Continental Shelf Research 118 (2016) 88–99

Contents lists available at ScienceDirect

Continental Shelf Research

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

Factors governing phytoplankton biomass and production in tropical estuaries of western Taiwan

Ching-Wen Pan [a], Yi-Li Chuang [a], Lien-Siang Chou [b], Meng-Hsien Chen [c], Hsing-Juh Lin [a,d,*]

[a] Department of Life Sciences and Research Center for Global Change Biology, National Chung Hsing University, Taichung 402, Taiwan
[b] Institute of Ecology and Evolutionary Biology, National Taiwan University, Taipei 106, Taiwan
[c] Department of Oceanography and Asia-Pacific Ocean Research Center, National Sun Yat-sen University, Kaohsiung 804, Taiwan
[d] Biodiversity Research Center, Academia Sinica, Taipei 115, Taiwan

ARTICLE INFO

Article history:
Received 3 September 2015
Received in revised form
17 February 2016
Accepted 26 February 2016
Available online 2 March 2016

Keywords:
Functional trait
Irradiance
P-E curve
SiO_2
Temperature
Turbidity

ABSTRACT

Factors governing phytoplankton community composition and production in tropical estuaries remain mostly unknown. We aimed to quantify phytoplankton biomass, production, and community composition seasonally in 2 tropical estuaries with different levels of nutrient concentrations and turbidity, and we compared them with an offshore control site on the western coast of central Taiwan for two years. Phytoplankton biomass and production varied with season and site. Annual integrated primary production showed that these three sites were mesotrophic systems. Spearman rank correlations showed that phytoplankton biomass and production were positively correlated with water temperature, but negatively correlated with turbidity. The threshold of turbidity was 12 Nephelometric Turbidity Units (NTU), above which phytoplankton chlorophyll *a* concentrations were <0.5 mg m^{-3}, and gross production rate was <100 mg C m^{-3} d^{-1}. The results of nonmetric multidimensional scaling (MDS) showed that the community was primarily structured by season and secondarily by site. The functional traits further showed that turbidity, water temperature, and SiO_2 concentration were governing factors for the variations in the community. In summary, turbidity was the main factor governing phytoplankton biomass and production, whereas water temperature and SiO_2 concentration had both a direct effect on production and an indirect effect by changing community composition.

1. Introduction

Coastal waters are highly productive ecosystems (Nixon et al., 1986). Although the volume of coastal waters occupies only 0.5% of the ocean, they can contribute up to 30% of primary production (Longhurst et al., 1995). However, a wide range of phytoplankton production from -692 to 1890 g C m^{-2} yr^{-1} was reported from 131 estuaries in the world (Cloern et al., 2014), indicating that influencing factors may differ remarkably among different estuaries. In addition, most of these studies were conducted in temperate waters. Studies are rarely conducted in tropical waters to quantify phytoplankton production and determine the influencing factors.

Irradiance and nutrients are generally considered as main factors governing phytoplankton production. Turbid water may constrain the photic zone to the surface layer and result in the mixed layer being much deeper than the photic depth, which can limit phytoplankton production due to the lack of sufficient irradiance (Cloern, 1987). Moreover, irradiance may regulate the absorption and assimilation of nutrients of phytoplankton, which can affect primary production (Huppe and Turpin, 1994). In North San Francisco Bay, turbid water and lower irradiance were reported to result in a consistently low level of phytoplankton production, despite the high nutrient concentrations (Cloern, 1999). Suspended sediments in river flows (Wetsteyn and Kromkamp, 1994) and colored dissolved organic matter (Lawrenz et al., 2013) were indicated as the limiting factors of phytoplankton production. Resuspended sediments disturbed by tidal currents or strong winds in estuaries can reduce phytoplankton production by lowering the irradiance in the water column (Cloern, 1996; Schubel, 1968). In the northern Gulf of Carpentaria, Burford and Rothlisberg (1999) also noticed that the strong southeastern monsoon in winter could disturb the water column and lower the irradiance, which may reduce phytoplankton production to 60% of the summer level. Horizontal stratification, due to salinity, can help phytoplankton remain in the photic zone, which may increase the biomass (Cloern et al., 2014). However, tidal currents or strong winds can break the stratification and distribute phytoplankton evenly in the water column, which may reduce the irradiance

* Corresponding author at: Department of Life Sciences and Research Center for Global Change Biology, National Chung Hsing University, Taichung 402, Taiwan.
E-mail address: hjlin@dragon.nchu.edu.tw (H.-J. Lin).

http://dx.doi.org/10.1016/j.csr.2016.02.015
0278-4343/

conceived by phytoplankton (Koseff et al., 1993). On the contrary, such water mixing may reduce photoinhibition in the surface water and increase phytoplankton production (Mallin and Paerl, 1992).

Nutrients in estuaries are derived primarily from loadings of river flows and/or microbial detrital decomposition. In general, nitrogen (N) is the limiting factor in ocean and coastal waters (Elmgren and Larsson, 2001; Paerl et al., 1995). However, some estuaries highly influenced by river flows are phosphorus (P)-limited or co-limited by N and P due to the inputs of sewage containing more N (Sylvan et al., 2006). Silicon (Si) is an essential element for diatom growth and enters aquatic systems through the weathering of rocks and soil minerals in the catchment. Concentration of dissolved silica (SiO_2) in estuaries can be reduced by river eutrophication, and the enrichment of N and P in estuaries may increase the relative importance of SiO_2 (Howarth and Marino, 2006). Egge and Aksnes (1992) indicated that under the condition of <2 μM of SiO_2 concentration, phytoplankton may shift from a diatom-dominated to a flagellate-dominated community. Reduction of the relative importance of diatoms to phytoplankton production can further decrease overall production or biomass of phytoplankton (Butrón et al., 2009; Wu and Chou, 2003).

In addition to the effect on phytoplankton production, irradiance and nutrients may change the community composition. Ecological functional traits of phytoplankton have rarely been linked to environmental factors. Such approaches have the potential of increasing our ability to explain the composition of phytoplankton communities and predict their reorganizations under environmental change (Litchman and Klausmeier, 2008). Diatoms often occur in eutrophic and turbid coastal waters (Cloern and Dufford, 2005) due to the rapid growth rate (Smayda, 1997) and tolerance to low irradiance (Goldman and McGillicuddy, 2003). Moreover, most of them are centric diatoms, which can form resting spores and sink to the bottom during unfavorable conditions (Sugie and Kuma, 2008), thus revealing seasonal and spatial variations. Sarthou et al. (2005) indicated that absorption efficiency, nutrient capacity, and photon capture efficiency by diatoms depended upon the cell size. The growth rate of small-sized diatoms was faster due to the efficiency in nutrient absorption and photon capture. However, large-sized diatoms had higher nutrient capacity and often became the dominant species in coastal waters. Key et al. (2010) indicated that large-sized diatoms were relatively not affected by photoinhibition and adapted to the rapid change of irradiance in coastal waters.

In this study, we aimed to quantify phytoplankton biomass and production and characterize the community composition in 2 tropical estuaries with different levels of nutrient concentrations and turbidity, and we compared them with an offshore control site on the western coast of central Taiwan. We hypothesized that turbidity was the governing factor on phytoplankton biomass and production rather than nutrients. Despite the high nutrient concentrations, phytoplankton production and biomass were expected to be lower in the estuary with a high level of turbidity, and the community composition was dominated by the species adapting to a low level of irradiance.

2. Materials and methods

2.1. Study sites

The estuaries of Zhuoshui River (Ez) and the Xin Huwei River (Ex) are located in the coastal waters of western central Taiwan (Fig. 1). The shallow-sloped coast is characterized by muddy flats. The average water temperature over the year is 24.1 °C, with an annual rainfall of 2384 mm. The wet season is from April to September, and the dry season lasts from October to the next March. According to the water quality monitoring data of the Environmental Protection Agency of Taiwan (2012–2013), the mean suspended solid concentration at Ez reached 894.7 mg L^{-1} due to the high content of slate clay in the river. The mean concentrations of NH_4, NO_x (NO_2+NO_3), and total phosphorus (TP) at Ez were 4.29 μM, 12.89 μM, and 5.24 μM, respectively. The mean suspended solid concentration was much lower (168.2 mg L^{-1}) at Ex, but the mean nutrient concentrations were higher (the concentrations of NH_4, NO_x, and TP were 219.6 μM, 96.5 μM, and 7.81 μM, respectively), due to the loading of piggery sewage in the catchment of Ex.

We set up 3 study sites in the coastal waters (Fig. 1). Ez and Ex were located at approximately 2 km outside of the Zhuoshui River Estuary (23°50′49.06″N, 120°11′18.26″E) and of the Xin Huwei

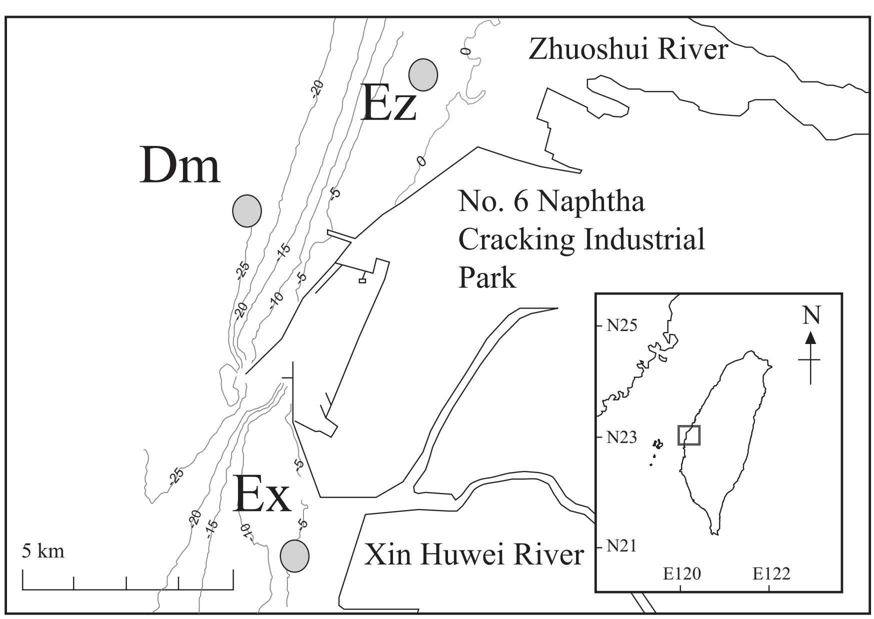

Fig. 1. The location of the three study sites (Ez, Dm, and Ex) in the coastal waters of western central Taiwan.