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NOTE

Bloom of the marine diazotrophic cyanobacterium *Trichodesmium erythraeum* in the Northwest African Upwelling

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ABSTRACT: A bloom of the non-heterocystous diazotrophic cyanobacterium *Trichodesmium erythraeum* Ehrenberg is reported in the Canary Islands Archipelago during August of 2004, the warmest period of a meteorological series recorded by the National Institute of Meteorology (Spain) since 1912. Samples showed massive occurrences of *T. erythraeum* (1000 filaments ml^{-1}) in different sectors of northern and southern waters off the central Canary Islands. Water analyses also showed a relatively low presence of dinoflagellates and diatoms. Quasi-true colour satellite images of dust storms, elevated sea surface temperature (the warmest satellite-derived record), chlorophyll *a* and geostrophic current fields showed satellite-derived optical positives of *Trichodesmium* in an African upwelling advective, jet-drifting westward current off the south Canary Islands. Analyses for cyanotoxins using HPLC found microcystins, which was confirmed by immunoassay, at concentrations from 0.1 to 1.0 µg microcystin-LR equivalents (g^{-1} dry weight of bloom material). A *T. erythraeum* bloom such as that observed in August 2004 in the NW African Upwelling does not appear to have been recorded for the area previously. The bloom may have developed due to the exceptionally warm weather and/or to the massive dust storms from the Sahara Desert observed in the NE Atlantic in August 2004.

KEY WORDS: Cyanobacteria · *Trichodesmium erythraeum* · Remote sensing · NW African Upwelling · Advective jet · Toxicity

During the warmest summer reported by the National Institute of Meteorology for Spain (INM Spain) in the Canary Islands since 1912, satellite and *in situ* observations in August 2004 detected an extensive bloom of the diazotrophic cyanobacterium *Trichodesmium erythraeum* Ehrenberg, which has never been detected in the NW African Upwelling and adjacent areas before (Capone et al. 1997, Lenes et al. 2001, Hood et al. 2002).

At the end of July 2004, quasi-true-colour images from the OrbView-2 SeaWIFS satellite revealed con-

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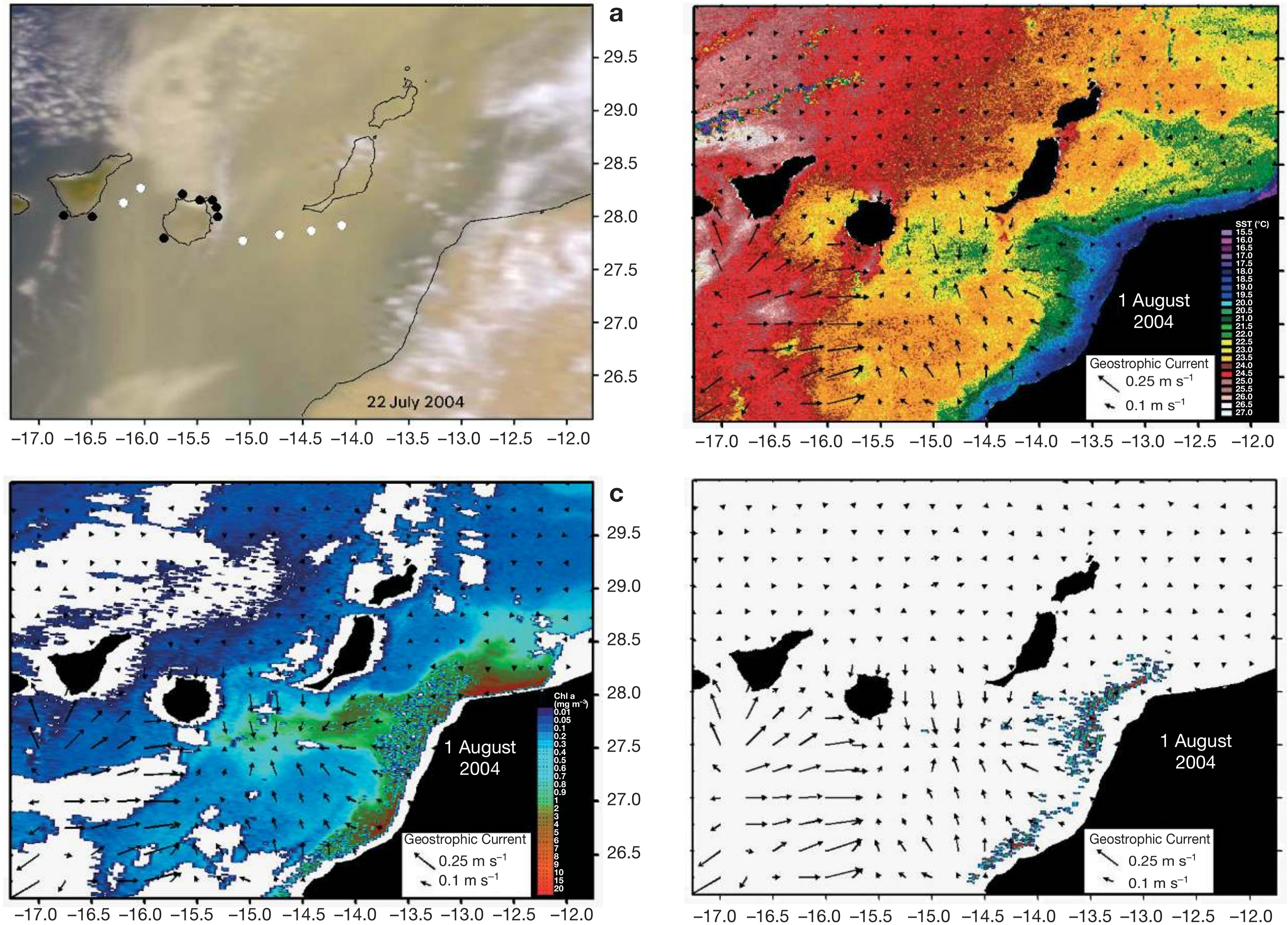

Fig. 1. Sea surface distribution of *Trichodesmium erythraeum*, NW African Upwelling. Satellite images at latitude 26° to 30° N, longitude 11° 30′ to 17° 30′ W. Satellite-derived geostrophic current fields (JASON Altimeter satellite) are plotted. (a) Sampling points (black circles) and flight sighting (white circles) on quasi-true-colour images generated from the OrbView-2 SeaWiFS satellite on 22 July 2004. Brown/green colouration represents high concentrations of dust granules suspended in the air. (b) Sea surface temperature (SST) images generated from NOAA AVHRR satellite of the same area depicted in (a). The warmest SST (27.5°C) in the whole satellite-derived SST series (15 yr) was reported in the Canary Islands (1 August 2004). (c) Chlorophyll *a* images from the OrbView-2 SeaWIFS satellite (1 August 2004). Image shows an advective jet (chlorophyll *a* >3 mg m^{-3}) drifting westward off the south Canary Islands. (d) Optical model of remote-sensed reflectances from the OrbView-2 SeaWIFS satellite parameterized for *T. erthraeum* (1 August 2004). Model showed significant 'optical positives' of *T. erythraeum* in the advective jet. See www.gobiernodecanarias.org/agricultura/pesca/seasflota/default.htm for further details

current dust storms from the Sahara Desert which covered the NE Atlantic area (Fig. 1a). In this area, the annual average dry flux of Saharan dust can range from 0.03 to 0.08 g m^{-2} d^{-1} or 1.7×10^6 tons yr^{-1} as inferred from experimental dry deposition (Torres et al. 2002). Dust fluxes produce a significant impact on the biogeochemical cycle of trace elements, providing a source of the Fe required for diazotrophic heterocystous and non-heterocystous cyanobacterial growth due to the demand for nitrogenase (Capone et al. 1997, Lenes et al. 2001).

Beginning in August, satellite-derived AVHRR/NOAA sea surface temperature (SST) images recorded 28.5°C, the warmest record within the last 15 yr in Canary Island waters. SST imagery also detected convergent warm (23°C) oceanic waters over the NW African shelf where the upwelling originates (Fig. 1b). Chlorophyll *a* images from the OrbView-2 SeaWIFS satellite showed richly productive coastal upwelled waters (chl $a > 3$ mg m^{-3}) of an advective jet at an anomalously warmer SST (24.5°C) compared to the normal SST for upwelled waters (i.e. 18 to 22°C). The jet was observed from satellite-derived geostrophic current field pictures of the CLS-AVISO Altimeter Satellite Data Centre, and advected westward with the offshore-directed surface-current drift fields to reach the position and configuration seen in Fig. 1c.

An optical model of water leaving radiance images from the OrbView-2 SeaWIFS satellite parameterized for *Trichodesmium* (Hood et al. 2002) was tested during the bloom event (Fig. 1d). The model detected significant remote-sensed optical positives of *Trichodesmium* in the NW African shelf. It also showed optical positives in the advective jet drifting westward off the south Canary Islands.

Subsurface water samples (2 l) were collected around the seashore at different locations off the islands off Gran Canaria and Tenerife during August 2004. Samples were fixed in 1% Lugol's Iodine immediately and trichomes were counted after a 24 h settling period. Cyanobacteria were identified according to Anagnostidis & Komàrek (1998). Concentrations of heterocystous and non-heterocystous cyanobacteria, together with other phytoplankton counts, were carried out with an inverted microscope using the Utermöhl technique. Results showed the absence of heterocystous diazotrophic cyanobacteria. Ninety-seven percent of the cells consisted of the non-heterocystous diazotrophic cyanobacterium *Trichodesmium erythraeum* (1240 filaments ml^{-1}). The remaining cells (10 cells ml^{-1}) consisted of dinoflagellates and diatoms (*Gymnodinium*, *Ostreopsis* and *Zygabikodinium*). The high water temperatures may have accounted for the dominance of the bloom by *T. erythraeum*, rather than by heterocystous diazotrophic cyanobacteria. Indeed, differences in temperature-dependent O_2 flux activity, respiration and of O_2-sensitive nitrogen fixation appear to favour the diazotrophic growth of *Trichodesmium* at elevated temperatures, rather than that of heterocystous cyanobacteria (Staal et al. 2003).

In order to determine environmental and health impacts of the *Trichodesmium erythraeum* blooms off the Canary Islands the cyanotoxins were analysed: microcystins by means of HPLC and immunoassay, and anatoxin-a and cylindrospermopsin by HPLC (Metcalf et al. 2000, Codd et al. 2001). Anatoxin-a and cylindrospermopsin were not detectable, but microcystins were found by HPLC, with photodiode array detection, with confirmation by immunoassay at concentrations from 0.1 to 1.0 µg microcystin-LR equivalents (g^{-1} dry weight of bloom material).

Such *Trichodesmium erythraeum* blooms have apparently not been recorded previously anywhere along the coast bordering the NW African Upwelling. Reliable satellite observations and verification on the ground have confirmed that the early stages of this anomalous event are associated with the exceptionally warm weather and dust storms observed in this area in August 2004. This phenomenon may be an increasingly observed characteristic of higher temperatures (global warming), with consequent increases in primary production and N_2 fixation, which may be accompanied by bloom toxicity.

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