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廈門大學

硕士学位论文

亚热带潮间带底栖微藻群落组成和
初级生产力的时空变化及其调控机制

**Spatial and temporal distribution of microphytobenthic
composition and primary production and their controlling
factors in subtropical intertidal areas**

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缩略词表

缩略词	英文名称	中文名称
Chl <i>a</i>	Chlorophyll <i>a</i>	叶绿素 <i>a</i>
Fuco	Fucoxanthin	岩藻黄素
Diadino	Diadinoxanthin	硅甲藻黄素
Diato	Diatoxanthin	硅藻黄素
Zea	Zeaxanthin	玉米黄素
Allo	Alloxanthin	别藻黄素
Peri	Peridinin	多甲藻素
Chl <i>c2+c1</i>	Chlorophyll <i>c2+c1</i>	叶绿素 <i>c2+c1</i>
Chl <i>b</i>	Chlorophyll <i>b</i>	叶绿素 <i>b</i>
Lut	Lutein	叶黄素
β -car	β -carotene	β 胡萝卜素
Neo	Neoxanthin	新黄素
DIN	Dissolved inorganic nitrogen	溶解态无机氮
DIP	Dissolved inorganic phosphorus	溶解态无机磷
HPLC	High performance liquid chromatography	高效液相色谱
GPP	Gross primary production	总初级生产力
R	Respiration	呼吸
NCP	Net community production	净群落生产力

摘要

作为近岸潮间带中最主要的初级生产者,底栖微藻是滩涂初级生产力的主要贡献者。对底栖微藻初级生产力及其调控机制的研究,主要集中于中纬度温带地区,而对亚热带生态系统的研究则较少。本论文针对“亚热带潮间带底栖微藻初级生产力及其调控因子”这一科学问题,于2014年5月至2016年3月,分别于厦门湾、漳江河口区及漳江口红树林保护区,应用显微镜、高效液相色谱及红外气体分析仪,研究了潮间带不同类型的光滩底栖微藻种类组成、光合色素组成及初级生产力的时空分布特征,同时探讨了影响底栖微藻群落组成和初级生产力分布变化的环境因子,初步分析了不同潮间带底质滩涂底栖微藻初级生产力,并初步估算了底栖微藻对群落净生产的贡献,结果主要如下:

1. 底栖微藻中硅藻为主要优势类群,显微镜下检出藻类以硅藻门(Bacillariophyta)为主,包括中心纲3个属,羽纹纲16个属;同时还有少量蓝藻门(Cyanophyta)检出,属于颤藻属(*Oscillatoria*)。三个不同采样点各个季节的优势类群不尽相同,但主要的优势类群都包括硅藻门布纹藻属(*Gyrosigma*)、斜纹藻属(*Pleurosigma*)、舟形藻属(*Navicula*),颤藻只在个别季节出现。三个不同的采样点均为春夏季节的藻类多样性要大于秋冬季节。

2. 表层沉积样品中共检测出12种底栖微藻光合色素,生物量具有明显的季节变化,主要表现为冬春季节较高,夏秋季节相对较低,主要底栖类群的代表色素也有类似的变化趋势。PCA分析显示主要色素包括Chl *a*、Fuco、Chl *b*、 β -Carotene和Chl *c1+c2*,平均Chl *a*浓度在三个站点之间无显著差异,但Fuco、Chl *b*、 β -Carotene和Chl *c1+c2*在站位间显示出平均浓度的差异,其中Chl *b*和 β -Carotene还表现出显著的年际间差异。厦门湾区底栖微藻色素组成主要受营养盐、温度、降雨量和盐度的影响,漳江河口区受氮磷比和降雨量的影响,而漳江红树林区受降雨量和温度的影响,可以发现不同地点调控因素不同,但底栖微藻组成都受到环境因素的影响。

3. 三个研究区域底栖微藻总初级生产力分别为厦门湾 $0.27\sim 4.31 \text{ mg C m}^{-2} \text{ h}^{-1}$,河口区 $0.36\sim 9.84 \text{ mg C m}^{-2} \text{ h}^{-1}$,红树林区滩涂 $0.11\sim 4.03 \text{ mg C m}^{-2} \text{ h}^{-1}$;三个研究区域群落呼吸的变化范围分别是厦门湾 $0.056\sim 6.85 \text{ mg C m}^{-2} \text{ h}^{-1}$ 、河口区

0.17~4.06 mg C m⁻² h⁻¹ 及红树林区滩涂 0.96~4.37 mg C m⁻² h⁻¹；净群落生产力在三个研究区域分别为厦门湾-3.91~5.83 mg C m⁻² h⁻¹、河口区-9.62~0.53 mg C m⁻² h⁻¹ 及红树林区滩涂-2.80~3.19 mg C m⁻² h⁻¹。

4. 影响底栖微藻光合作用不同过程的主要因素不同地点不尽相同。总初级生产力在不同类型潮间带间无显著差异，与 Chl *a* 浓度的情况是一致，呼吸和净群落生产力在不同点间的差异也很显著，而多因素方差分析显示总初级生产力，呼吸和净群落生产力在季节间的差异很大。厦门湾总初级生产力主要受到色素组成、DIN、氮磷比、温度和光照的影响，呼吸则受到色素组成、营养盐、降雨量、风速和温度的影响，净群落生产力同样受到色素组成、营养盐、降雨量和温度的影响，同时光照和生物量也有一定的作用。漳江河口区总初级生产力受温度和 pH 的影响而呼吸主要受色素组成和温度控制，净群落生产力受色素组成、温度和 pH 的影响。红树林区总初级生产力并没有显著的影响因素，而呼吸主要受色素组成、DIP、降雨量、光照和温度的控制，净群落生产力受降雨量、温度和 pH 的影响。可以发现，群落结构对不同过程都有一定的影响，温度、营养盐和降雨量是主要的环境影响因子。本研究发现潮间带 CO₂ 收支的变化在时间(季节)和空间尺度上分别由初级生产和呼吸速率作为主要决定因素，以前的研究仅限于季节变化的决定因素

5. 通过模型初步估算可得，厦门湾滩涂的总初级生产力为 7506.387 mg C m⁻² yr⁻¹，漳江河口区为 8735.928 mg C m⁻² yr⁻¹，漳江口红树林区为 7428.954 mg C m⁻² yr⁻¹，虽然在调查期间三个区域大部分时间内都呈现一个异养(CO₂ 源)的状态，但如果没有底栖微藻的固碳(碳汇)贡献，释放进入大气的 CO₂ 将十分可观，因此滩涂底栖微藻的固碳能力值得继续深入探究。

关键词：潮间带；底栖微藻；光合色素；群落组成；初级生产力；固碳潜力

Abstract

As the main primary producer, microphytobenthos contribute greatly to the benthic primary production. Research on microphytobenthic primary production and its regulating factors were mainly done in temperate areas, while little is known in subtropical areas. This thesis aims at “Distribution and regulatory factors of microphytobenthic primary production in subtropical areas”. Spatial and temporal distribution of microphytobenthic pigments, composition and primary production were studied in the intertidal zone of Xiamen Bay, Zhangjiang Estuary and Zhangjiang Mangrove from May 2014 to March 2016, using microscopy, high performance liquid chromatography (HPLC) and infrared gas analyzer. The regulatory factors affecting microphytobenthic structure composition and distribution of primary production were also discussed, primary production under different sampling sites and balance of CO₂ were preliminarily analysed and illustrated. The main results were as followed:

1. Bacillariophyta were the main dominant species in benthic environment, which was also observed under microscopy, belonging to Centricae (3 genus) and Pennatae (16 genus), *Cyanophyta* were also observed, belong to *Oscillatoria*. The dominant species in different study sites were not all the same, but *Gyrosigma*, *Pleurosigma*, *Navicula* were predominant in all three sites, *Oscillatoria* was seen in certain seasons. Benthic diversity was high in summer than in winter.

2. 12 photosynthetic pigments were identified, biomass showed an apparent seasonal change, high in winter and spring while low in summer and autumn, which is also found in the main photosynthetic pigments. PCA analysis showed the main pigments included Chl *a*, Fuco, Chl *b*, β -Carotene and Chl *c1+c2*. Average Chl *a* was not significantly different in three study sites, but Fuco, Chl *b*, β -Carotene and Chl *c1+c2* were significantly different among different sites, Chl *b*, β -Carotene were even different in different years. The pigments composition in Xiamen Bay were mainly affected by nutrients, temperature, rainfall and salinity, while in Zhangjiang Estury, it

is influenced by N/P and rainfall, and in Zhangjiang Mangrove, rainfall and temperature played the main part. Different regulatory factors were found in different sites, but benthic structure was all affected by environmental factors.

3. The primary production were $0.27\sim 4.31 \text{ mg C m}^{-2} \text{ h}^{-1}$, $0.36\sim 9.84 \text{ mg C m}^{-2} \text{ h}^{-1}$ and $0.11\sim 4.03 \text{ mg C m}^{-2} \text{ h}^{-1}$ in Xiamen Bay, Zhangjiang Estuary and Zhangjiang Mangrove. Respiration were $0.056\sim 6.85 \text{ mg C m}^{-2} \text{ h}^{-1}$ in Xiamen Bay, $0.17\sim 4.06 \text{ mg C m}^{-2} \text{ h}^{-1}$ in Zhangjiang Estuary and $0.96\sim 4.37 \text{ mg C m}^{-2} \text{ h}^{-1}$ in Zhangjiang Mangrove. Net Community production were $-3.91\sim 5.83 \text{ mg C m}^{-2} \text{ h}^{-1}$, $-9.62\sim 0.53 \text{ mg C m}^{-2} \text{ h}^{-1}$ and $-2.80\sim 3.19 \text{ mg C m}^{-2} \text{ h}^{-1}$ in Xiamen Bay, Zhangjiang Estuary and Zhangjiang Mangrove, respectively.

4. The factors influencing different photosynthetic processes were not the same in different study sites. Gross primary production was not significantly different among study sites, which is correspondent with Chl *a*, while net CO₂ flux and respiration were significantly different. PCA analysis showed that primary production, respiration and net CO₂ flux were significantly different among different seasons. In Xiamen Bay, gross primary production were affected by pigments composition, dissolved inorganic carbon, N/P, temperature and irradiance; respiration were affected by pigments composition, nutrient, rainfall, windspeed and temperature; net CO₂ flux was influenced by pigments composition, nutrients, rainfall and temperature, irradiance and Chl *a* also affected net CO₂ flux. In Zhangjiang Estuary, gross primary production was affected by temperature and pH while respiration was controlled by pigments composition and temperature, net CO₂ flux was affected by pigments composition, temperature and pH. In Zhangjiang Mangrove, environmental factors didn't pose effect on gross primary production, however, respiration was affected by pigments composition, dissolved inorganic phosphate, rainfall, irradiance and temperature, net CO₂ flux was influenced by rainfall, temperature and pH. It can be inferred that pigments composition affected all the photosynthetic processes, temperature, nutrients and rainfall were the main regulatory factors.

5. Estimating gross primary production by modelling, the final results were $7506.387 \text{ mg C m}^{-2} \text{ yr}^{-1}$ in Xiamen Bay, $8735.928 \text{ mg C m}^{-2} \text{ yr}^{-1}$ in Zhangjiang

Estuary and $7428.954 \text{ mg C m}^{-2} \text{ yr}^{-1}$ in Zhangjiang Mangrove. In most of our study period, three study sites were heterotrophic, if without the contribution of microphytobenthos, CO_2 releasing into the atmosphere would be considerable, thus the capacity of carbon fixation for intertidal areas worth further investigation.

Key Words: Intertidal areas; Microphytobenthos; Photosynthetic pigments; Community composition; Primary production; Carbon fixation.

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第 1 章 绪 论

工业革命时期以来,由于受到经济利益的驱使,人类排放出大量的温室气体,这导致了 CO₂、甲烷等气体的浓度逐步升高,远高于过去八十万年的水平(Pachauri, *et al.*, 2014)。CO₂ 浓度上升引起的温室效应导致全球变暖及海平面上升等一系列问题,对居住在沿海及海岛上,占世界人口比例很大部分的居民生活造成了直接而重大的影响。

根据 2013《中国温室气体公报》,2013 年青海瓦里关全球大气本底站监测的二氧化碳、甲烷和氧化亚氮 3 种主要温室气体年平均浓度分别升至 397.3 ppm(ppm 为浓度单位,即每百万个干空气气体分子中所含该种气体分子数)、1886 ppb(ppb 为浓度单位,即每十亿个干空气气体分子中所含该种气体分子数)和 326.4 ppb,均创下 1990 年建站以来的新高,与北半球中纬度地区平均浓度大体相当,高于同期全球平均值。2009 年哥本哈根气候大会上,中国做出了碳减排的目标,但作为世界上最大的碳排放总量和增量国家,中国碳减排的国际压力日益增大。

众所周知,海洋是全球最大的 CO₂ 汇(孙云明 & 宋金明, 2002), JGOFS(全球海洋通量联合研究)经过十余年的研究表明,海洋每年大约可从大气吸收人类排放 CO₂ 的 1/3(宋金明, 2011),但是这份研究没有考虑近海生态系统的贡献。近海生态系统一般是指水深小于 200 m 的大陆架区域及其他浅水生态系统,面积占了海洋总面积的 7~8%,初级生产力约占了海洋总初级生产力约 26%(Lalli & Parsons, 1997)。作为近岸浅水生态系统的重要组成部分,海陆交汇区的潮间带与相邻的海洋相比,其初级生产力十分可观(Ansell, *et al.*, 1999),而生活在潮间带表层的底栖微藻,作为主要的初级生产者,对潮间带滩涂乃至近岸浅水生态系统具有十分至关重要的作用(MacIntyre, *et al.*, 1996, Rejil, 2013)。

1.1 潮间带生态系统的意义

根据冯士筌, *et al.* (1999)定义,潮间带是指在大潮期的最高潮和最低潮之间的海岸带,而根据潮汐涨、落时,海岸带露出水面得到情况,可以分为潮上带(平均高潮线至特大高潮线之间)、潮间带(平均高、低潮之间)和潮下带(平均低潮线之下)。由于潮间带是水圈、岩石圈、大气圈、生物圈四圈交汇共同作用的地带,

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