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Shift in the species composition of the diatom community in the eutrophic Mauritanian coastal upwelling: Results from a multi-year sediment trap experiment (2003–2010)

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ABSTRACT

A multiannual, continuous sediment trap experiment was conducted at the mooring site CB_{eu} (Cape Blanc eutrophic, ca. 20 °N, ca. 18 °W; trap depth = 1256–1296 m) in the high-productive Mauritanian coastal upwelling. Here we present fluxes and the species-specific composition of the diatom assemblage, and fluxes of biogenic silica (BSi, opal) and total organic carbon (TOC) for the time interval June 2003-Feb 2010. Flux ranges of studied parameters are (i) total diatoms = $1.2 * 10^8$–$4.7 * 10^4$ valves $m^{-2} d^{-1}$ (average = 5.9×10^6 valves ± 1.4×10^7); (ii) BSi = 296–0.5 mg $m^{-2} d^{-1}$ (average = 41.1 ± 53.5 mg $m^{-2} d^{-1}$), and (iii) TOC = 97–1 mg $m^{-2} d^{-1}$ (average = 20.5 ± 17.8 mg $m^{-2} d^{-1}$). Throughout the experiment, the overall good match of total diatom, BSi and TOC fluxes is reasonably consistent and reflects well the temporal occurrence of the main Mauritanian upwelling season. Spring and summer are the most favorable seasons for diatom production and sedimentation: out of the recorded 14 diatom maxima of different magnitude, six occurred in spring and four in summer.

The diverse diatom community at site CB_{eu} is composed of four main assemblages: benthic, coastal upwelling, coastal planktonic and open-ocean diatoms, reflecting different productivity conditions and water masses. A striking feature of the temporal variability of the diatom populations is the persistent pattern of seasonal groups' contribution: benthic and coastal upwelling taxa dominated during the main upwelling season in spring, while open-ocean diatoms were more abundant in fall and winter, when the upper water column becomes stratified, upwelling relaxes and productivity decreases. The relative abundance of benthic diatoms strongly increased after 2006, yet their spring-summer contribution remained high until the end of the trap experiment. The occurrence of large populations of benthic diatoms at the hemipelagic CB_{eu} site is interpreted to indicate transport from shallow waters via nepheloid layers. We argue that a significant amount of valves, BSi and TOC produced in waters overlying the Banc d'Arguin and the Mauritanian shelf is effectively transported to the CB_{eu} trap in intermediate waters at the outer Mauritanian slope. The impact of the intermediate and bottom-near nepheloid layers-driven transport in the transfer of valves and bulk particulates and its potential contribution to the export of biogenic materials from the shelf and uppermost slope might play a significant role in hemipelagial fluxes off Mauritania.

1. Introduction

Among present-day Eastern Boundary Upwelling Ecosystems (EBUEs: Benguela, Canary, Californian and Humboldt), the Canary Current (CC) system is perhaps the least understood due to the paucity of information and the region's complex topography and circulation (Mittelstaedt, 1983; Arístegui et al., 2009; Cropper et al., 2014). Within the Canary EBUE, the Mauritanian coastal upwelling ecosystem is characterized by intense offshore Ekman transport and strong mesoscale heterogeneity that facilitates the exchange of neritic and pelagic water masses (Chavez and Messié, 2009). The Ekman transport is augmented by the offshore channeling of waters through mesoscale instabilities of the coastal jet, like upwelling filaments, squirts, eddies and submarine canyons that dramatically alter the large-scale picture (Zenk et al., 1991; Van Camp et al., 1991; Krastel et al., 2006; Meunier et al., 2012). Regional factors, like nutrient trapping efficiency of the upwelling cells (Arístegui et al., 2009), dust deposition at the ocean surface (Fischer et al., 2016; Friese et al., 2016) or the shelf width

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(Hagen, 2001; Cropper et al., 2014), additionally affect the magnitude and intensity of primary production in and particle export from surface waters along the Mauritanian coast.

The intense offshore transport is an important mechanism for the export of cool, nutrient-rich shelf and upper slope waters offshore Mauritania (Gabric et al., 1993). Based on satellite imagery and *in situ* data, it has been estimated that the giant Cape Blanc filament could export about 50% of the particulate coastal new production to the open ocean during intervals of most intense upwelling. Coastal phytoplankton might be transported at the surface as far as 400 km offshore (Gabric et al., 1993; Barton et al., 1998; Lange et al., 1998; Helmke et al., 2005). The effect of this transport could extend to even more distant regions in the deep ocean, since particles sink not only vertically but also laterally (Fischer and Karakaş, 2009).

Observations off Mauritania during the past two decades prove that substantial year-to-year variations in fluxes and SST occur (Fischer et al., 1996, 2009, 2016; Bory et al., 2001; Müller and Fischer, 2001; Romero et al., 1999, 2002, 2003; Marcello et al., 2011; Skonieczny et al., 2013; Mollenhauer et al., 2015). Whether these variations are related to global- or Atlantic-scale climatic variations or to a natural level of basin-wide atmospheric and/or oceanic variability is still under discussion (Barton et al., 1998; Cropper et al., 2014; Fischer et al., 2016).

Here, we present the first continuous record of diatom, biogenic silica and total organic carbon fluxes collected between June 2003 and February 2010 (ca. 2500 days of sampling) at the mooring site CB_{eu} (Cape Blanc eutrophic), located within the giant Cape Blanc filament around 80 nm west of the Mauritanian coastline (Fig. 1). Seasonal and multi-year variability in fluxes and species-specific composition of the diatom assemblage, and biogenic silica and total organic carbon fluxes are presented and discussed in the context of variations of hydrographic and atmospheric conditions.

2. The study area

This study was carried out in the Mauritanian upwelling area (Fig. 1a), one of the prominent EBUEs located at the eastern border of the North Atlantic Subtropical Gyre (Arístegui et al., 2009; Chavez and Messié, 2009; Cropper et al., 2014). The occurrence and intensity of the Mauritanian upwelling depends on the shelf width and seafloor topography along NW Africa (Mittelstaedt, 1983; Hagen, 2001). The Mauritanian shelf, which is wider than that to the north and to the south along the northwestern African margin, gently slopes from the coastline up to water depths of 200–300 m (Fig. 1b; Hagen, 2001). The shelf break zone with its steep continental slope extends over a distance of approximately 100 km (Hagen, 2001). According to Lathuilière et al. (2008), our study area is located within the Cape Blanc intergyre region (19–24°N), which is characterized by a weak seasonality. Following the definition by Cropper et al. (2014), our study area is situated on the southern rim of the strong and permanent coastal upwelling zone (21°–26°N). Details of hydrography, upwelling dynamics and main wind systems affecting the area off Mauritania are given below.

2.1. Hydrography, wind and upwelling dynamics

The source of upwelling waters in the Cape Blanc area are either North Atlantic Central Water (NACW), north of about 23°N, or South Atlantic Central Water (SACW), south of 21°N, or both (Fig. 1a). The nutrient-poorer NACW has its source in the North Atlantic subducting zone and reaches subsurface waters at lower latitudes through the thermocline circulation (Sarmiento et al., 2004). The nutrient-richer, less saline SACW originates in the Subantarctic Zone of the Southern Ocean and travels via the South Atlantic thermocline equatorward into low-latitude regions (Sarmiento et al., 2004). The SACW occurs in layers between 100 and 400 m depth off Cape Blanc. The hydrographic properties of the upwelling waters on the shelf suggest that they ascend from depths of 100 to 200 m south off the Banc d'Arguin (Mittelstaedt, 1983). North of it, the SACW merges gradually into deeper layers (200–400 m) below the CC (Fig. 1a) (Mittelstaedt, 1983). During the upwelling season, the stratification of shelf waters weakens, as does the stratification offshore, usually within the upper 100 m (Mittelstaedt, 1991). The biological response is drastically accelerated in the upwelled waters when the nutrient-richer SACW feeds the onshore transport of intermediate layers to form mixed-water types over the shelf (Zenk et al., 1991).

The Mauritanian Current (MC, surface coastal countercurrent, Fig. 1a) gradually flows northward along the coast to about 20°N (Mittelstaedt, 1991). It brings warmer surface water masses from the equatorial realm into the study area. Towards late autumn, the MC is gradually replaced again by a southward flow associated with upwelling water due to the increasing influence of trade winds south of 20°N (Zenk et al., 1991), and becomes a narrow strip of less than 100 km width in winter (Mittelstaedt, 1983). The MC advances onto the shelf during summer and is enhanced by the relatively strong Equatorial Countercurrent and the southerly monsoons (Mittelstaedt, 1983). The existence of the strong coastal currents during the upwelling season causes substantial horizontal shear within the surface layer, where currents tend to converge (Mittelstaedt, 1983).

Below the surface waters between ~150 and ~600 m south of the CB_{eu} site, the unstable Cape Verde Frontal Zone (CVFZ) occurs. This front builds where the NACW meets the SACW (Zenk et al., 1991). The boundary between both water masses is convoluted, variable in position and characterized by intense mixing and interleaving processes (Barton et al., 1998, and references therein; Fig. 1a). Year-to-year perturbations of the location of the CVFZ might influence the nutrient availability off Mauritania.

The giant Cape Blanc filament extends more than 300 km offshore (Fig. 1a; Van Camp et al., 1991; Zenk et al., 1991; Hagen, 2001; Santos et al., 2008; Arístegui et al., 2009; Cropper et al., 2014). It carries SACW offshore through an intense jet-like flow (Meunier et al., 2012; Fig. 1a). The chlorophyll concentration in the filament lies normally above 1 mg m^{-3} year-round, hence representing eutrophic conditions. Convergence of southern and northern waters at the frontal zone produces offshore export of the relatively cold upwelling waters. The upwelling cell drives vertically nutrient-rich subsurface waters to the baroclinic zone. In this manner, the upwelling jet, if deep enough, may play a decisive role in the along-shore advection of the northern water masses (Santos et al., 2008).

Climate over Northwest Africa is also influenced by the latitudinal migration of the continental Intertropical Convergence Zone (ITCZ; also named Intertropical Front, Nicholson, 2013). This low-pressure zone separates the warm and moist SW monsoon flow from the dry NE trade winds (TW), blowing from the northern Sahara (Fig. 1a). Northeasterly TW dominates in fall-winter and are restricted to a shallow layer (approximately 1.5 km, Chiapello et al., 1995). A further source of nutrients is the deposition of significant amounts of Saharan dust into the low-latitude northern Atlantic by the westward, mid-tropospheric Harmattan winds within the Saharan Air Layer (SAL, altitude = 5–6 km), originated in the central Sahara (Mittelstaedt, 1983; Swap et al., 1996). Highest dust load within the SAL occurs during summer (Prospero, 1990). Highest dust deposition in the study area, however, occurs predominantly in winter (Fischer et al., 2016) due to gravitational settling (Friese et al., 2016). Dust supply to the NE Atlantic Ocean depends not only on the strength of the transporting wind systems but also on the rainfall and dryness in the multiple source regions in northwestern Africa (Chiapello et al., 1995; Nicholson, 2013).