ELSEVIER

Deep-Sea Research II 53 (2006) 1516–1529

DEEP-SEA RESEARCH
PART II

www.elsevier.com/locate/dsr2

Latitudinal changes in the standing stocks of nano- and picoeukaryotic phytoplankton in the Atlantic Ocean

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Received 15 September 2005; received in revised form 26 January 2006; accepted 11 May 2006
Available online 8 August 2006

Abstract

The latitudinal distributions of picoeukaryote phytoplankton (PEUK), coccolithophores (COCCO), cryptophytes (CRYPTO) and other nanoeukaryote phytoplankton (NEUK) were studied in the Atlantic Ocean between 49°N and 46°S in September–October 2003 and April–June 2004 by flow cytometry. Phytoplankton abundance and carbon (C) biomass varied considerably with latitude and down through the water column. Abundance and C biomass of all eukaryotic groups studied were highest in North and South Atlantic temperate waters and in the Mauritanian Upwelling off the west coast of Africa, where the total C biomass of eukaryotic phytoplankton smaller than 10 μm reached almost 150 mg C m^{-3}. Phytoplankton in the Equatorial Upwelling region was concentrated well below the surface at 50–80 m, with total C biomass in this layer being approximately 4 times that in the mixed layer. The North and South Atlantic Gyres supported much lower eukaryotic phytoplankton C biomass, with total eukaryote C biomass only reaching 2–3 mg C m^{-3}, peaking below 100 m. Of the four eukaryote groups studied, the PEUK were the most abundant, reaching densities of up to 40,000 cells cm^{-3}. They often contributed between 25% and 60% of total C biomass, particularly in the deep chlorophyll maxima of the different oceanic regions and also in the South Atlantic temperate waters, both in austral spring and autumn. NEUK also contributed significantly to C biomass. They generally dominated in the mixed layer, where they contributed 65–85% of total C biomass in the subtropical gyres and in North Atlantic temperate waters. CRYPTO and COCCO were generally less abundant. CRYPTO attained highest abundance in the Southern Temperate waters of over 500 cells cm^{-3} on both cruises. COCCO were often undetectable but on the European continental shelf abundance reached up to 2600 cells cm^{-3} during AMT 14. The C biomass standing stock of eukaryotic phytoplankton (<10 μm) for the Atlantic Ocean as a whole was estimated to be 80 million tonnes C during AMT 13, approximately one-third of total phytoplankton C biomass in the Atlantic Ocean.

Keywords: Atlantic Ocean; Atlantic Meridional Transect; Flow cytometry; Nanoplankton; Picoplankton; Community composition

1. Introduction

Within the marine food web, phytoplankton are of great importance: as primary producers, food for zooplankton, and as producers of biogases (Archer et al., 2002; Joint et al., 2001; Karl et al., 2001;

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0967-0645/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.dsr2.2006.05.004

Stelfox-Widdicombe et al., 2000; Sanders et al., 2000; Paffenhöfer et al., 2003). Within the phytoplankton, eukaryotic flagellates in the pico-size (0.2–2.0 μm) to nano-size (2–20 μm) range often dominate the phytoplankton C biomass (Tarran et al., 2001; Marañón et al., 2000; Garibotti et al., 2003; Vanucci and Mangoni, 1999). Pico- and nanophytoplankton are commonly analysed by epifluorescence and light microscopy. This is very time-consuming and is often made difficult because sample preservation techniques mean that cells become distorted or lose flagella that are key characteristics for identification. It is also often difficult to discriminate between heterotrophic and autotrophic flagellates, as auto-fluorescence in the phytoplanktonic flagellates deteriorates over time.

Flow cytometry is a rapid quantitative technique that has been used to quantify smaller phytoplankton for the past 20 years (Tarran et al., 2001; Partensky et al., 1996; Li, 1995; Li and Harrison, 2001; Zubkov et al., 1998; Cavender-Bares et al., 2001). Apart from the speed of analysis, the main advantage of flow cytometers is that they can be taken onboard ship and used to quantify phytoplankton in vivo, eliminating any errors associated with sample preservation and subsequent analysis back on land. The focus for the use of flow cytometry has been picophytoplankton ($\leqslant 2\,\mu m$), particularly marine cyanobacteria of the genus *Synechococcus* sp. and *Prochlorococcus* sp. (Chisholm et al., 1988; Partensky et al., 1996; Li, 1998; Tarran et al., 1999, 2001; Zubkov et al., 1998, 2000). Picoeukaryotes have also been quantified, as they can generally be visualised using the same instrument settings as are used for the cyanobacteria (Zubkov et al., 1998, 2000; Li and Harrison, 2001). However, there has been less attention paid to the nanophytoplankton, which are just as easily enumerated by flow cytometry. Studies including nanophytoplankton have generally been conducted using microscopy to enumerate them (Marañón et al., 2000; Sanders et al., 2000; Vaillancourt et al., 2003; Vanucci and Mangoni, 1999; Paffenhöfer et al., 2003) or high-performance liquid chromatography techniques to characterise pigment signatures (Gibb et al., 2000; Claustre et al., 2004), although some have employed flow cytometry (Tarran et al., 2001; Cavender-Bares et al., 2001; Mostajir et al., 2001). So nanoeukaryotic (NEUK) and picoeukaryotic phytoplankton (PEUK) are important components of the plankton in the open ocean, but most studies have been concentrated in temperate regions. Very little indeed is known about the open-ocean gyres and equatorial regions.

The Atlantic Ocean, is the world's second largest ocean, which covers an area of approx. 82 million km^2 (Pandolfo, 2005). There are five main oceanic regions or provinces, based on composite remotely sensed satellite images of sea-surface temperature, which run in bands from east to west (Fig. 1). At either end of the ocean are the Northern Temperate (NT) and Southern Temperate (ST) regions. In the central region is the Equatorial Upwelling (EU). In between the EU and the NT and ST waters there are the Northern Gyre and Southern Gyre. The Northern Gyre moves in a clockwise direction and the Southern Gyre moves in an anti-clockwise direction. Between them they cover an area around 26 million km^2, almost one-third of the area of the Atlantic

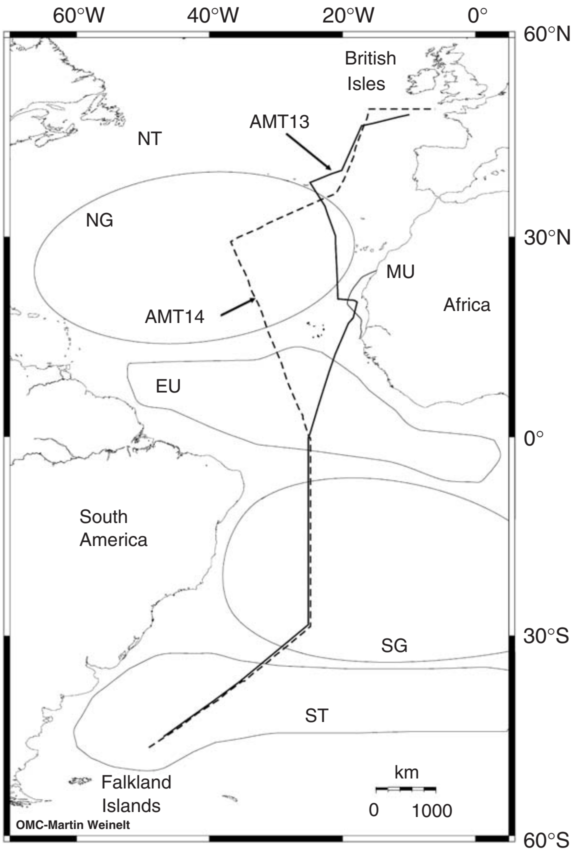

Fig. 1. Cruise tracks of the RRS James Clark Ross during AMT 13 and AMT 14 with approximate positions of oceanic provinces. NT, Northern Temperate waters; NG, Northern Gyre; MU, Mauritanian Upwelling; EU, Equatorial Upwelling; SG, Southern Gyre; ST, Southern Temperate waters.