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Ono, Itsuro
Department of Earth and Planetary Sciences, Graduate School of Sciences, Kyushu University

Takahashi, Kozo
Department of Earth and Planetary Sciences, Graduate School of Sciences, Kyushu University

Kobayashi, Fumiko
Department of Earth and Planetary Sciences, Graduate School of Sciences, Kyushu University

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Time-series fluxes of diatoms in the central and western equatorial Pacific, 1999–2000

Itsuro Ono, Kozo Takahashi & Fumiko Kobayashi

Department of Earth and Planetary Sciences, Graduate School of Sciences, Kyushu University, Hakozaki 6–10 –1, Fukuoka, 812–8581, Japan.

Abstract

The central and western equatorial Pacific is characterized by the Western Pacific Warm Pool (WPWP). The behavior of the WPWP has a significant influence on global climate changes such as El Niño and Southern Oscillation and it drastically modifies the oceanographic conditions in the area every few years. It is important to evaluate time-series diatom fluxes during El Niño and La Niña events. As a part of the Global Carbon Cycle and Related Mapping based on Satellite Imagery Program (GCMAPS), time-series sediment traps were deployed at two water depths, approximately 1,000 m and 3,000 m, in the central and western equatorial Pacific for two years between January 1999 through December 2000. Sites MT1–3 were located in the WPWP and sites MT5 and 6 were in the Equatorial Upwelling Region (EUR). Total diatom fluxes showed seasonal patterns at all sites. The diatom species compositions in the flux assemblages were different between the WPWP and EUR. Pennate diatoms (e.g. *Nitzschia bicapitata*, *Thalassionema nitzschioides*) dominated the diatom assemblages in the WPWP. However, in the EUR, relative abundances of centric diatoms (e.g. *Rhizosolenia bergonii*, *Azpeitia* spp., *Thalassiosira* spp.) were higher than those of pennate diatoms. Thus, the seasonal changes of diatom fluxes and the taxonomic composition are considered to be excellent environmental proxies responding to the conditions of the water masses of the WPWP and the EUR.

Introduction

In the western equatorial Pacific, the surface layer is covered by the western Pacific warm pool (WPWP) characterized by surface waters greater than about 28°C all year round (Picaut *et al.* 1996). The deep thermocline at the Equator around 160°E characterizes the oligotrophic ocean, therefore, the upwelling intensity in the area is generally weaker than in the eastern equatorial Pacific. However, the behavior of the WPWP has a significant influence on global climate changes such as El Niño and Southern Oscillation (ENSO), and it drastically modifies the oceanographic conditions in the area every few years. It is important to evaluate time-series diatom fluxes during El Niño and La Niña events, because diatom assemblages contribute significantly to the biological pump. They produce organic carbon in their cellular protoplasm without emitting CO_2, like coccolithophores do (e.g. Takahashi 1987; Takahashi *et al.* 2000, 2002a).

Here we investigated seasonal and longitudinal variations in diatom assemblages and fluxes in the central and western equatorial Pacific for two years during 1999–2000 when La Niña conditions persisted, and to discuss their relationships with local hydrographic conditions.

Material and Methods

Time-series sediment traps consisting of cone-shaped traps with 26-cup collectors and a collection apertural area of 0.5 m^2 were deployed at two water depths, approximately 1,000 m and 3,000 m at five sites (Table 1, Fig. 1) in the central and western equatorial Pacific for two years between January 1999 and December 2000 during La Niña conditions. At Site MT3, the deep trap was deployed at 2,000m due to shallow water depth while at Sites MT2 and MT6 only a deep trap each was moored. In this paper, the 1,000 m trap depth is defined as Shallow trap depth and the 3,000 m (2000 m at MT3) is defined as Deep trap depth. The exact trap depths, sampled durations, and site locations are presented in Table 1.

Table 1. Summary of logistic in sediment trap deployments conducted in the western and central equatorial Pacific in 1999–2000.

Site	Location	Water depth (m)	Trap depth (m)	No. of time-series samples	sampled duration
MT1 shallow	4° 02N 135° 00E	4,762	970	22	01. Jan. 99 - 21. Nov. 99
MT1 deep	4° 02N 135° 00E	4,762	2,940	44	01. Jan. 99 - 23. Oct. 00
MT2 deep	5° 03N 140° 06E	4,174	2,970	22	03. Jan. 99 - 21. Nov. 99
MT3 shallow	0° 00N 145° 01E	3,638	1,020	22	05. Jan. 99 - 21. Nov. 99
MT3 deep	0° 00N 145° 01E	3,638	2,060	44	05. Jan. 99 - 01. Jan. 01
MT5 shallow	0° 02N 174° 56W	4,831	1,040	22	13. Jan. 99 - 01. Dec. 99
MT5 deep	0° 02N 174° 56W	4,831	3,000	21	13. Jan. 99 - 01. Dec. 99
MT6 deep	0° 00N 170° 10W	5,645	2,910	22	16. Dec. 99 - 16. Jan. 01

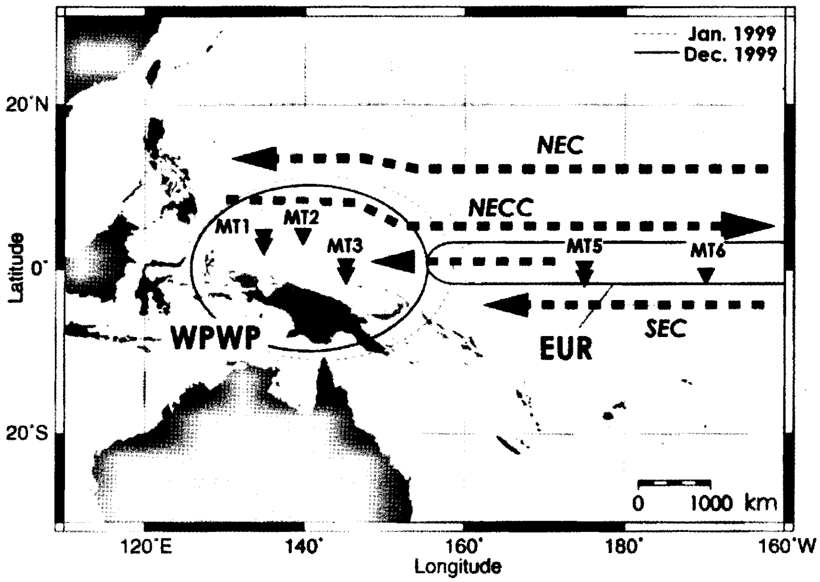


Fig. 1. Location of the time-series sediment traps deployed in the western and central equatorial Pacific in 1999 and 2000, and the representative surface ocean currents: North Equatorial Current (NEC), the North Equatorial Counter Current (NECC) and South Equatorial Current (SEC). The Western Pacific Warm Pool (WPWP) and the Equatorial Upwelling Region (EUR) are highlighted.

For diatom analysis, we employed splits of 1/256–1/1,024 aliquot sizes of the original trap samples. A fraction of the liquid sample was filtered through a Gelman® membrane filter (47 mm diameter, 0.45 μm pore size). The filtered sample was mounted on a microscopic slide with Canada Balsam as the mounting medium. Diatoms were counted under an Olympus BX–50 light microscope (LM) at 400x magnification. The number of fields examined under LM ranged from 50 to 212. The diatom assemblage was investigated by identifying more than 400 specimens per sample in LM. Detailed morphological observations under a scanning electron microscope were also carried out for specific taxa to assist in taxonomy. Diatom taxa were identified to species level where possible. The resulting counts yielded estimates of daily fluxes of diatom valves (e.g. Takahashi 1986, 1997). Relative abundances of individual diatom taxa are given as percentages of the total diatom assemblage in each trap sample.

The identification of the diatom species was made possible with the following references: Cupp (1943), Fryxell & Hasle (1979, 1980), Hasle & Sims (1986), Hasle & Syvertsen (1996), Herzig & Fryxell (1986), Round *et al.* (1990), Semina (1976), Syvertsen (1979), Takahashi *et al.* (1994), Yamaji (1966) and Winter (2001).

Results and Discussion

Total diatom fluxes at Deep traps in the WPWP

At MT1 and MT3 Deep traps, high total diatom fluxes were measured from February to June 1999 and low total diatom fluxes were measured from July to November 1999 (Figs 2, 4). This seasonal variation pattern is markedly different from other latitudinal regions. For example, it is significantly different from that in the subarctic Pacific where two large peaks are present in spring and autumn at Stations AB and SA (Takahashi *et al.* 2000, 2002a) and Stations PAPA and C (Takahashi 1997). It is thought that this high/low flux pattern in the Tropical Pacific is related to winter/summer Monsoon conditions in this area. Kawahata *et al.* (2000) indicated that the nutrient supply increased by strong upwelling in the Mindanao Dome (Masumoto & Yamagata 1991) or river input generated by the winter Monsoon (November–March which is the rainy season in South Asia), which enhanced the primary production in this region off New Guinea in the western WPWP (Site MT1). However, total diatom fluxes at MT1 in 2000 did not show a clear seasonal variation. It is inferred that the upwelling was weaker in 2000 than in the previous year.

The total diatom fluxes at MT2 Deep trap remained low between January and November 1999, although fluxes increased slightly during May/June 1999 (Fig. 2).

Total diatom fluxes at Deep traps in the EUR

At MT5 Deep trap, high total diatom fluxes were measured from February to September 1999, with one maximum value observed in August (Fig. 5). The annual mean flux of total diatoms at MT6 Deep was the highest among all sites in this study (Fig. 6). Generally, the upwelling process enhances the nutrient supply to the euphotic zone which contributes to increase the primary productivity in the regions close to the Equator. At Site MT5, the mean of total mass fluxes was twice as much as in the 1999 La Niña condition (53.7 mg m^{-2}) when compared to the 1992 El Niño event (25.7 mg m^{-2}) (Kawahata *et al.* 2002). For this reason, high total diatom fluxes in the EUR could be ascribed to a deeper mixing of the upper ocean or an upwelling caused by the wind in the 1999–2000 La Niña conditions.

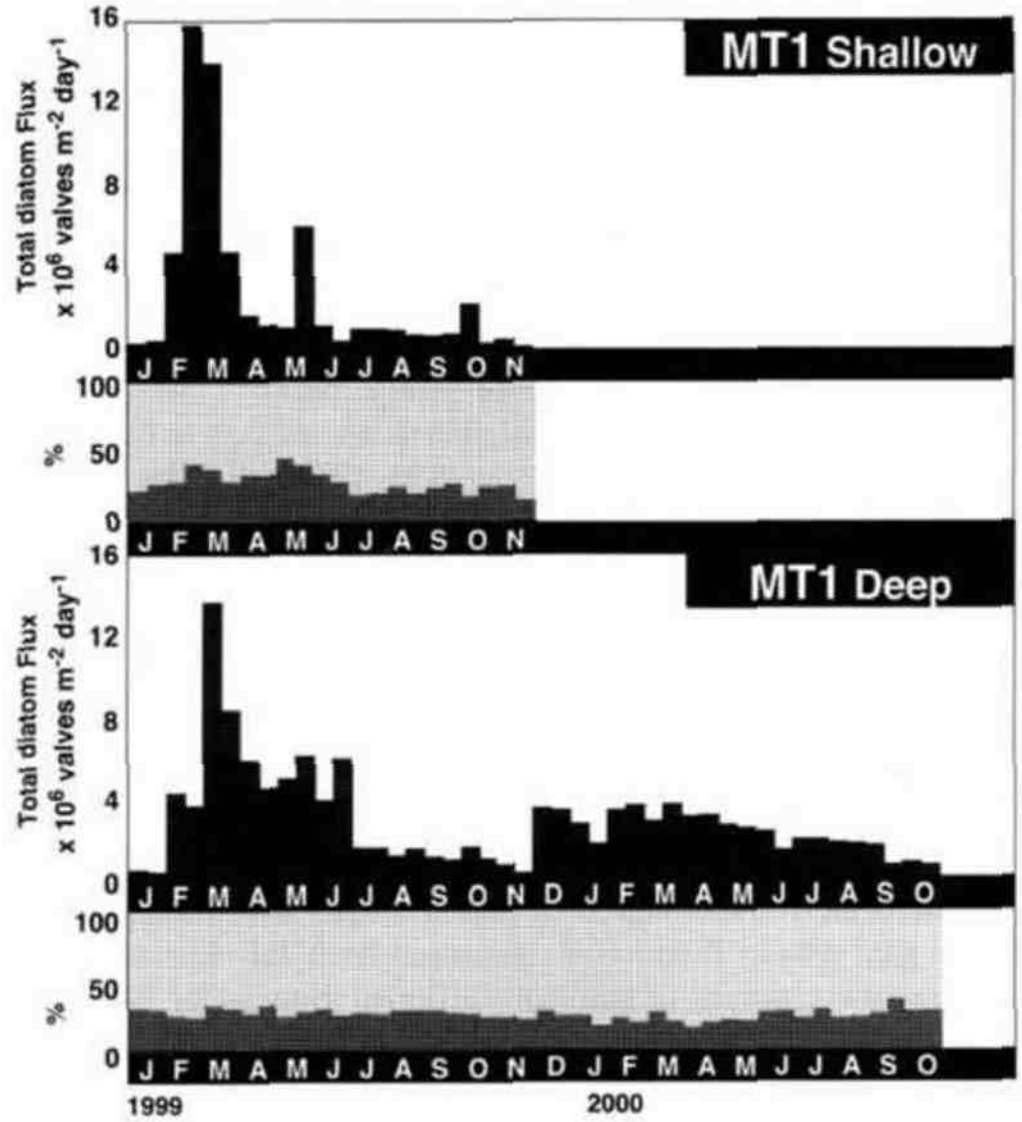


Fig. 2. Time-series fluxes of total diatoms and relative abundances of centric (pale grey) and pennate (medium grey) diatoms in Shallow and Deep traps at Site MT1 in the western equatorial Pacific in 1999 and 2000.

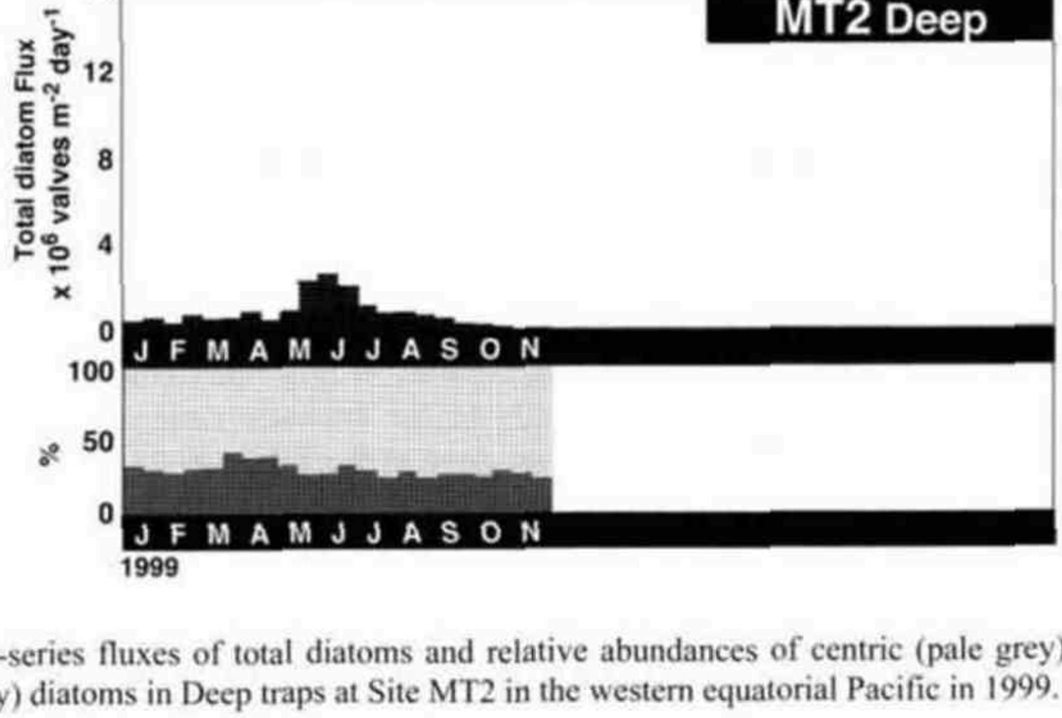


Fig. 3. Time-series fluxes of total diatoms and relative abundances of centric (pale grey) and pennate (medium grey) diatoms in Deep traps at Site MT2 in the western equatorial Pacific in 1999.

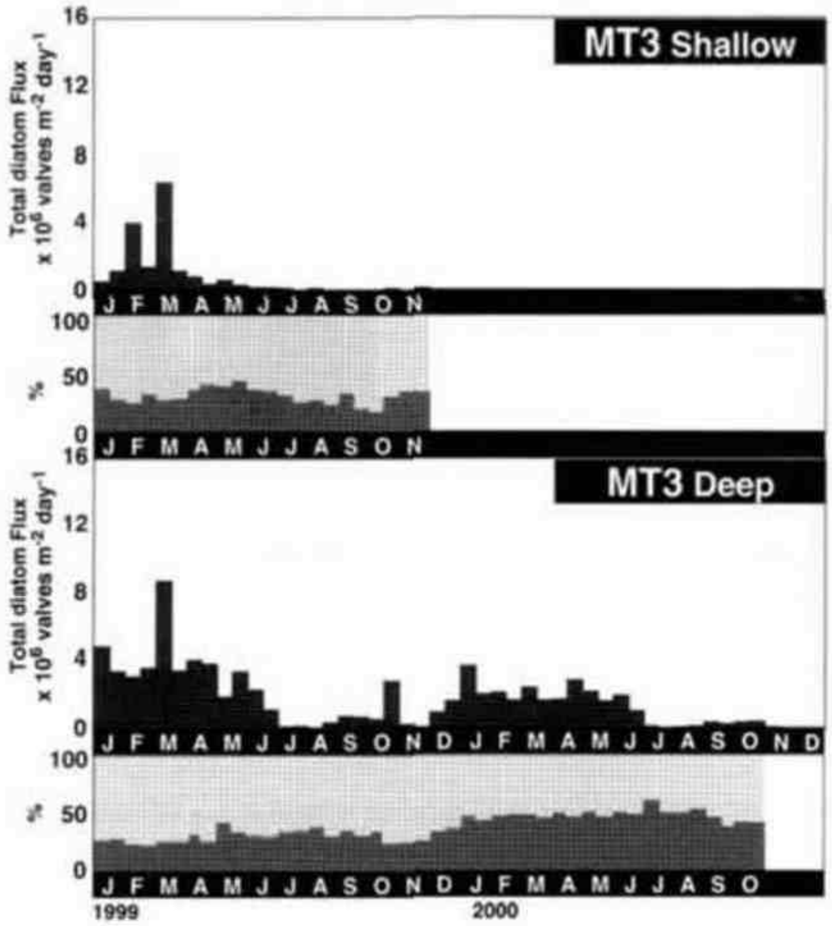


Fig. 4. Time-series fluxes of total diatoms and relative abundances of centric (pale grey) and pennate (medium grey) diatoms in Shallow and Deep traps at Site MT3 in the western equatorial Pacific in 1999 and 2000.

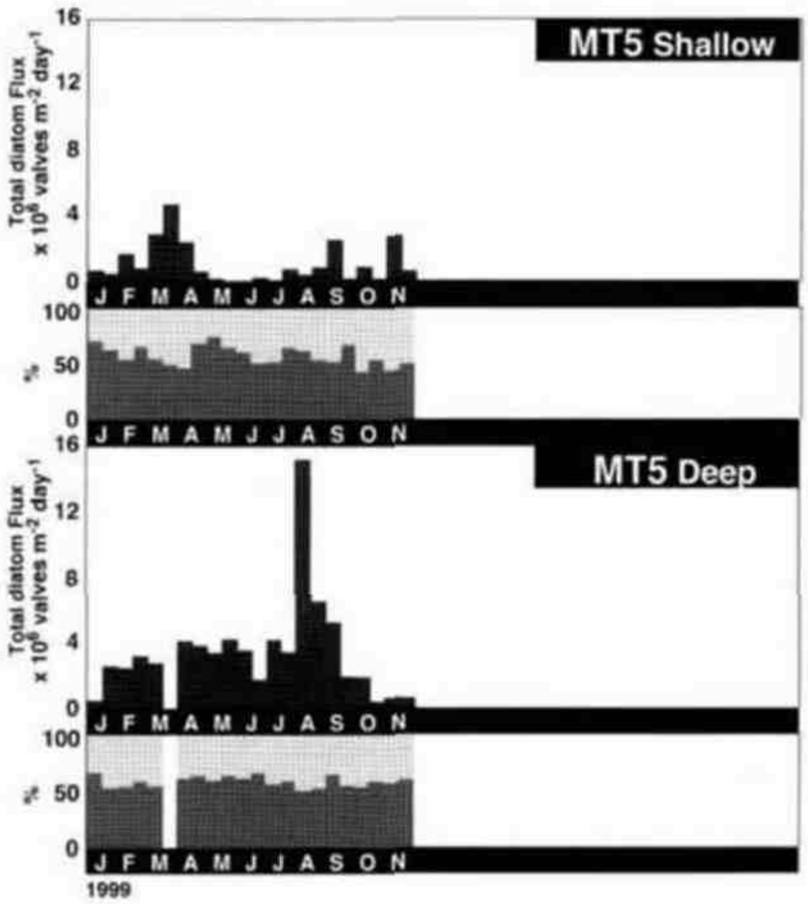


Fig. 5. Time-series fluxes of total diatoms and relative abundances of centric (pale grey) and pennate (medium grey) diatoms in Shallow and Deep traps at Site MT5 in the central equatorial Pacific in 1999.

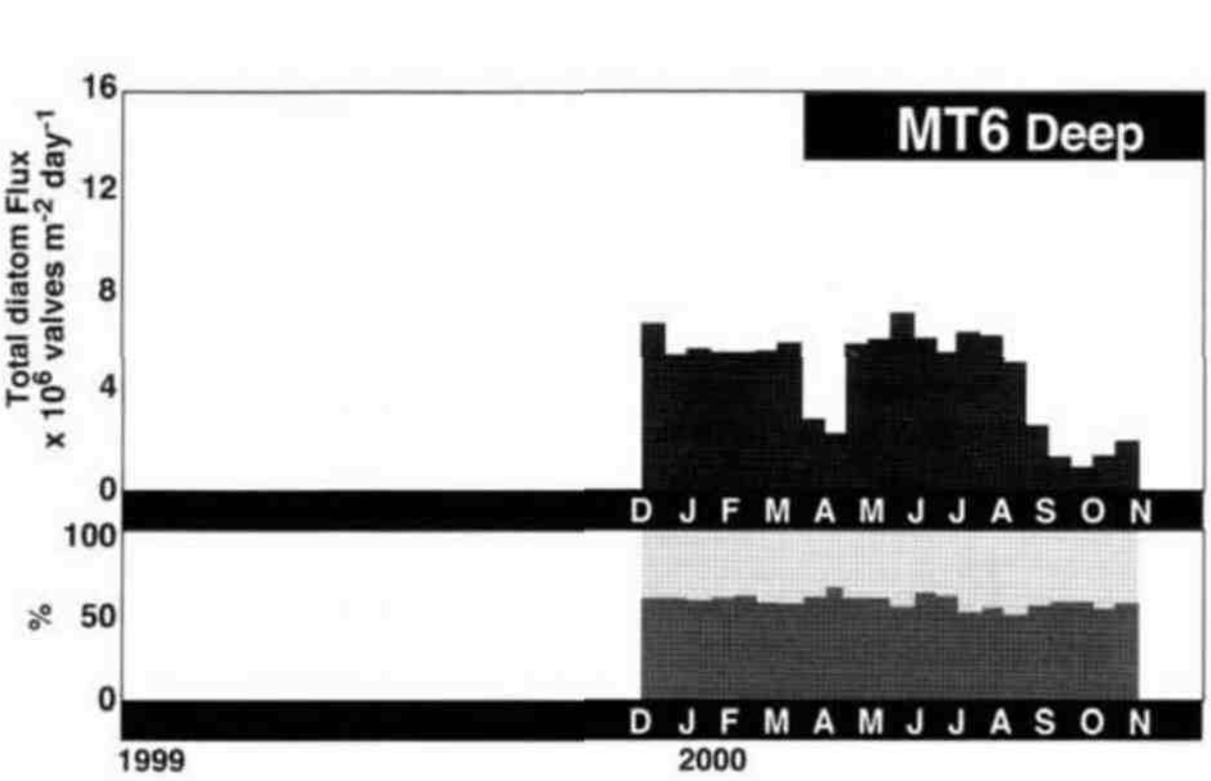


Fig. 6. Time-series fluxes of total diatoms and relative abundances of centric (pale grey) and pennate (medium grey) diatoms in Deep traps at Site MT6 in the central equatorial Pacific in 2000.

Diatom assemblages

Pennate diatoms (e.g. *Nitzschia bicapitata* Cleve, *Thalassionema nitzschioides* (Grunow) Grunow ex Hustedt) dominated the diatom assemblages in the WPWP (Sites MT1–3). However, in the EUR (Sites MT5–6), relative abundances of centric diatoms (e.g. *Rhizosolenia bergonii* H. Peragallo, *Azpeitia* spp.) were higher than those of pennate diatoms (Figs 2–6). The results of this study clearly reflect the living diatom assemblages in the surface waters in the same study area shown by Kobayashi & Takahashi (2002) and Takahashi *et al.* (2002b). Similarly, living radiolarians are also well represented in the sinking assemblages (Takahashi *et al.* 2002b, Yamashita *et al.* 2002).

Longitudinal (135°E–170°W) flux variations

High export fluxes of *Nitzschia bicapitata*, which is also dominant in the equatorial Atlantic (Romero *et al.* 2000, Treppke *et al.* 1996) and *Thalassionema nitzschioides* were recorded in the WPWP (Sites MT1–3), but exhibited reduced fluxes in the EUR (Sites MT5 and 6) (Fig. 7). Delicate species such as *N. bicapitata* and *T. nitzschioides* var. *parvum* Heiden seem to maintain high abundance even in oligotrophic conditions. *Rhizosolenia bergonii*, well-known from open-ocean conditions (Romero *et al.* 2000, 2001) dominated the diatom flux assemblages at Site MT5 in 1999 and Site MT6 in 2000 in the EUR, and was accompanied by *N. bicapitata* and *T. nitzschioides*. We thought that diatom fluxes in the WPWP (the oligotrophic area) were strongly limited by levels of macronutrients such as nitrate. Fluxes of *Azpeitia neocrenulata* (VanLandingham) Fryxell & Watkins and *Roperia tesselata* (Roper) Grunow ex Pelletan in 2000 were higher than those observed in 1999 in the area, and their fluxes in the EUR were higher than the ones observed in the WPWP (Fig. 7). It is hypothesized that these results represented the diatom responses to the high river discharge (primarily from Papua New Guinea, Indonesia) due to high precipitation during the rainy season in 2000.

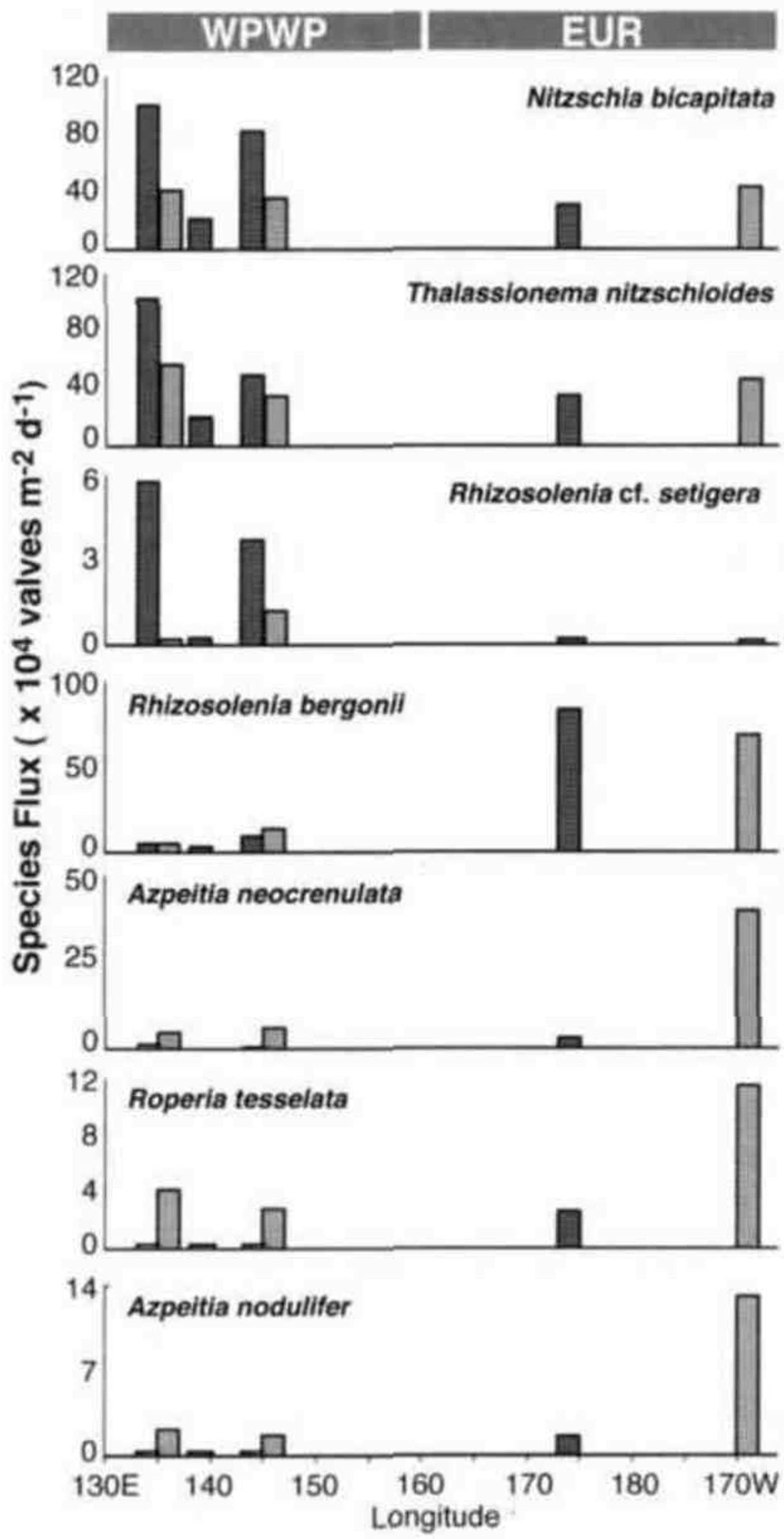
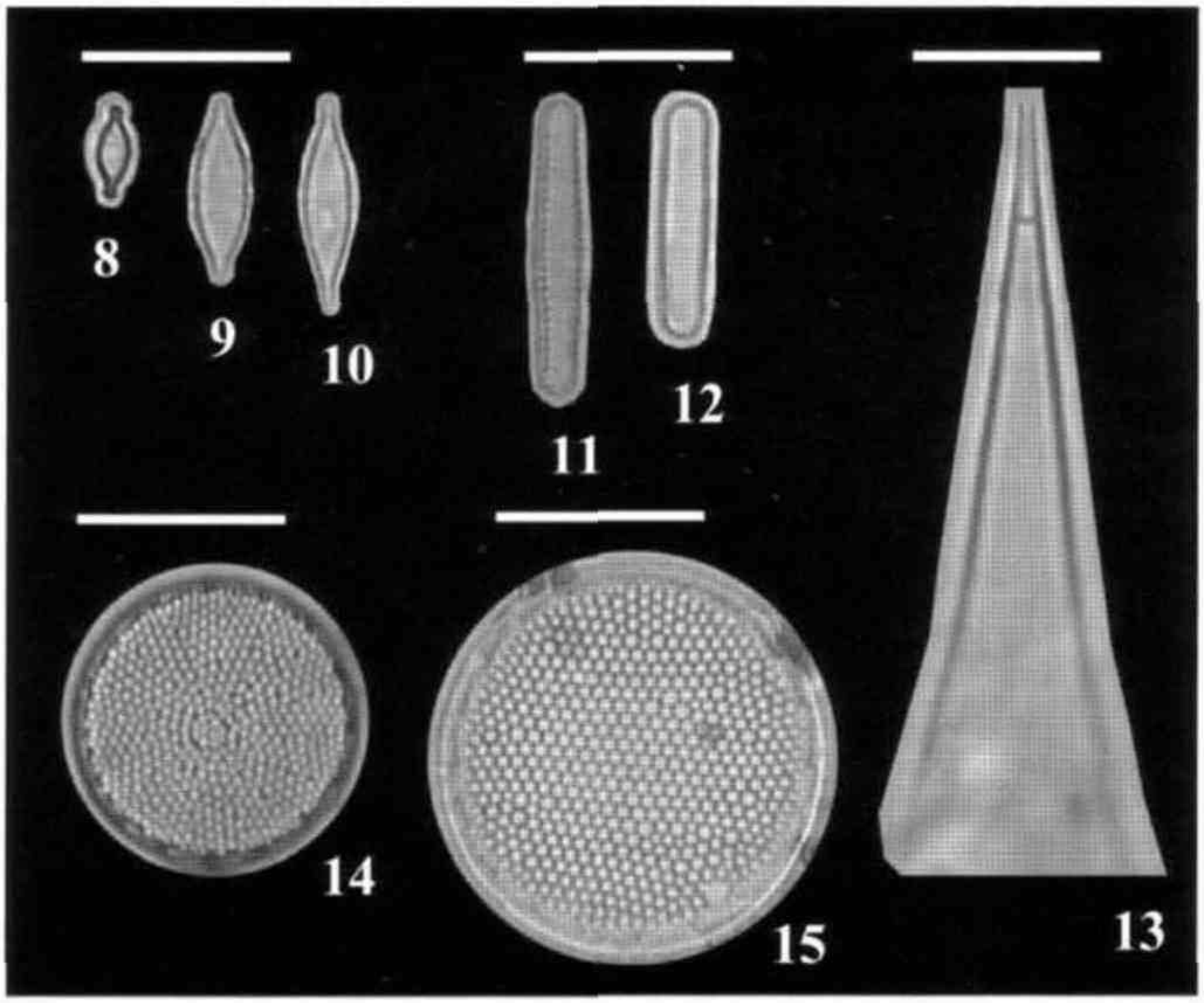


Fig. 7. Longitudinal variations in the mean annual fluxes of the dominant diatom taxa in the WPWP and the EUR. Dark bars: 1999; grey bars: 2000.

Comparison of Deep traps with Shallow traps

Total diatom fluxes at Deep traps were higher than those at Shallow traps (Sites MT1, 3 and 5 in 1999, Figs 2–5). Similar results were reported also from different regions of the world (e.g. Leventer & Dunbar 1987, Sancetta 1992, Takahashi 1986, 1987, Treppke *et al.* 1996). Lateral advection, high-velocity currents of the Equatorial Undercurrent (EUC) at a depth of 20 to 200 m, and the influence of swimmers in shallow traps may explain the significant difference in the Shallow and Deep traps. François *et al.* (2001) summarized that the trapping efficiency approached to 100% with respect to expected values based on radionucleoids in the traps deployed at water depths deeper than 1,500 m.



Figs 8–15. Light micrographs of diatoms collected from Sites MT1–6 in the western and central equatorial Pacific. **Figs 8–10**. *Nitzschia bicapitata* complex including *Nitzschia* spp. **Figs 11, 12**. *Thalassionema nitzschioides*. **Fig. 13**. *Rhizosolenia bergonii*. **Fig. 14**. *Azpeitia neocrenulata*. **Fig. 15**. *Roperia tesselata*. Scale bars = 10 µm

Conclusions

The two year period of this study (January 1999–November 2000) fell within the La Niña event and provided an excellent opportunity for us to characterize diatom flux assemblages both in the western (WPWP) and central (EUR) equatorial Pacific. Total diatom fluxes showed seasonal variations, especially at Deep traps of all sites in 1999. The temporal flux variation patterns are a reflection of the characteristic oceanographic conditions in each of these water masses. The annual mean flux of total diatoms at MT6 Deep trap was the highest among all sites and depths. The diatom assemblages were dominated by pennate diatoms in the WPWP and by centric diatoms in the EUR. Diatom fluxes in 1999 were different from those in 2000, and the diatom assemblages in 1999 also differed from the succeeding year. Interestingly, the relative abundances of pennate and centric diatoms in each of the water masses did not change notably during 1999 and 2000.

Acknowledgements

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