Journal of Experimental Marine Biology and Ecology 487 (2017) 1–10

Contents lists available at ScienceDirect

Journal of Experimental Marine Biology and Ecology

journal homepage: www.elsevier.com/locate/jembe

Marine planktonic ecosystem dynamics in an artificial upwelling area of Japan: Phytoplankton production and biomass fate

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ARTICLE INFO

Article history:
Received 21 January 2016
Received in revised form 1 November 2016
Accepted 3 November 2016
Available online xxxx

Keywords:
Artificial seamount
Nutrients
Primary production
Organic carbon remineralization
Excess production
Carbon sequestration

ABSTRACT

Marine phytoplankton production as well as biomass is globally significant. This study hypothesized that a mild increase in nutrients concentrations (by a factor 1–2 higher) from artificial upwelling in oligotrophic water can alter phytoplankton dynamics (biomass, composition and size), and consequently, phytoplankton-derived particulate organic carbon flux. Primary production, carbon biomass of different planktonic groups, and organic carbon remineralization were examined by incubating seawater collected from two oceanographic stations in the vicinities of Ikitsuki Island, Japan, in 2004 and 2005. Station C, located near to and downstream of an artificial seamount that generates upwelling, had higher nutrient concentrations and biomass (Chl. *a* and carbon) than Station O-2, which was upstream and far from the seamount. Phytoplankton biomass and primary production rates remained higher during incubation for station C than for station O-2 in both 2004 and 2005. Phytoplankton composition also differed between the two stations. Picophytoplankton contributions to total biomass were smaller at station C than at station O-2 while those of micro- and nanophytoplankton were higher at station C. The results of this study indicate that even a small increase in nutrient availability in oligotrophic waters can alter productivity, biomass, and phytoplankton composition. Additionally, around 4.0% of net primary production was estimated to escape from grazers and remineralization, instead sinking into deep ocean layers in the form of less easily degraded particles. The difference in net primary productivity between Stns. C and O-2 gave an estimation of excess production at Stn. C resulting from upwelled nutrients. Owing to this 1.3 to 1.5 mg more carbon $m^{-2}\ d^{-1}$ is likely to be exported at Stn. C compared to Stn. O-2.

1. Introduction

Marine phytoplankton plays an important role in regulating the global carbon cycle (Beardall et al., 2009; Chisholm, 2000). These organisms contribute approximately 50% of the total global primary production (Beardall et al., 2009; Falkowski and Raven, 2007) and play a vital role in mitigating the amount of carbon dioxide (CO_2) in the atmosphere by fixing carbon that is then sequestered into the deep ocean via the biological pump (Falkowski and Raven, 2007). On average, 35% of carbon fixed by phytoplankton in the ocean is exported to the ocean interior (Falkowski et al., 1998). Many studies have recently shown that the amount of carbon exported depends on phytoplankton's production (Marañón et al., 2003), biomass (Roberts et al., 2003), composition (Boyd and Newton, 1999), and size (Smetacek, 1999).

The production of phytoplankton in the ocean can be enhanced by increasing nutrient availability in the euphotic zone (Lampitt et al., 2008; Matear and Elliott, 2004; Nishino et al., 2011). Upwelling of nutrient-rich deep water to the shallow layer is a natural source of nutrients for phytoplankton in the euphotic zone but it is slow and exhibits spatial and temporal variations. A number of researchers have proposed artificial fertilization of the ocean to enhance primary productivity, and hence, the biological pump (export of carbon) (Lampitt et al., 2008; Matear and Elliott, 2004). Others have suggested that the supply of nutrients in the euphotic zone can be increased by generating controlled (artificial) upwelling, with the deployment of ocean pipes below the surface layer (Lovelock and Rapley, 2007; White et al., 2010), leading to net carbon sequestration (Karl and Letelier, 2008). Nutrients can also be supplied to the euphotic zone by artificial upwelling using manmade marine structures (seamounts) (Casareto et al., 2006; Magi et al., 2005). Magi et al. (2005, 2006) showed that a seamount established in the vicinity of Ikitsuki Island, Japan (33° 28′ 40′′ N, 129° 25′ 29′′ E), naturally upwelled bottom water with the help of tidal currents. This upwelled water was then transported by the Tsushima Current (a branch of the Kuroshio Current), resulting in a small increase in nutrient concentrations downstream of the seamount compared to upstream. The present study wanted to know whether such a mild increase in nutrient concentrations (by a factor 1–2 higher) caused by

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http://dx.doi.org/10.1016/j.jembe.2016.11.002
0022-0981/

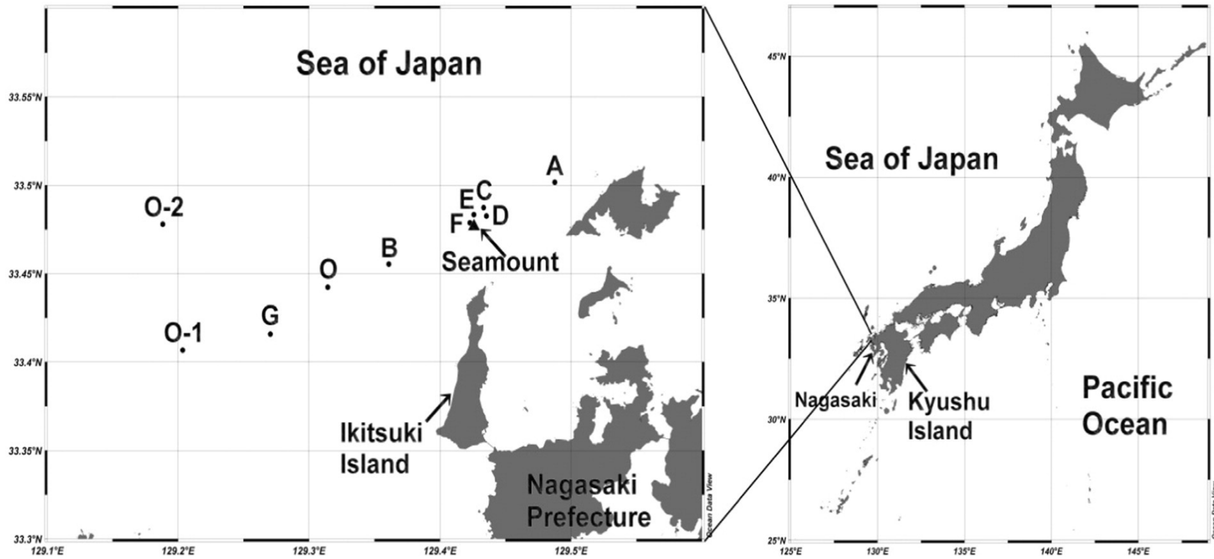

Fig. 1. Position of stations in the vicinity of the artificial marine structure (seamount).

artificial upwelling may have implications for plankton ecosystem dynamics (primary production, phytoplankton biomass, heterotrophic metabolism, and food web structure) and the fate and flux of carbon.

The present research hypothesized that a mild increase in nutrient concentrations caused by artificial upwelling will i) increase phytoplankton biomass and production, ii) alter phytoplankton composition and size, iii) change the balance between autotrophs and heterotrophs, and iv) have implications in the export flux of carbon via the biological pump. These hypotheses were tested by comparing Station (Stn.) C and Stn. O-2 located downstream (near the seamount influenced area) and upstream (far from the seamount influenced area), respectively.

2. Materials and methods

2.1. Study site, field observations, and seawater sampling

This research was carried out in cooperation with the Nagasaki Prefecture. Field observations were conducted on board the research vessel *Tsurumaru*, (which belongs to the Laboratory of Fisheries Experimental Station of Nagasaki Prefecture), in areas around an artificial marine structure or seamount located northwest of Kyushu Island, near Ikitsuki Island, Nagasaki Prefecture, Kyushu, Japan (33° 28′ 40″ N, 129° 25′ 29″ E) (Fig. 1). The seamount was constructed as a permanent structure to generate upwelling in these regions. The construction started in 1997 and finished in 2000, using 4860 concrete blocks (2 m × 2 m in size) made of cement and fly ash. The seamount is 12 m high, 120 m long, 60 m wide, and is set up at a depth of 80 m. The area where the artificial seamount was constructed and stations were studied is under the administration of the Nagasaki Prefecture of Japan; therefore, no specific permissions were required for this research. This research did not involve endangered or protected species.

Field observation methods are described in detail in Magi et al. (2005). In brief physical parameters were measured using a fixed mooring system with a current meter and a thermistor chain fixed about 500 m from the seamount. In addition, data were collected from a ship-based Acoustic Doppler Current Profiler (ADCP) with Differential Global Positioning System (DGPS), a weather-measurement system (WS-40) (Davis Instruments) on the roof of the Nagasaki Prefecture Fisheries Agency, and a tide level sensor (RML-10) (RIGO) at the Ikitsuki Fisheries Port. Data from ADCP and DGPS were collected at fixed time to check the status of upwelling along 2 transect lines each 2 km long, one on each side of the structure parallel to the main currents and at 50° angles with respect to the main axis of the seamount. Salinity and temperature vertical profiles were measured using a salinity, temperature, and depth meter (STD) (Alec Electronics) and light vertical profiles were measured using a multi-sensor (AAQ1183 series, Alec Electronics) at Stns. C, A, B, and O-2, in May 2004; and at Stns. F, E, D, C and A (downstream and east-northeast of the seamount) and Stns. B, O and G (upstream and west-southwest of the seamount) in September 2004; and at Stns. C and O-2 in July, August and October 2005. Total inorganic carbon (TIC) was measured at Stns. C and O-2 in October 2005 only. Nutrients were measured at Stns. C, A, B, O-2, in May 2004; and at Stns. F, E, D, C, A, B, O and G in September 2004; and at Stns. C and O-2, in July, August and October 2005. Chlorophyll *a* (Chl. *a*) vertical profiles were measured using a multi-sensor (AAQ1183 series, Alec Electronics) at Stns. C, A, B, and O-2 in May 2004; and at Stns. F, E, D, C, A, B, O and G

Table 1
Average seawater temperature and salinity at different stations in 2004 and 2005 ± represents standard deviations. n = 3 for each depth.

2004					
	May				
	Temperature (°C)		Salinity		Observed depth up to
Stn. C	18.2	±0.1	34.5	±0.02	60 m
Stn. A	18.1	±0.4	34.4	±0.03	60 m
Stn. B	18.1	±0.1	34.5	±0.00	60 m
Stn. O-2	18.2	±0.1	34.5	±0.02	60 m
	September				
	Temperature (°C)		Salinity		Observed depth up to
Stn. F	24.0	±0.8	34.1	±0.1	70 m
Stn. E	24.0	±0.8	34.1	±0.1	70 m
Stn. D	23.9	±0.8	34.1	±0.1	70 m
Stn. C	24.4	±0.3	34.1	±0.0	70 m
Stn. A	24.1	±0.5	34.1	±0.1	70 m
Stn. B	24.2	±1.1	34.1	±0.1	70 m
Stn. O	25.0	±0.6	34.0	±0.1	70 m
Stn. G	24.3	±1.3	34.1	±0.1	70 m
2005					
	July				
	Temperature (°C)		Salinity		Observed depth up to
Stn. C	21.72	±2.7	33.29	±0.9	50 m
Stn. O-2	22.70	±4.0	32.70	±1.5	50 m
	August				
	Temperature (°C)		Salinity		Observed depth up to
Stn. C	26.86	±2.3	32.58	±0.9	50 m
Stn. O-2	27.87	±2.0	32.64	±1.7	50 m
	October				
	Temperature (°C)		Salinity		Observed depth up to
Stn. C	24.15	±0.1	33.74	±0.01	50 m
Stn. O-2	24.16	±0.6	33.77	±0.05	50 m