Journal of Oceanography, Vol. 60, pp. 553 to 562, 2004

Temporal Variations in the Dissolved Nutrient Stocks in the Surface Water of the Western North Atlantic Ocean

INSAF S. BABIKER*, MOHAMED A. A. MOHAMED, KAORI KOMAKI, KEIICHI OHTA† and KIKUO KATO

Hydrospheric Atmospheric Research Center, Nagoya University, Chikusa-ku, Furo-cho, Nagoya 464-8601, Japan

(Received 26 February 2003; in revised form 10 July 2003; accepted 15 July 2003)

Changes in patterns of undetectability and molar ratios of dissolved nutrients in the euphotic zone of the oligotrophic western North Atlantic Ocean were investigated utilizing the Bermuda Atlantic Time-series Study (BATS) data set of the US Joint Global Ocean Flux Study (JGOFS). Our aim was to examine the temporal dynamics of nutrient stocks over a decade (1989~1998) and to gain insight into the interactions between the different biotic and abiotic factors underlying BATS. Patterns of nutrient undetectability clearly revealed the depleted nature of the nutrients in surface water at the BATS location, particularly phosphorous. The N:P ratio was consistently far above the nominal Redfield ratio (mean, 38.5) but was significantly lower during the 1993~1994 period (22.1). Over the same period the proportion of samples depleted in N only increased while the proportion of samples depleted in P only decreased. This indicates an overall reduction of N relative to P in the surface water at BATS during the 1993~1994 period, the reasons for this anomaly, though, are not clear. The correlation analysis between the biotic and abiotic variables at BATS has indicated some interesting relationships that can help understand some of the parameters affecting nutrient stocks in the euphotic zone and their consequent impacts on marine biota. Although nutrient stocks in the oligotrophic environment are limited, they might be subject to interannual variation that may become anomalous in some cases. These variations might underlay significant feedback mechanisms by affecting marine productivity, the prime factor controlling the sequestration of atmospheric CO_2 by the oceans.

Keywords:
· Nutrient depletion,
· variability,
· winter mixing,
· phytoplankton,
· North Atlantic Ocean,
· BATS.

1. Introduction

There has been recently an increasing demand for an understanding of the variability of ocean systems and this feedback response in relation to the global carbon cycle. Over the last few decades the ocean is estimated to have taken up about 30% of the anthropogenic CO_2 released to the atmosphere. Ocean ecosystems are subject to variability over a wide range of time and space scales (Dickey, 1991). A combination of chemical, physical and biological processes is responsible for this variability. Of the world's ocean surface waters, 80% are considered to be depleted in the major nutrients necessary to support oceanic production (nitrate, phosphate and silicate). These are termed oligotrophic ocean systems. Oligotrophic oceans, which are always supposed to support a biological community in a steady state, have already witnessed some major ecosystem shifts over various time scales. The reasons for this variation are not well understood, however, and are sometimes attributed to short-term or long-term climate variability (Karl *et al*., 1995; Karl *et al*., 2001). Nevertheless, the Redfield ratios of nutrients in the ocean, which are assumed to be constant, were found to change in response to a range of dynamic processes (Siegel *et al*., 2001). For example, the North Atlantic Ocean exhibited an exceptionally high N:P ratio, partly due to the deposition of fixed nitrogen from urbanized North America (Fanning, 1992), while in the North Pacific Ocean high C:N and C:P ratios have been attributed to the intensified export production (Pahlow and

* Corresponding author. E-mail: s010103d@mbox.nagoya-u.ac.jp

† Present address: School of Environmental Science, The University of Shiga Prefecture, 2500 Hassaka-cho, Hikone, Shiga 522-8533, Japan.

Riebesell, 2000).

The utilization of primary nutrients by marine organisms during photosynthesis and the subsequent remineralization of the product organic matter dictate the distribution of these nutrients in the ocean. By contrast, the availability of nutrients in the surface water controls the productivity and biodiversity of the oceanic biota. The temporal dynamics of nutrient cycles in the euphotic zone therefore determine the ecosystem productivity. Here we examine the interannual variation in the patterns of undetectability and in the molar ratios of dissolved nutrients within the euphotic zone (upper 200 meters) of the western North Atlantic Ocean, utilizing the Bermuda Atlantic Time-series Study (BATS) data set of the US Joint Global Ocean Flux Study (JGOFS). Our aim was to look at the interannual fluctuations of the limited nutrient stocks in a typical oligotrophic gyre such as Bermuda. We also attempted to highlight some probable relationships between those interannual patterns of nutrient undetectability and the different hydrographic, climatologic and biologic variables at BATS. The underlying rationale is that nutrients, those are more likely to be consumed by or to limit plankton growth, are also expected to display a greater frequency of undetectable concentrations in the euphotic zone, and that the deep winter mixing and phytoplankton growth largely affects the variation of nutrient stocks in the surface ocean.

The input of nutrients to the surface water at BATS is typically controlled by deep winter mixing which has shown some coherence with global scale climate events such as El Niño Southern Oscillation and North Atlantic Oscillation (Michaels and Knap, 1996; Bates, 2001). The one-decade record of oceanic data from BATS which recently became available permits an investigation of the tradeoffs between nutrients availability, ecosystem functionality and interannual climate variability.

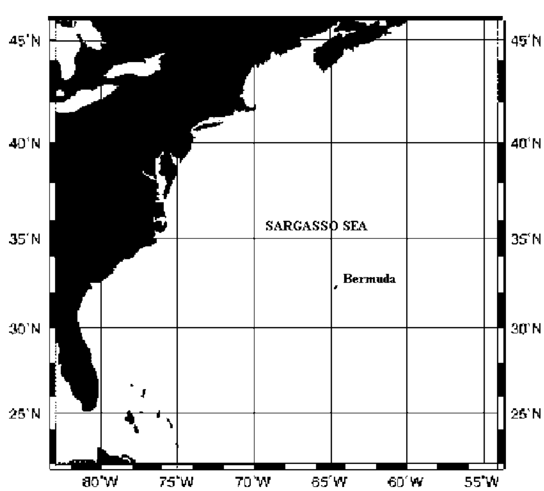

Fig. 1. Map of the Northwest Atlantic Ocean showing the Sargasso Sea and the location of Bermuda Island (modified from Steinberg *et al.*, 2001).

2. Materials and Methods

The BATS station, which is located 82 km southeast of Bermuda island (31°40′ N, 64°10′ W), is part of the western North Atlantic subtropical gyre represented by the Sargasso Sea (Fig. 1). It was taken into use, together with the HOT station near Hawaii, by the US Joint Global Ocean Flux Study (JGOFS) since October 1988 to sample the ocean at biweekly to monthly intervals. The basic goal was to monitor the basic processes in the ocean that control the biogeochemistry at seasonal to decadal timescales. A list of core measurements made at the BATS site is provided in Michaels and Knap (1996) and Steinberg *et al.* (2001). All BATS data sets are available online from the BATS ftp site (ftp://ftp.bbsr.edu).

2.1 Nutrient data and analysis of patterns of undetectability

This study utilized nutrient measurements of 1667 samples from 158 cruises covering a 10-year period (1989~1998) of the Bermuda Atlantic Time-series (BATS) data. Only measurements with quality flag (-3) were omitted from the data set due to suspected bottle leakage. Basically, water samples for nitrate + nitrite (referred to hereafter as nitrate), soluble reactive phosphate, and silicic acid are filtered through 0.8 μm Nuclepore filters using in-line polycarbonate filter holders attached to the Niskin spigots. The nitrate + nitrite and soluble reactive phosphate samples are frozen until analysis within two weeks on a technicon Auto-Analyzer II with an approximate analytical precision of 0.03–0.05 μmol kg^{-1} (Steinberg *et al.*, 2001). The silicic acid samples are refrigerated at 4°C and analyzed within a few days. The minimum detection limits for nitrate + nitrite, soluble reactive phosphate, and silicic acid are 0.05, 0.03 and 0.2 μmol kg^{-1}, respectively.

Because we are looking for the annual frequency of measurements below detection limits as a relative measure of nutrient depletion, our main concern is that the data quality (accuracy and precision) remained constant throughout the entire period, and that the temporal changes found should reflect the real natural variability and not changes in measurement techniques or data quality.

To insure a consistent quality of data and constant or improved precision and accuracy of measurement, BATS scientists have applied a number of data quality assessment techniques (Michaels and Knap, 1996). First, duplicate samples are routinely taken from the same Niskin sampling bottle for 10–20% of the sampled depths to determine the precision of each measurement. This intra-