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廈門大學

硕士学位论文

九龙江口秋茄红树林土壤-大气温室气体  
通量随植被恢复变化的研究

Studies on Changes in Atmospheric Greenhouse Gas Fluxes  
from Soils of *Kandelia obovata* Mangrove Forests with the  
Development of Restored Vegetation in Jiulong River  
Estuary

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## 目 录

摘要.....	VII
Abstract.....	IX
表索引.....	XI
Table index.....	XII
图索引.....	XIII
Figure index .....	XIV
第 1 章 前言 .....	1
1.1 研究背景.....	1
1.2 相关研究进展.....	2
1.2.1 湿地土壤 N <sub>2</sub> O 通量研究进展 .....	2
1.2.2 湿地土壤 CH <sub>4</sub> 通量研究进展.....	5
1.2.3 湿地土壤 CO <sub>2</sub> 通量研究进展.....	9
1.2.4 人工恢复对红树林湿地生态系统影响研究进展.....	11
1.3 研究意义.....	13
1.4 研究目标和研究内容.....	14
第 2 章 九龙江口秋茄红树林土壤-大气温室气体通量的滩位变化和 日变化.....	15
2.1 样地概况.....	15
2.2 样品的采集与分析.....	16
2.2.1 气体样品.....	16
2.2.2 土壤样品.....	17
2.2.3 数据处理与统计分析.....	17
2.3 结果.....	18
2.3.1 大潮日红树林土壤温室气体通量日变化.....	18
2.3.2 小潮日红树林土壤温室气体通量日变化.....	20

2.3.3	土壤参数日变化及其对红树林土壤温室气体通量的影响.....	22
2.4	讨论.....	29
<b>第 3 章 九龙江口秋茄红树林土壤-大气温室气体通量随植被恢复的变化.....</b>		<b>32</b>
3.1	样地概况.....	32
3.2	样品的采集与分析.....	33
3.2.1	气体样品.....	33
3.2.2	数据处理与统计分析.....	34
3.3	结果.....	34
3.3.1	N <sub>2</sub> O 通量随植被恢复时间变化.....	34
3.3.2	CH <sub>4</sub> 通量随植被恢复时间变化.....	37
3.3.3	CO <sub>2</sub> 通量随植被恢复时间变化.....	38
3.3.4	CO <sub>2</sub> 当量通量随植被恢复时间变化.....	40
3.4	讨论.....	42
<b>第 4 章 九龙江口秋茄红树林土壤理化性质对土壤-大气温室气体通量的影响.....</b>		<b>48</b>
4.1	样地概况.....	48
4.2	样品的采集与分析.....	48
4.2.1	土壤样品.....	48
4.2.2	数据处理与统计分析.....	49
4.3	结果.....	49
4.3.1	土壤 Eh、含水率和 pH.....	49
4.3.2	土壤无机氮含量.....	51
4.3.3	土壤有机碳、总氮、总磷含量以及碳氮比.....	53
4.3.4	土壤理化性质与土壤-大气温室气体通量的相关性.....	57
4.4	讨论.....	57
<b>第 5 章 总结.....</b>		<b>62</b>

5.1 主要结论 .....	62
5.2 创新点 .....	63
5.3 不足与展望 .....	64
参考文献 .....	65
附录 .....	80
致谢 .....	81

厦门大学博硕士学位论文摘要库

Contents

Abstract in Chinese.....	VII
Abstract in English.....	IX
Table Index in Chinese.....	XI
Table Index in English.....	XII
Figure Index in Chinese.....	XIII
Figure Index in English.....	XIV
Chapter 1 Preface.....	1
1.1 Background.....	1
1.2 Study Progress on Greenhouse Gas Fluxes from Wetland Soils.....	2
1.2.1 CO <sub>2</sub> Fluxes from Wetland Soils.....	2
1.2.2 CH <sub>4</sub> Fluxes from Wetland Soils.....	5
1.2.3 N <sub>2</sub> O Fluxes from Wetland Soils.....	9
1.2.4 Impacts of Vegetation Restoration on Mangrove Ecosystems.....	11
1.3 Importance of the Present Study.....	13
1.4 Purposes and Main Contents of the Present Study.....	14
Chapter 2 Spatial and Diurnal Variations of Greenhouse Gas Fluxes from <i>Kandelia obovata</i> Mangrove Soils in Jiulong River Estuary.....	15
2.1 Study Sites.....	15
2.2 Samplings and Analyses.....	16
2.2.1 Gas Sampling.....	16
2.2.2 Soil Sampling.....	17
2.2.3 Data Processing and Statistic Analysis.....	17
2.3 Results.....	18
2.3.1 Spatial and Diurnal Variations of Greenhouse Gas Fluxes from Mangrove Soils on a Spring Day.....	18

2.3.2	Spatial and Diurnal Variations of Greenhouse Gas Fluxes from Mangrove Soils on a Neap Day .....	20
2.3.3	Spatial and Diurnal Variations of Environmental Factors and their Effects on Greenhouse Gas Fluxes from Mangrove Soils .....	22
2.4	Discussion .....	29
 Chapter 3 Variations of Greenhouse Gas Fluxes from Soils of <i>Kandelia obovata</i> Mangrove Forests with the Development of Restored Vegetation in Jiulong River Estuary.....		
3.1	Study Sites .....	32
3.2	Samplings and Analyses .....	33
3.2.1	Gas Sampling .....	33
3.2.2	Data Processing and Statistic Analysis .....	34
3.3	Results .....	34
3.3.1	N <sub>2</sub> O Fluxes.....	34
3.3.2	CH <sub>4</sub> Fluxes .....	37
3.3.3	CO <sub>2</sub> Fluxes .....	38
3.3.4	CO <sub>2</sub> -equivalent Fluxes .....	40
3.4	Discussion .....	42
 Chapter 4 Effects of Soil Properties on Greenhouse Gas Fluxes from Mangrove Soils .....		
4.1	Study Sites .....	48
4.2	Samplings and Analyses .....	48
4.2.1	Soil Sampling.....	48
4.2.2	Data Processing and Statistic Analysis .....	49
4.3	Results .....	49
4.3.1	Eh, Water Content and pH .....	49
4.3.2	Inorganic Nitrogen Contents.....	51
4.3.3	Organic Carbon, Total Nitrogen and Total Phosphorus Contents and	



Ratio of C and N .....	53
4.3.4 Correlations between Greenhouse Gas Fluxes and Soil Parameters . .....	57
4.4 Discussion .....	57
Chapter 5 Summary .....	62
5.1 General Conclusion .....	62
5.2 Innovation.....	63
5.3 Deficiency and Outlook.....	64
References.....	65
Appendix.....	80
Acknowledgements.....	81

## 摘 要

选取福建九龙江口南岸浮宫镇霞郭村秋茄红树林研究断面, 研究夏季白天的一个潮汐周期内未被潮水浸没时红树林土壤 3 种温室气体 ( $\text{N}_2\text{O}$ 、 $\text{CH}_4$  和  $\text{CO}_2$ ) 通量变化情况, 探究滩位和潮汐日变化对该地区红树林土壤大气界面温室气体通量的影响。在此基础上, 以光滩为对照和恢复的起点, 再选取 26 年生和 50 年生的人工秋茄红树林以及天然成熟林代表不同恢复阶段, 探讨不同植被恢复阶段红树林土壤-大气界面这 3 种温室气体通量随植被恢复时间的关系, 并分析植被恢复导致的土壤环境变化对温室气体通量的影响, 为人工红树林的功能恢复提供参考依据。

夏季大潮日和小潮日白天的潮汐周期内 3 种温室气体通量的滩位变化研究结果显示, 大潮日红树林土壤这 3 种温室气体通量均没有显著的滩位差异, 小潮日  $\text{N}_2\text{O}$ 、 $\text{CH}_4$  通量也没有显著的滩位差异, 但  $\text{CO}_2$  通量却表现出从陆向海降低的趋势。3 种温室气体通量在小潮日的潮汐周期内日变化特征不显著, 且  $\text{N}_2\text{O}$  和  $\text{CH}_4$  通量在大潮日和小潮日没有显著差异。土壤温度是影响红树林土壤温室气体通量日变化的重要因素。

不同恢复阶段红树林 3 种温室气体通量研究显示,  $\text{N}_2\text{O}$  年均通量范围为  $0.17\sim 0.76 \mu\text{mol m}^{-2} \text{h}^{-1}$ ,  $\text{CH}_4$  年均通量范围为  $4.52\sim 73.27 \mu\text{mol m}^{-2} \text{h}^{-1}$ ,  $\text{CO}_2$  年均通量范围为  $-0.22\sim 4.35 \text{mmol m}^{-2} \text{h}^{-1}$ ,  $\text{N}_2\text{O}$ 、 $\text{CH}_4$  和  $\text{CO}_2$  通量均表现出显著的季节差异, 总体上为夏季高、冬季低。3 种温室气体通量均表现出随植被恢复的差异,  $\text{CO}_2$  和  $\text{CH}_4$  通量表现出随植被恢复时间的延长而增加的趋势, 而  $\text{N}_2\text{O}$  通量则表现出植被恢复的初期较低, 随着植被恢复时间的延长而增加的趋势。根据不同温室气体的增温潜势, 将九龙江口红树林湿地土壤 3 种温室气体通量换算得到总的  $\text{CO}_2$  当量, 其年均通量为  $124.32 \text{mg CO}_2 \text{m}^{-2} \text{h}^{-1}$ , 其中  $\text{CO}_2$  是最主要的贡献气体, 且总  $\text{CO}_2$  当量通量也表现出随着植被恢复时间的延长而增加的趋势。

不同恢复阶段红树林土壤理化性质研究结果表明, 土壤 Eh、含水率、pH、氨态氮、硝态氮、有机碳、总氮、总磷和碳氮比等指标中, 除总氮含量外均表现出显著的季节变化动态。红树林植被恢复对土壤各理化指标有显著的影响, 其中氨态氮表现为在植被恢复后含量下降, 而随着植被恢复时间的延长, 氨态氮含量

增加，pH 表现为随植被恢复时间的延长而下降，有机碳和总氮含量以及碳氮比表现出随着植被恢复时间的延长而增加。通过对土壤理化性质与 3 种温室气体通量的相关性分析，发现红树林植被恢复进程对土壤  $\text{N}_2\text{O}$  通量的影响是由于土壤氨态氮含量的变化而造成的，而对  $\text{CH}_4$  和  $\text{CO}_2$  通量的影响则主要由于土壤有机碳和总氮含量的变化而造成的。

总之，随着秋茄植被的恢复，土壤理化性质发生变化，从而导致红树林土壤-大气界面温室气体通量的变化。

**关键词：**河口；红树林；温室气体通量；植被发育

## Abstract

In order to understand the spatial and diurnal variations of greenhouse gas fluxes from mangrove soils, the fluxes of N<sub>2</sub>O, CH<sub>4</sub> and CO<sub>2</sub> were measured in one *Kandelia obovata* mangrove forest in Jiulong River estuary, China, when mangrove soils were exposed to air during one tidal cycle on spring or neap day in summer. Based on that study, effect of age of restored mangrove forests on the atmospheric greenhouse gas fluxes from soils were investigated, choosing one bare flat (K0), one 26-year old restored forest (K26) and one 50-year old restored mangrove forest (K50) as well as one natural mature forest (MF) as representative forests. Seasonal variations of greenhouse gas fluxes and soil parameters from all these mangrove forests with different ages were measured. The correlation relationships between greenhouse gas fluxes and soil parameters were tested in order to understand the variation of greenhouse gas fluxes with the development of restored mangrove forests.

There were no significant differences in the fluxes of N<sub>2</sub>O, CH<sub>4</sub> and CO<sub>2</sub> from different study sites (inner site and outer site) in the present mangrove forest during the spring day of summer. It was the same for the fluxes of N<sub>2</sub>O and CH<sub>4</sub> during the neap day, while CO<sub>2</sub> showed significantly higher fluxes at the inner site than the outer site. Significantly diurnal variations of fluxes of the three greenhouse gases in one tidal cycle were not found during the neap day. Moreover, the average fluxes of N<sub>2</sub>O and CH<sub>4</sub> were similar between spring and neap days, while fluxes of CO<sub>2</sub> were a little higher on neap day than on spring day. The soil temperature and inorganic nitrogen contents were important factors that affect the diurnal variations of the greenhouse gas fluxes.

As for the effect of age of restored mangrove forests on the fluxes of atmospheric greenhouse gases from soils, annual fluxes of N<sub>2</sub>O, CH<sub>4</sub> and CO<sub>2</sub> ranged from 0.17 to 0.76  $\mu\text{mol m}^{-2} \text{h}^{-1}$ , 4.52 to 73.27  $\mu\text{mol m}^{-2} \text{h}^{-1}$  and -0.22 to 4.35  $\text{mmol m}^{-2} \text{h}^{-1}$ , respectively. Fluxes of the three greenhouse gases differed significantly among sampling seasons, as well as among restored forests with different ages. In general,

fluxes of the three greenhouse gases were highest in summer and lowest in winter. Meanwhile, fluxes of CH<sub>4</sub> and CO<sub>2</sub> increased with the development of restored forests, but fluxes of N<sub>2</sub>O from soils firstly decreased after the replanting of vegetation and then increased with the later development of vegetation. Total CO<sub>2</sub>-equivalent fluxes of the three gases from soils of restored forests with different ages, indicating their global warming potential, ranged from 82.33 to 674.92 mg CO<sub>2</sub> m<sup>-2</sup> h<sup>-1</sup>, and CO<sub>2</sub> was the most dominant in the total flux in all mangrove forests. Therefore, total CO<sub>2</sub>-equivalent fluxes also increased with the development of restored forests.

Soils were also sampled after the sampling of greenhouse gases. Soil parameters of Eh, water content, pH, ammonia nitrogen, nitrate nitrogen, organic carbon, total nitrogen, total phosphorus and ratio of carbon and nitrogen were analyzed. All soil parameters showed significant differences among sampling seasons, while soil total nitrogen was an exception. Significant variations of soil parameters among restored forests with different ages were found though different soil parameters showed different variation patterns. Soil ammonia nitrogen contents firstly decreased after the replanting of vegetation and then increased with the later development of vegetation, like the variation of N<sub>2</sub>O fluxes. The value of soil pH decreased with the development of vegetation, while soil organic carbon content, total nitrogen content and ratio of carbon and nitrogen increased with the development of vegetation. Furthermore, fluxes of N<sub>2</sub>O among restored forests with different ages were significantly correlated with the contents of soil ammonia nitrogen, while fluxes of CH<sub>4</sub> and CO<sub>2</sub> were significantly correlated with the contents of soil organic carbon and total nitrogen.

As a summary, with the development of restored mangrove forests, soil parameters varied and those soil parameters were vital factors that caused the variations of greenhouse gas fluxes from mangrove soils.

**Key Words:** Estuary; Mangrove forests; Greenhouse gas fluxes; Restoration

## 表索引

表 2-1 大潮日滩位和时间对红树林土壤温室气体通量影响的双因素方差分析	20
表 2-2 小潮日滩位和时间对红树林土壤温室气体通量影响的双因素方差分析	22
表 2-3 大潮日和小潮日土壤温室气体通量配对 t 检验	22
表 2-4 大潮日和小潮日滩位和时间对红树林土壤无机氮含量以及 Eh 影响的双因素方差分析	28
表 2-5 大潮日和小潮日红树林土壤温室气体通量与土壤指标相关性分析	29
表 3-1 各植被恢复时间秋茄红树林样地群落参数	33
表 3-2 季节和植被恢复时间对红树林土壤温室气体通量影响的双因素方差分析	36
表 3-3 红树林土壤温室气体年均通量的 CO <sub>2</sub> 当量通量	41
表 3-4 不同地区红树林土壤 N <sub>2</sub> O、CH <sub>4</sub> 和 CO <sub>2</sub> 通量	43
表 3-5 九龙江口不同植被恢复时间秋茄红树林生态系统净 C 总量估算	45
表 4-1 季节和植被恢复时间对土壤 Eh、含水率以及 pH 影响的双因素方差分析	51
表 4-2 季节和植被恢复时间对土壤无机氮含量影响的双因素方差分析	53
表 4-3 季节和植被恢复时间对土壤有机碳、总氮和总磷含量以及碳氮比影响的双因素方差分析	56
表 4-4 不同植被恢复时间秋茄红树林土壤温室气体通量与土壤理化性质相关性分析	57

## Table index

Table 2-1 Two-way ANOVA for effects of spatial site (S) and time (T) on atmospheric greenhouse gas fluxes from mangrove soils on a spring day.....	20
Table 2-2 Two-way ANOVA for effects of spatial site (S) and time (T) on atmospheric greenhouse gas fluxes from mangrove soils on a neap day .....	22
Table 2-3 Paired sample t tests on atmospheric greenhouse gas fluxes from mangrove soils on the spring and neap day .....	22
Table 2-4 Two-way ANOVA for effects of spatial site (S) and time (T) on soil $\text{NO}_3^-$ -N, $\text{NH}_4^+$ -N contents and Eh on the spring and neap days.....	28
Table 2-5 Pearson correlations between greenhouse gas fluxes and environmental parameters in mangrove soilson the spring and neap days .....	29
Table 3-2 Two-way ANOVA for effects of season (S) and restored age of mangrove forest (A) on soil fluxes of greenhouse gases .....	36
Table 3-3 Annual mean $\text{CO}_2$ -equivalent fluxes of the three greenhouse gases from soils of mangrove forests with different ages .....	41
Table 3-1 Community parameters of <i>Kandelia obovata</i> mangrove forests with different ages .....	33
Table 3-4 Soil fluxes of $\text{N}_2\text{O}$ , $\text{CH}_4$ and $\text{CO}_2$ from different mangroves forests .....	43
Table 3-5 Estimation of net C fluxes of mangrove forests with different ages in Jiulong River estuary .....	45
Table 4-1 Two-way ANOVA for effects of season (S) and restored age of mangrove forest (A) on soil Eh, water content (WC) and pH value.....	51
Table 4-2 Two-way ANOVA for effects of season (S) and restored age of mangrove forest (A) on soil $\text{NO}_3^-$ -N and $\text{NH}_4^+$ -N contents .....	53
Table 4-3 Two-way ANOVA for effects of season (S) and restored age of mangrove forest (A) on soil OC, TN and TP contents and C/N .....	56
Table 4-4 Pearson correlations between greenhouse gas fluxes and soil parameters of mangrove forests with different ages .....	57

## 图索引

图 2-1 大潮日土壤 $\text{N}_2\text{O}$ 、 $\text{CH}_4$ 和 $\text{CO}_2$ 通量的滩位变化和日变化 .....	19
图 2-2 小潮日土壤 $\text{N}_2\text{O}$ 、 $\text{CH}_4$ 和 $\text{CO}_2$ 通量的滩位变化和日变化 .....	21
图 2-3 大潮日和小潮日土壤硝态氮含量的滩位变化和日变化 .....	23
图 2-4 大潮日和小潮日土壤氨态氮含量的滩位变化和日变化 .....	24
图 2-5 大潮日和小潮日土壤 Eh 的滩位变化和日变化 .....	25
图 2-6 大潮日和小潮日气温的滩位变化和日变化 .....	26
图 2-7 大潮日和小潮日土温的滩位变化和日变化 .....	27
图 3-1 本研究中九龙江口红树林样地 .....	33
图 3-2 不同植被恢复时间红树林土壤 $\text{N}_2\text{O}$ 通量 .....	35
图 3-3 不同植被恢复时间红树林土壤年均 $\text{N}_2\text{O}$ 通量 .....	36
图 3-4 不同植被恢复时间红树林土壤 $\text{CH}_4$ 通量 .....	37
图 3-5 不同植被恢复时间红树林土壤年均 $\text{CH}_4$ 通量 .....	38
图 3-6 不同被恢复时间红树林土壤 $\text{CO}_2$ 通量 .....	39
图 3-7 不同植被恢复时间红树林土壤年均 $\text{CO}_2$ 通量 .....	40
图 3-8 不同植被恢复时间红树林土壤温室气体通量的 $\text{CO}_2$ 当量通量 .....	41
图 4-1 不同植被恢复时间红树林土壤 Eh .....	50
图 4-2 不同植被恢复时间红树林土壤含水率 .....	50
图 4-3 不同植被恢复时间红树林土壤 pH .....	51
图 4-4 不同植被恢复时间红树林土壤硝态氮含量 .....	52
图 4-5 不同植被恢复时间红树林土壤氨态氮含量 .....	53
图 4-6 不同植被恢复时间红树林土壤有机碳含量 .....	54
图 4-7 不同植被恢复时间红树林土壤总氮含量 .....	55
图 4-8 不同植被恢复时间红树林土壤总磷含量 .....	55
图 4-9 不同植被恢复时间红树林土壤碳氮比 .....	56



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