, bacteria may represent a more stable element in the food web, TVC for upwelling region and TC for non-upwelling region.

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1. Introduction

Physical forcings such as ocean currents, winds and river influx introduce varying complexities in the interlinkages between biotic components and environmental characteristics especially in the coastal waters. Wind-driven coastal upwelling is one such forcing that has been acknowledged to change the associated regional ecology (Chen et al., 2004; Tweddle et al., 2010; Wetz and Wheeler, 2004). Hence, biotic variables such as phytoplankton and bacteria which forms the basis of marine food web (Sherr and Sherr, 1988) are affected. Upwelling of nutrient-rich subsurface waters increases primary producers followed by an increase in metazoan standing stocks (Peterson et al., 1988).

Upwelling, caused by oceanic winds blowing from the southwest during early summer monsoon, is a regular phenomenon occurring between May–September in the Southeast Arabian Sea (SEAS) along the southwest coast of India. The upwelling activity that propagates from southern peninsula of India to the north due to an east boundary current known as West India Coastal Current (WICC) has been well documented (Joshi and Rao, 2012; Luis and Kawamura, 2004; Shetye and Shenoi, 1988; Thomas et al., 2013). Upwelling in SEAS is of moderate intensity and could be graded between the least intense New Zealand and highly intense Benguela and Humboldt Current (Blanchette et al., 2009; Carr, 2002; Patti et al., 2008; Verlecar and Parulekar, 2001). Moreover, upwelling of cold nutrient-rich subsurface waters enhances primary productivity in the area, which otherwise is characterized by nutrient depleted waters and low biological productivity (Bhattathiri et al., 1996; Madhupratap et al., 1990; Packard et al., 1984; Thomas et al., 2013).

Much of the literature on upwelling ecosystems addresses the cascading effect of physical and chemical processes, and biological

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responses at different trophic levels, during upwelling (Blanchette et al., 2009; Blasco et al., 1980; Lehmann and Myrberg, 2008; Margalef, 1978; Oleg et al., 2003; Pei et al., 2009; Schukat et al., 2014), with few publications on the bacterial contribution during the process (Capone and Hutchins, 2013; Hyun et al., 2009; Kirchman et al., 2000; Wetz and Wheeler, 2004). Bacteria play a mediating role in a spectrum of biogeochemical processes that decide the status of an ecosystem (Madsen, 2011). However, the interactions between abiotic and biotic variables and between different trophic levels which form the basis for the maintenance of balance in an upwelling region, is poorly understood.

The primary goal of this study was to discern the interlinkages between the trophic levels in upwelling and non-upwelling regions during summer monsoons. We therefore hypothesize that shift in environmental parameters would be accompanied by the changes in "network of interactions" between trophic levels in upwelling and non-upwelling regions especially at the bacterial level. In this study, the term "network of interactions" refers to the web of statistically significant interlinkages between different biotic variables.

Therefore, in this study, a dataset comprising of biological and environmental parameters from coastal pelagic regions with (Trivandrum) and without (Calicut) signatures of upwelling were examined and the trophic interactions analyzed. Trivandrum is located towards the southern tip of India at ~8.3°N while Calicut lies approximately 230 nautical miles towards the north at 11.2°N. For the first time, the study highlights how bacteria wield considerable influence on higher trophic levels in a upwelling system, thus indirectly yet significantly augmenting and sustaining the productivity of upwelling areas.

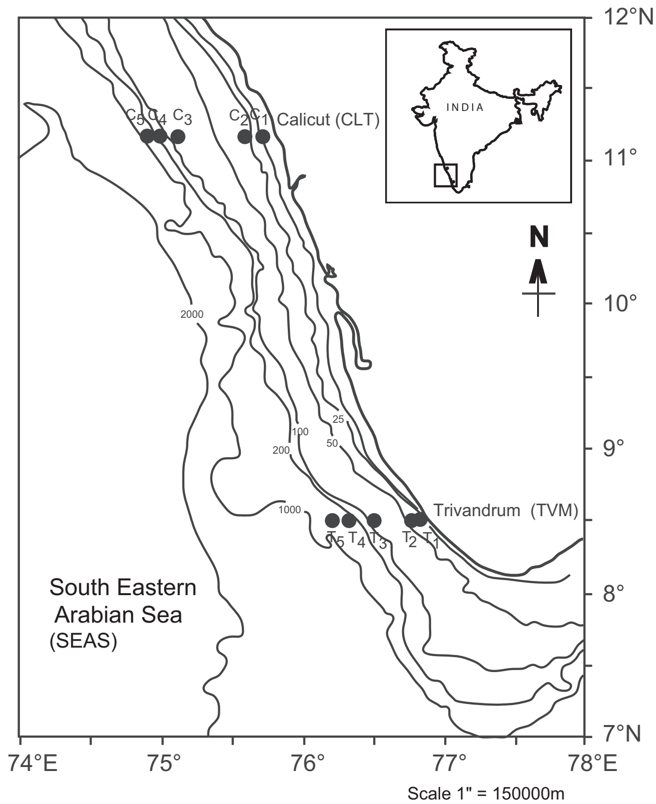

Fig. 1. Map showing geographical location of the sampling stations.

2. Material and methods

2.1. Study area

Sampling was carried out along the Southwest coast of India in SEAS onboard FORV Sagar Sampada from 30th May–15th June 2009 (Fig. 1). Two transects were chosen, an upwelling region off Trivandrum (TVM) located towards the southern tip of India at 8°26′N 76°20′E–8°30′N 76°50′E and a non-upwelling region, off Calicut (CLT) located approximately 230 nautical miles north off TVM at 11°11′N 75°30′E–11°14′N 74°54′E. Both sites are relatively unaffected by rivers, estuaries or harbors.

2.2. Physical forcings

Wind and meteorology data were collected by the automated weather station, onboard. Salinity and temperature measurements were derived from the Sea Bird CTD attached sensors. The sea surface temperature (SST) was plotted using the blended Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) and Advanced Microwave Scanning Radiometer (AMSR-E). SST daily dataset was at 0.25° × 0.25° spatial resolution (http://www.ssmi.com/sst/microwave_oi_sst_data_description.html).

2.3. Water sample collection and processing

Water samples were collected at discrete depths from ten litre Niskin bottles attached to a CTD-rosette system (Fig. 1, Table 1).

2.3.1. Chemical analyses

The collection bottles for chemical analyses were acid washed (1 M HCl), rinsed thrice with Milli-Q water and completely dried before use. These bottles were also rinsed with sample before collection. Water samples for dissolved oxygen (DO) were collected in 125 mL stoppered glass bottles without trapping air bubbles, fixed with Winkler's reagents and estimated according to Strickland and Parsons (1965) using a dosimeter (Metrohm 785 DMP Titrino). Samples for nutrient analysis such as nitrate, nitrite, phosphate, silicate and ammonia were collected in 125 mL HDPE bottles. Estimation of nitrate, nitrite, phosphate and silicate was carried out using an autoanalyzer (SKALAR) as described by Wurl (2009). Ammonia was estimated manually according to Grasshoff et al. (1983). For the estimation of particulate organic matter (POM) in the form of particulate organic carbon (POC) and particulate organic nitrogen

Table 1
Station and sampling details.

a) Water sampling depths

Station	Co-ordinates	Depths sampled (m)
Trivandrum (TVM)		
1#	8°30′N 76°50′E	5, 10, 20
2*#	8°30′N 76°43′E	5, 10, 25, 45
3#	8°28′N 76°30′E	5, 25, 50, 75, 90
4	8°27′N 76°24′E	5, 25, 50, 75, 150, 250
5	8°26′N 76°20′E	5, 25, 50, 75, 150, 250, 450
Calicut (CLT)		
1#	11°11′N 75°30′E	5, 15, 25
2*#	11°12′N 75°23′E	5, 10, 25, 45
3#	11°13′N 75°10′E	5, 10, 20, 40, 60, 80, 90
4	11°13′N 74°55′E	5, 10, 20, 40, 60, 80, 100, 120,150, 175
5	11°14′N 74°54′E	5, 10, 20, 40, 60, 80, 100, 120, 150, 250, 450

* PP station for in situ primary productivity measurement, # Grab operated for sediments sample collection

b) Vertical haul for zooplankton sampling

Water depth	Sampling depths (m)
30 m	(0–20)m, (20–25)m
50 m	(0–7)m, (7–45)m
100 m	(0–10)m, (10–90)m
300 m	(0–9)m, (9–158)m, (158–255)m
450 m	(0–10)m, (10–182)m, (182–300)m, (300–450)m

The number of depths sampled at each station is dependent on the depth of the station ranging from with two depths at 30 m station to four depths at 450 m station.

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