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ORIGINAL RESEARCH ARTICLE

Summer distribution patterns of *Trichodesmium* spp. in the Changjiang (Yangtze River) Estuary and adjacent East China Sea shelf

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Summary To examine the distribution of *Trichodesmium* relative to physicochemical factors during summer in the Changjiang (Yangtze River) Estuary and adjacent East China Sea shelf, three cruises were conducted separately in June 2009, July 2011, and August 2009. *Trichodesmium* species found were *T. thiebautii*, *T. erythraeum*, and *T. hildebrandtii*. The population was dominated by *T. thiebautii*, which accounted for >85% of the samples found. Most of them were free trichomes. Colonial forms were rarely observed (approximately 10% of our samples), occurring only in offshore waters. The depth integrated abundances of *Trichodesmium* were 308×10^3, 1709×10^3, and 3448×10^3 trichomes m^{-2} in June, July, and August, respectively. *Trichodesmium* was distributed abundantly in the southern or southeastern part of our study area,

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where nutrients were low and light penetration, temperature, and salinity were high, which were influenced by the Taiwan Warm Current (TWC) and Kuroshio. *Trichodesmium* was found in low abundance in inshore, eutrophic, low-salinity waters, which were mainly controlled by the Changjiang Diluted Water (CDW) and coastal current. These results suggest that spatiotemporal changes in the summer *Trichodesmium* distribution correlate highly with the variations in physicochemical properties that are primarily controlled by the TWC, Kuroshio, and CDW. The summer N_2 fixation rate of *Trichodesmium* was estimated at 12.3 μmol N m^{-2} d^{-1} in our study area, contributing >50% of biological N_2 fixation.

1. Introduction

Trichodesmium spp. (hereafter, *Trichodesmium*) are diazotrophic filamentous nonheterocystous cyanobacteria that live as colony-forming or individual filaments. *Trichodesmium* is broadly distributed in the photic zones of tropical and subtropical seas with low nutrients, clear waters, and deep light penetration (Capone et al., 1997). *Trichodesmium* is the main primary producer and likely the major contributor of N_2 fixation in these oligotrophic water regiments (typically in temperatures >20°C). This N_2 fixation relieves the restraining of the nitrogen limitation to the marine primary production and produces more biological carbon, which enhances the efficiency of the biological pump in oligotrophic oceans (Falkowski, 1997; Hutchins et al., 2015). *Trichodesmium* plays an essential role in the carbon and nitrogen biogeochemical cycles and is therefore of great interest regarding global warming and increased pCO_2 (Capone et al., 1997; Das and Mangwani, 2015; Hutchins et al., 2015; Jiang et al., 2015b; Karl et al., 1997).

During the summer, the East China Sea (ECS), which is the largest marginal sea in the western North Pacific Ocean, undergoes significant changes in circulation and water mass (Fig. 1; Chen, 2009; Jiang et al., 2015a; Su and Yuan, 2005; Zhou et al., 2015). Many studies have found that *Trichodesmium* is relatively abundant and occasionally blooms in warm months in the ECS and Kuroshio areas (Chang et al., 2000; Chen et al., 2014; Ding, 2009; Marumo and Asaoka, 1974; Shiozaki et al., 2010, 2015; Yang, 1998; Zhang et al., 2014). *Trichodesmium* populations and especially blooms may contribute considerably to the local carbon and nitrogen budget of the ECS during summer stratification with water temperatures above 20°C, particularly in the offshore waters controlled by the Taiwan Warm Current (TWC) and Kuroshio (Saino, 1977; Shiozaki et al., 2010, 2015; Zhang et al., 2012). Although abundant *Trichodesmium* in the Changjiang Estuary (CE) and adjacent ECS is conveyed by the TWC and Kuroshio, their distribution is limited by low-salinity and -temperature water masses, including the Changjiang Diluted Water (CDW), coastal current, and Yellow Sea Cold Water Mass (YSCWM). Additionally, the eutrophic, low-salinity CDW and coastal current promote diatom and dinoflagellate blooms (Jiang et al., 2015a; Zhu et al., 2009), which are not conducive to *Trichodesmium* growth or N_2 fixation because of the contemporary principles of phytoplankton physiological and ecological trade-offs (Carpenter, 1983; Fu and Bell, 2003). However, previous studies have indicated that large rivers, such as the Amazon (Olson et al., 2015; Subramaniam et al., 2008) and Mekong (Grosse et al., 2010; Voss et al., 2006), enhance the biomass and N_2 fixation of diazotrophic cyanobacteria (e.g., *Richelia* and *Trichodesmium*) in the shelves influenced by the riverine plume. These reports have revealed that the water column stability of and micronutrients and trace metals (e.g., Fe, Mo, and Ni) in the river plumes may enhance cyanobacterial growth. Therefore, investigating the distribution patterns and N_2 fixation of *Trichodesmium* in the CE and adjacent ECS (which is directly subjected to a considerable amount of riverine freshwater and terrestrial materials) is necessary.

In summer, spatiotemporal changes are apparent in the physicochemical properties of the CE and adjacent ECS, including variations in river discharge associated with abundant nutrients, the turning and extension of the CDW, seawater temperature elevation, and an increase in the incursion of the TWC because of the prevailing southwestern monsoon (Jiang et al., 2015a; Su and Yuan, 2005; Zhou et al., 2015). In this context, we hypothesized that summer *Trichodesmium* populations may exhibit significant spatiotemporal changes in the CE and adjacent ECS. However, the effects of environmental factors on *Trichodesmium* in summer remain poorly documented (Yang, 1998). Regional accelerated warming (Jiang et al., 2014; Tang et al., 2009), the increasing transport of the Kuroshio and TWC (Tang et al., 2009), and enhanced stratification (which prevents the supplementation of upwelling bottom nitrogen) may affect the distribution boundary, growth, and N_2 fixation of *Trichodesmium*. However, the effects of these factors remain largely undetermined, and their contributions to phytoplankton biomass and N_2 fixation are also unclear. We observed how the changing physicochemical properties in the CE and adjacent ECS shelf during summer affected the *Trichodesmium* population. Our objectives were to (1) examine the *Trichodesmium* species composition and population structure, (2) explore its distribution patterns in relation to environmental factors, and (3) estimate its contributions to phytoplankton biomass and biological N_2 fixation.

2. Material and methods

2.1. Study area and sample collection

During summer, the Kuroshio mainstream flows northeastward along the ECS shelf break (200-m isobath) and the Kuroshio branch northeast of Taiwan flows northeastward