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Patterns of primary production in the Red Sea

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ABSTRACT

This paper presents data on various parameters of primary production (chlorophyll concentration, carbon uptake, nitrogen uptake, phytoplankton groups) measured in 4 cruises in the Saudi Arabian waters of the Red Sea between 2012 and 2015. The results showed that while there was a tendency for an increase from north to south, the meridional distributions were distinguished by alternating high and low concentrations of chlorophyll, carbon uptake rates and cell densities of various phytoplankton groups, with the higher levels being associated with zonal currents and the lower values lying in between. These patterns of distributions lead us to conclude that the biological production in the Red Sea is influenced more by anticyclonic eddy, and less by meridional, circulations at any time of the year. Synthesizing the present results with earlier ones on the patterns of distributions of nutrients and the flow of Gulf of Aden Intermediate Water (GAIW), we also conclude that entrainment of GAIW in successive eddies is the cause for higher nutrients and biological production in the regions of eddy boundary currents. Data on size-fractionated carbon uptake and nitrogen uptake showed that the eddies in Red Sea favour the proliferation of producers across a range of size classes rather than one class. The amount of nutrients injected into the euphotic zone in the eddy boundary currents is probably not high enough to induce a definite shift in phytoplankton size classes, and the primary production still remains to a significant extent regenerated nutrient-driven.

1. Introduction

The Red Sea, a marginal sea of the Indian Ocean, is a marine region that has been grossly under-sampled spatially and temporally for biological properties, with only a few oceanographic stations occupied in comparison with the several thousands in the Indian Ocean (source - Oceanographic database for Indian Ocean, National Institute of Oceanography, India). If we exclude the measurements made in the extreme north of the Gulf of Aqaba which itself is a northern extension of the Red Sea (Levanon-Spanier et al., 1979; Badran, 2001; Badran and Foster, 1998) or localized coastal stations (Fahmy, 2003; Shaikh et al., 1986; Al-Farawati, 2010), then what are available as data on phytoplankton biomass and primary production in the main body of Red Sea in the last six decades result from no more than a few studies (Yentsch and Wood, 1961; Halim, 1969; Khmeleva, 1970; Petzold, 1986; Weikert, 1987; Lenz et al., 1988; Qurban et al., 2014), with direct measurements only at wide temporal and spatial intervals. Only two studies (Acker et al., 2008; Elawad, 2012) have a basin-wide coverage, and in different seasons, but these are limited to remotely-sensed (SeaWIFS, Modis) data on chlorophyll. In yet another one (Longhurst et al., 1995), remotely-sensed (CZCS) chlorophyll data were used to make deductions on rates of primary production at basin-scale.

The conclusion consistently arrived at from all earlier studies on phytoplankton pigments and primary production in the main body of the Red Sea is that the waters of the Red Sea are oligotrophic with low levels of biomass and production (Weikert, 1987). However, two recent studies provide a different picture. In the first, Acker et al. (2008) observed a semicircular feature of elevated chlorophyll concentrations visible between 22 and 23°N in the satellite data, presumably associated with an anticyclonic eddy. In the second, Qurban et al. (2014) measured primary production rates at two stations near 23°N that were 3–5 times higher than at others, both in terms of C uptake (750–950 mg C m^{-2} d^{-1}) and N (nitrate, ammonium and urea) uptake, along with the presence of measurable concentrations of nutrients, up to 1.3 μmol L^{-1} of nitrate, within the euphotic zone. The results from these two studies, considered together, led us to believe that within the canvas of low production, region of higher production, associated with eddies, if present, should be distinguishable.

Such a hypothesis of eddy-associated higher production in Red Sea is not untenable since eddies, most of them anticyclonic, are quasi-perennial features of Red Sea circulation (Quadfasel and Baunder, 1993; Zhan et al., 2014). In fact, Wafar et al. (2016b), based on physical and chemical data gathered during four cruises between 2012 and 2015 in the Saudi Arabian waters of the Red Sea, have shown that the patterns of

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nutrient concentrations within the Red Sea could be explained in terms of three successive anticyclonic eddy circulations, at 18°N–20.5°N, 22°N–24°N and 24.5°N–26°N. In this paper we demonstrate, using the biological data gathered in the same four cruises, that the meridional distribution of chlorophyll *a* (Chl *a*), rates of primary production and phytoplankton cell counts in the Red Sea can also be explained in terms of eddy circulations.

2. Material and methods

Fig. 1 shows the location of the stations occupied during the four cruises. In 2012 (13–27 November), stations at quarter-degree intervals from 27.5°N to 25°N, and at half-degree intervals between 25°N and 23°N in four transects (A–D) were occupied. In the 2013 cruise (6–30 November), stations placed at half-degree intervals from 17°N to 27°N

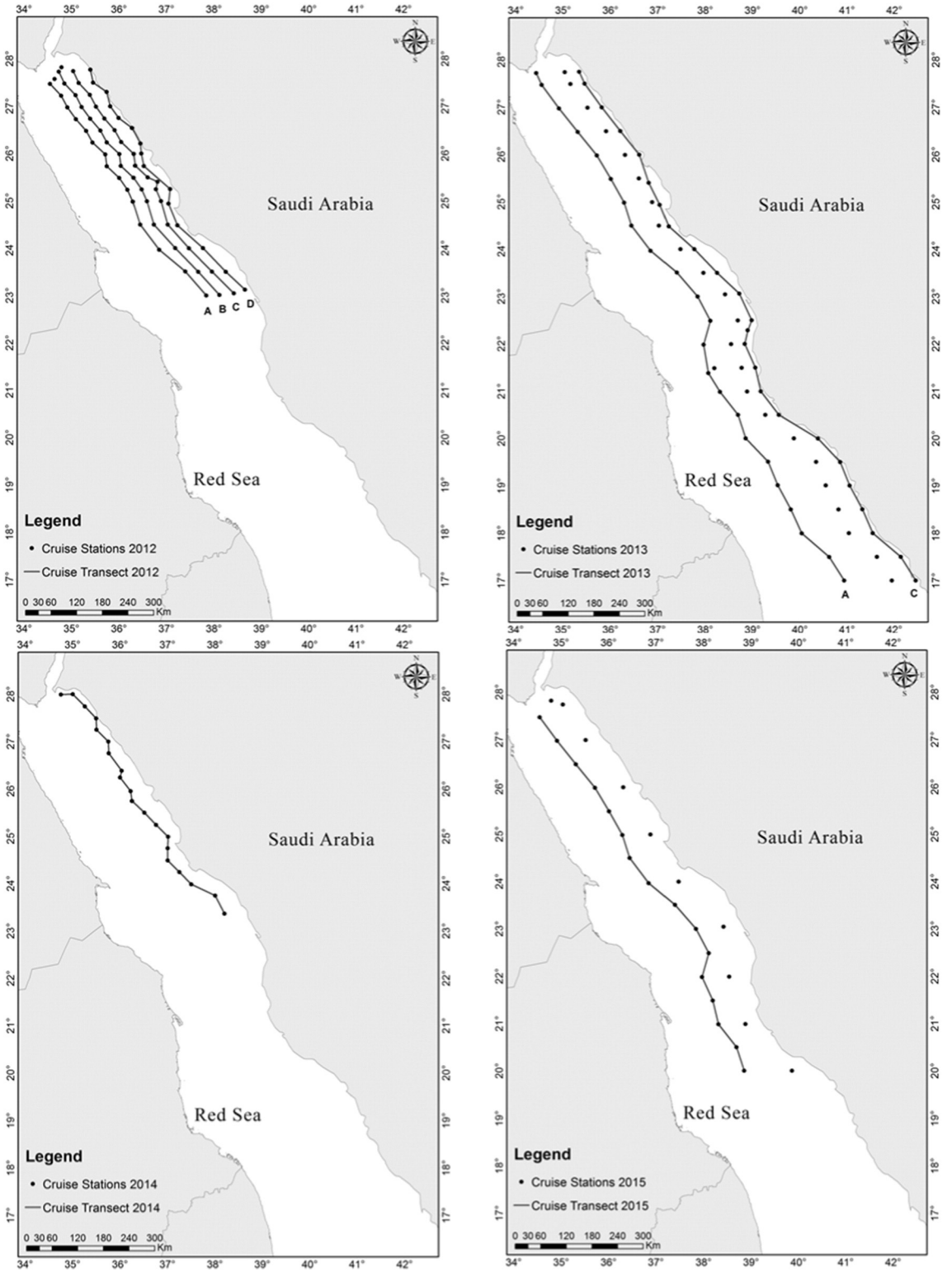

Fig. 1. Locations of the stations occupied during the four cruises and the layout of the transects.