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厦门大学

博士学位论文

南海陆架区束毛藻的丰度、分布及其调控因子研究

Abundance and Distribution of *Trichodesmium* in the Continental Shelf Waters of the South China Sea

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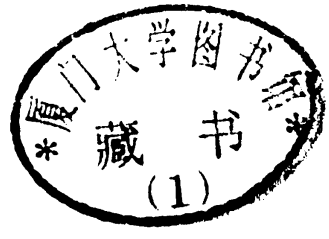

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缩略词中英文对照表

缩略词	英文	中文
yr	year	年
ADP	adenosinee-diphosphate	腺嘌呤核苷二磷酸
ATP	adenosine-triphosphate	腺嘌呤核苷三磷酸
C	Carbon	碳
Chl-α	Chlorophyll-α	叶绿素 α
CTD	Conductivity, Temperature and Depth sensor	剖面仪电导率传感器
d	day	天
DIN	Dissolved Inorganic Nitrogen	溶解无机氮
DIP	Dissolved Inorganic Phosphorus	溶解无机磷
DON	Dissolved Organic Nitrogen	溶解有机氮
DOP	Dissolved Organic Phosphorus	溶解有机磷
*het*R	Regulation of heterocyst differentiation	异型胞分化的调控
HNLC	High Nutrient Low Chlorophyll	高营养盐低叶绿素
m	meter	米
mg	microgram	毫克
mRNA	messenger ribonucleic acid	信使 RNA，信使核糖核酸
M	mol/L	摩尔/升
POC	Particulate Organic Carbon	颗粒有机碳
N	Nitrogen	氮
N_2	dinitrogen	氮气
NCBI	National Center for Biotechnology Information	美国国家生物信息中心
*nif*H	nitrogenase reductase	固氮酶还原酶

缩略词	英文	中文
nM	nano mol/L	纳摩尔/升
NH_4^+	ammonium	铵盐
NO_3^-	nitrate	硝酸盐
NO_2^-	nitrite	亚硝酸盐
P	Phosphorus	磷
pO_2	Pressure of O_2	氧分压
PAR	Photosynthetically Available Radistion	光合有效辐射
pg	Pico gram	皮克
Pi	inorganic phosphate	无机磷酸盐
PO_4^{3-}	phosphate	磷酸盐
POC	Particulate Organic Carbon	颗粒有机碳
PS Ⅰ	Photosynthesis System Ⅰ	光合系统Ⅰ
PS Ⅱ	Photosynthesis System Ⅱ	光合系统Ⅱ
S	Salinity	盐度
s	second	秒
SRP	Soluble Reactive Phosphorus	活性磷酸盐
T	water temperature	水温
Tg	Trillion gram	万亿克
μM	micro mol/L	微摩尔/升
μ_{max}	specific growth rate	比生长率
16S rDNA	16S ribosomal DNA	16S 亚基-核糖体核糖核酸

摘要

束毛藻（*Trichodesmium*）属于群体海洋固氮蓝细菌，主要分布于贫营养的亚热带和热带大洋，被认为是贫营养海区“新”氮的重要来源。它在我国近海（包括渤海、黄海、东海和南海）和沿岸水域都有一定数量的分布，甚至多次形成赤潮。当前对“陆架泵”（大气CO_2吸收机制）研究的关注，大大增强了陆架区水域束毛藻的丰度、分布及固氮速率研究的重要性。

本文首次报道了南海陆架区（包括南海北部陆架区和北部湾东侧海域）束毛藻的丰度、水平和垂直分布模式，探讨了陆架区水域束毛藻丰度与分布的调控因子，旨在为陆架区以至中国海的束毛藻的生物量及其对固氮贡献的估算等提供参考依据。

主要成果如下：

1. 南海陆架区，束毛藻主要以单条藻丝（single trichome）的形式存在，种类有：薛氏束毛藻（*T. thiebautii*）、汉氏束毛藻（*T. hildebrandtii*）和红海束毛藻（*T. erythreaum*）。

2. 北部湾东侧海域表层水体中，春季，束毛藻的平均丰度最高，为 274 条/升（变化范围为：0~3,510 条/升）；秋季次之，为 50 条/升（变化范围为：0~212 条/升）；夏季和冬季，平均丰度较低，夏季为 29（变化范围为：0~196 条/升），冬季为 29 条/升（变化范围为：0~356 条/升）。南海北部陆架区表层水体中，春季，束毛藻的平均丰度为 118 条/升（变化范围为：0~670 条/升）；夏季，平均丰度略高于春季，为 241 条/升（变化范围为：0~2,797 条/升）。

3. 北部湾东侧海域表层水体中，束毛藻的水平分布模式与[NO_3^- + NO_2^-]、SRP的浓度（两者浓度变化趋势相同）有关。在[NO_3^- + NO_2^-]、SRP浓度的高值区，束毛藻的丰度均较低；四季，束毛藻丰度的高值区均分布在[NO_3^- + NO_2^-]和SRP浓度较低的区域。南海北部陆架区，在营养盐较高的珠江口水域和琼东沿岸上升流区，束毛藻丰度较低；在低营养盐的反

气旋漩涡（19° N, 112° E），束毛藻丰度最高，南海北部陆架区束毛藻的这种分布模式与北部湾东侧海域类似。

4. 北部湾东侧海域束毛藻的垂直分布模式为表层（1 m）平均丰度最大。尽管，个别站位束毛藻丰度的最大层位于 10 m、30 m甚至更深水层；但是，在束毛藻丰度相对较高（某一或几个水层丰度达到 10^2条/升）的站位，束毛藻丰度的最大层多位于表层（1 m）；这与以往在外海和大洋的研究结果（次表层，即 10~40 m层最大）有所不同。光强很可能是调控束毛藻垂直分布模式的主要因子。此外，$[NO_3^- + NO_2^-]$浓度也会影响束毛藻的垂直分布。若表层水中$[NO_3^- + NO_2^-]$浓度较高，而深层水中浓度较低，则束毛藻的丰度在深层水中较高，这与$[NO_3^- + NO_2^-]$对束毛藻的水平分布模式的调控相同。一些站位在 50 m以深水层出现较高丰度（1 L水中有几十至上百条）的束毛藻，这些站位往往表层水中SRP的浓度较低，束毛藻的这种分布很可能与磷酸盐的获取有关。

5. 北部湾东侧海域表层水体，束毛藻的固氮速率，春季最高，约为 521~4,083 pg N L^{-1} h^{-1}；秋季仅次于春季，约为 95~745 pg N L^{-1} h^{-1}；冬季和夏季，均为 55~432 pg N L^{-1} h^{-1}；周年平均固氮速率为 182~1,423 pg N L^{-1} h^{-1}。南海北部陆架区表层水体中，春季束毛藻的固氮速率约为 224~1,758 pg N L^{-1} h^{-1}；夏季约为 458~3,591 pg N L^{-1} h^{-1}。

关键词：束毛藻；丰度；分布；调控因子；南海陆架区

ABSTRACT

Trichodesmium, a colonial marine cyanobacterium, is primarily distributed in oligotrophic tropical and subtropical oceans. Its cosmopolitan distribution and capacity to fix N_2 make it an important contributor to the pool of new nitrogen in the oligotrophic oceans. It was also found in China Seas (including Bo Sea, Yellow Sea, East China Sea and South China Sea) and vicinity, and formed "algae bloom" in coastal waters frequently. The current focus on "continental shelf pump" (a mechanism for the absorption of atmospheric CO_2) has elevated the importance of quantifying *Trichodesmium* abundance and nitrogen fixing rates in the continental shelf waters.

Our research first reported *Trichodesmium* abundance and its distribution patterns in the continental shelf waters of South China Sea (including the continental shelf waters of northern South China Sea and eastern Beibu Gulf). The relationships between *Trichodesmium* abundance and ecological factors were discussed here in order to figure out the controlling factor(s) of *Trichodesmium* distribution. This will help to understand the role of *Trichodesmium* in the biogeochemical cycling and its importance of net sequestering of atmospheric CO_2 in the continental shelf waters. The main results are as follows:

1. In the continental shelf waters of South China Sea, *Trichodesmium* mostly appeared in single trichome. Three species were identified, and they were *Trichodesmium thiebautii*, *Trichodesmium hildebrandtii* and *Trichodesmium erythraeum*.

2. In the surface waters of eastern Beibu Gulf, *Trichodesmium* was most abundant in spring, with the average density of 274 trichome L^{-1} (range: 0-3,510 trichome L^{-1}). In autumn, *Trichodesmium* density was 50 trichome L^{-1} (range: 0-212 trichome L^{-1}). And its densities were 29 (range: 0-196 trichome L^{-1}) and 29 (range: 0-356 trichome L^{-1}) trichome L^{-1} in summer and in winter, respectively. In the surface

waters of continental shelf of northern South China Sea, *Trichodesmium* density was 118 trichome L^{-1} (range: 0-670 trichome L^{-1}) in spring and 241trichome L^{-1} (range: 0-2,797 trichome L^{-1}) in summer.

3. In the surface waters of eastern Beibu Gulf, the horizontal distribution of *Trichodesmium* abundance was related with nitrate and nitrite, SRP concentrations (which changed in the same trend). Low *Trichodesmium* abundance was observed in the areas with high nitrate and nitrite, SRP concentrations. And high *Trichodesmium* abundance mainly distributed in those areas with low nitrate and nitrite, SRP concentrations. In the continental shelf waters of north South China Sea, the nutrient are relative rich in the Zhujiang estuary and upwelling area along Qiongdong coast, where *Trichodesmium* abundance was low. By contrast, *Trichodesmium* was more abundant in the anticyclonic eddy (19° N, 112° E) where nutrient concentrations were especially low.

4. In the eastern Beibu Gulf, *Trichodesmium* abundance was highest at 1 m depth for those stations with relative high *Trichodesmium* densities (10^2 trichome L^{-1} in one or several water layers). A surface maximum of *Trichodesmium* density at 1 m depth was evident on all four cruises, which was different from the distribution pattern of *Trichodesmium* in the oceans (a subsurface maximum at 10-40 m). Light might be the main controlling factor of the vertical distribution of *Trichodesmium*. Besides, nitrate and nitrite concentrations also regulated *Trichodesmium* vertical distribution. High density of *Trichodesmium* appeared in the water layer with low nitrate and nitrite concentrations. At some stations, relative abundant (10-10^2 trichome L^{-1}) *Trichodesmium* was found below 50 m depth. The SRP concentrations were usually low at these stations, thus this vertical distribution pattern of *Trichodesmium* was probably related with the acquisition of SRP.

5. In the surface waters of eastern Beibu Gulf, the nitrogen fixation rate by *Trichodesmium* was about 52-4,083 pg N L^{-1} h^{-1} in spring. And the rate was