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厦门大学

硕 士 学 位 论 文

长江口及东海陆架区微型鞭毛虫的分布与多样性研究

Study on the distribution and diversity of nanoflagellate in the Yangtze estuary and continental shelf of East China Sea

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中文摘要

本研究应用荧光显微技术、荧光标记颗粒示踪法以及 Illumina 高通量测序技术，分别于 2013 年春季、2013 年夏季和 2013 年秋季开展了对长江口及东海陆架区微型鞭毛虫的丰度分布、异养细菌的摄食和群落多样性的研究，并初步探讨了影响微型鞭毛虫分布、摄食和群落多样性的因素。主要结果如下：

（1）长江口及东海陆架区微型鞭毛虫的丰度变化范围为 0.41-7.15×10^3 cells ml^{-1}，微型鞭毛虫丰度的最高值出现在夏季，最低值出现在秋季，表现出明显的季节变化特征。基于丰度比得出的微型鞭毛虫营养结构也有着典型的季节特点：春季微型鞭毛虫以含色素体微型鞭毛虫（PNF）为主；夏季和秋季微型鞭毛虫以异养微型鞭毛虫（HNF）为主。从粒径结构上来看，2-5 μm 粒级范围的微型鞭毛虫占主要优势,其在微型鞭毛虫中所占比例超过 65%。

（2）在不同季节，微型鞭毛虫在近岸区和陆架区的丰度分布有所不同。在春季，表层微型鞭毛虫在近岸区的丰度分布远远高于陆架区，特别是舟山和长江口以北的近岸海域，是微型鞭毛虫丰度的典型高值区。随着离岸距离的增加，微型鞭毛虫的丰度逐渐降低，说明春季表层微型鞭毛虫的分布受到陆地径流的影响较大。而春季底层微型鞭毛虫的分布则相反，其高值区位于水深 40-70 m 左右的陆架区，这与底层异养细菌的分布较为吻合，说明春季底层微型鞭毛虫的丰度分布可能都受到食物浓度的影响。在夏季，无论是表层还是底层，微型鞭毛虫的丰度分布受长江冲淡水的作用明显，长江口流域是典型的丰度高值区。而在其他调查区域微型鞭毛虫的丰度分布相对均匀。在秋季，表层微型鞭毛虫呈斑块状分布，在近岸区和陆架区都有较高的分布，可能是秋季东海陆架区受到较强的风海流的影响。而秋季底层微型鞭毛虫主要分布在水深 50 m 左右的陆架区，这与底层异养细菌的分布相吻合，说明秋季底层微型鞭毛虫的分布主要受食物浓度的影响。

（3）HNF 对异养细菌摄食率的变化范围为 0.92-47.97 cells HNF^{-1} h^{-1}，PNF 对异养细菌摄食率的变化范围为 0.88-43.60 cells PNF^{-1} h^{-1}。HNF 和 PNF 对异养细菌的摄食率在夏季最高，其次是春季，秋季最低。微型鞭毛虫对异养细菌摄食率的分布在表层和底层比较一致，其摄食率的高值区在春季和秋季位于水深 30-70 m 的陆架区，而夏季则位于长江口以北的近岸区。从粒级结构来看，在 HNF 中，2-5 μm 粒级范围的 HNF 是异养细菌的主要摄食者；在 PNF 中，2-5 μm、 5-10 μm 和 10-20 μm 粒级范围的 PNF 对异养细菌摄食率的贡献相当。

（4）统计结果显示，不同季节微型鞭毛虫对异养细菌的摄食率主要与食物浓度有关（$P<0.01$），而其他理化因子可能会通过影响食物浓度间接影响其摄食率。通过 Gasol 模型的分析表明，春季和夏季表层 HNF 主要受下行调控影响，而秋季表层 HNF 主要受上行调控影响；底层 HNF 更偏向于受下行调控影响。

（5）长江口及东海陆架区微型鞭毛虫的群落多样性在夏季（5.28）和秋季（5.35）较高，春季（4.21）相对较低。与表层样品相比，底层样品微型鞭毛虫群落的多样性较高。春季微型鞭毛虫群落在近岸区有较高的多样性，随着离岸距离的增加，多样性逐渐降低；而秋季则相反，其多样性在陆架区较高，随着离岸距离的增加，多样性逐渐上升。夏季航次微型鞭毛虫的多样性普遍较高，分布相对均匀。

（6）长江口及东海陆架区微型鞭毛虫群落在春季、夏季和秋季都是以囊泡虫类为主，其在微型鞭毛虫中所占比例超过 65%。囊泡虫中又以多甲藻和卵甲藻为主要优势种。而异鞭类、原始色素体生物、隐藻和后鞭毛生物等在东海微型生物群落中所占比例不超过 10%。此外，还有一部分是无法归类的物种，其所占比例为 6.91%-23.51%。统计分析的结果显示，春季微型鞭毛虫群落多样性与食物有极显著的相关性（$P<0.01$）；夏季除了食物的影响，还与其自身丰度有一定关系；秋季微型鞭毛虫群落多样性受理化因子和自身丰度的影响（$P<0.05$）。

关键词：微型鞭毛虫；长江口；东海；分布；多样性；摄食

Abstract

We carried out ecological studies on nanoflagellate(NF) in the Yangtze estuary and continental shelf of East China Sea. Through the use of the fluorescent microscope technique, fluorescent dye particle tracer method and illumina high-throughput sequencing, we investigated the spatial and temporal distributions, the grazing on heterotrophc bacteria and the community structure and diversity of nanoflagellates in spring 2013, summer 2013 and autumn 2013. Meanwhile, the relation between nanoflagellate and environmental factors also studied in the present study. The main results were as follows:

(1) The total abundance of NF in three investigated seasons of the Yangtze estuary and continental shelf of East China Sea ranged from $0.41\text{-}7.15\times10^{3}$ cells ml^{-1}, within which, the highest abundance was found in summer, while the lowest in autumn. The abundance-based trophic structure of NF showed that the proportion of HNF to total NF abundance was larger than PNF proportion in summer and autumn, but less in spring. The NF community in our study was dominated by 2-5 μm NF, which accounted for more than 65% of total NF abundance in our study.

(2) The distribution of NF was different between the nearshore and continental shelf zone. In spring, the abundance of NF in the surface layer of the nearshore zone was higher than that of the continental shelf zone. The abundance of NF decreased gradually with the increase in distance from the shore. It seemed that the NF was influenced by the runoff. On the contrary, the abundance of NF in the bottom layer displayed an opposite trend. The abundance of NF in the continental shelf zone was higher than the nearshore zone. In summer, NF were significantly affected by the Yangtze River Diluted Water, and the highest abundance of NF was found in the Yangtze estuary. The situation in autumn was similar to spring, but the distribution of NF in the surface layer was more complicated. The highest abundance of NF was found both the nearshore and offshore zone which was caused by the ocean current.

(3) The grazing rate of HNF and PNF on heterotrophic bacteria ranged from 0.92-47.97 cells HNF^{-1} h^{-1} and 0.88-43.60 cells PNF^{-1} h^{-1}, respectively. The highest

grazing rate of NF community on the heterotrophic bacteria was found in summer, while the lowest in autumn. We also found that the grazing rate of NF community in the continental shelf zone was higher than the nearshore zone in spring and autumn. In summer, a higher grazing rate of NF community was found in the north of the Yangtze estuary. By comparing the grazing rate of NF with different size, we found that the size 2-5 μm HNF played a major role on grazing hterotrophic bacteria, while in PNF, the 2-5 μm, 5-10 μm and 10-20 μm size class contributed comparatively to the grazing of PNF.

(4) The concentration of food should be the key factor which effected the grazing of NF ($p<0.01$). Physical and chemical factors may have an affect on the grazing of NF by impacting the concentration of food. The results of Gasol's model showed a top-down control in the surface layer of spring and summer,while a bottom-up control in the surface layer of autumn.

(5) The diversity of NF community was higher in summer(5.28)and autumn(5.35) than spring(4.21). The bottom samples had higher diversity than surface ones. Generally, the diversity of NF community varied among different seasons. The diversity of NF community was higher in the nearshore zone than the offshore zone in the spring. The diversity of NF community decreased gradually with the increase in distance from the shore. However, a opposite tendency was found in the autumn. The diversity was higher in the offshore zone and lower in the nearshore zone. In summer, the relatively homogeneous distributions of the diversity of NF community were found in investigating area.

(6) Alveolate, especially *Peridiniphycidae* and *Amyloodinium*, dominated NF community during the study period. It accounted for more than 65% of NF community, while the proportion of Stramenopiles, Archaeplastida, Cryptophyceae and Opisthokonta of NF community were less than 10%. In addition, the percentage of unclassified information ranged from 6.91% to 23.51%. In spring, the diversity of NF community was highly significant related to the concentration of food($p<0.01$). In summer, except the food concentration, we found some correlation between diversity

and the abundance of NF. In autumn, the diversity of NF community was found to be significant related to physical and chemical factors and the abundance of NF ($p<0.05$).

Key Words: nanoflagellate; Yangtze estuary; East China Sea; distribution; diversity; grazing