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博 士 学 位 论 文

九龙江口秋茄红树植被与主要大型底栖动物某些生态关系的研究

Study of certain ecological relationships between *Kandelia candel* vegetation and common macro-benthic fauna in Jiulongjiang Estuary

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摘要

本文采用室内模拟实验和野外控制实验相结合的研究方法，研究秋茄红树林生态恢复过程对大型底栖动物分布和群落结构的影响、大型底栖动物对红树植物叶片的摄食偏好和摄食量，大型底栖动物对秋茄凋落物的去除作用，以及大型底栖动物在摄食红树凋落叶的过程中对红树林土壤的作用。主要研究内容及结果如下：

1. 秋茄红树林人工恢复对大型底栖动物群落的影响

于 2005 年 7 月（夏季）、2005 年 10 月（秋季）、2006 年 1 月（冬季）和 2006 年 4 月（春季），选择福建九龙江口恢复背景相似，林龄分别为 4（K4）、7（K7）、19（K19）和 43 年（K43）的人工秋茄（*Kandelia candel*）林，以及两片光滩（NF1 和 NF2）作为对照，比较不同恢复时间的秋茄红树林内大型底栖动物的分布特征，以研究红树林恢复过程对大型底栖动物群落的影响。秋茄林内大型底栖动物的物种数量大于毗邻光滩内的物种数量，K4、K7 的物种数量大于 K19 和 K43 两片秋茄林内的物种数量。在获得的 22 种大型底栖动物中，弧边招潮（*Uca arcuata*）、秀丽长方蟹（*Metaplax elegans*）、可口革囊星虫（*Phascolosoma esculenta*）和黑口滨螺（*Littoraria melanostoma*）为优势种。不同红树林样地大型底栖动物群落结构也不同：秋茄幼林内的优势种为秀丽长方蟹，而弧边招潮则为光滩和 K19、K43 样地的优势种；腹足动物主要分布在 K4、K7 样地。大型底栖动物中的优势种在秋茄林样地中的分布特征也因恢复时间而不同。弧边招潮在光滩的密度最高，在秋茄林幼林内较少分布。秀丽长方蟹在秋茄幼林内密度较高。可口革囊星虫在恢复时间较长的秋茄林内密度较大，而黑口滨螺则更多分布在秋茄幼林内。考虑到 K19 和 K43 两片秋茄林样地的植被特征和底栖动物群落结构相似，但与 K4 和 K7 不同，认为恢复时间达到 19 年后，秋茄红树林的植被和底栖动物群落的发育趋于稳定。也就是说，从植被特征和底栖动物群落两个方面看，人工秋茄红树林生态系统在种植时间达到 20 年左右其发育可以趋于稳定。

2. 九龙江口红树林内褶痕相手蟹对植物叶片摄食生态研究

通过室内模拟和野外现场实验，比较大型底栖动物中草食性物种褶痕相手蟹（*Sesarma plicata*）对3种红树植物秋茄（*Kandelia candel*）、木榄（*Bruguiera gymnorrhiza*）和桐花树（*Aegiceras corniculatum*）的新鲜、凋落和腐烂叶片的摄食量，得出褶痕相手蟹对红树叶片的摄食偏好。研究结果表明，在实验室模拟条件下，当同时供给相同状态的3种红树叶片，褶痕相手蟹对秋茄叶片具有较强的摄食偏好；对于同一物种但不同状态的红树叶片，褶痕相手蟹对腐烂叶片的摄食偏好强于凋落和新鲜的红树叶片。褶痕相手蟹对秋茄叶片和腐烂叶片的摄食偏好不受螃蟹个体大小的影响。在野外条件下，褶痕相手蟹对腐烂叶片也存在摄食偏好，但对红树种类并未表现出明显的摄食偏好。红树叶片的营养特性影响褶痕相手蟹对不同种类和不同状态叶片的摄食偏好。叶片中较低的单宁含量和较高的含水量是引起相手蟹对腐烂叶片偏好的原因。叶片中的粗纤维含量是影响相手蟹对不同种类间的新鲜或者凋落叶片摄食偏好的最主要因素，而对不同种类的腐烂叶片的摄食偏好则与叶片中的含水率有关。

在实验室非选择性摄食实验中，褶痕相手蟹对 9 种不同叶片的摄食率也不同。对 9 种叶片的平均摄食率分别为 0.101 gDW ind^{-1} d^{-1}（大个体）、0.055 gDW ind^{-1} d^{-1}（中等个体）和 0.017 gDW ind^{-1} d^{-1}（小个体），分别对应研究的 3 种个体大小的螃蟹。在野外红树林中，褶痕相手蟹对 9 种红树叶片的摄食率与实验室条件下接近。

3. 九龙江口秋茄红树林蟹类对凋落叶片去除的季节动态

于2006年5月—2007年4月研究了红树林内的螃蟹对秋茄红树林凋落叶的去除率。九龙江口秋茄红树林每月的凋落叶生产力为 0.85～3.86 gDW m^{-2} d^{-1}，生产力在 5、8、10 和 11 四个月份较高。全年的凋落叶生产力为 6.48 t ha^{-1} a^{-1}（1.81 gDW m^{-2} d^{-1}）。秋茄林内地面现存凋落叶的全年平均生物量为 7.78 gDW m^{-2}，最低出现在 11 月，为 1.23 gDW m^{-2}，最高出现在 4 月，为 16.18 gDW m^{-2}。

秋茄林内螃蟹对凋落叶的全年平均去除率为 0.59 gDW m^{-2} d^{-1}。螃蟹对凋落叶去除率的季节性变化较大。冬季凋落叶的去除率（12 月—2 月）介于 0.07～0.09 gDW m^{-2} d^{-1}，明显低于其他月份（0.59～1.18 gDW m^{-2} d^{-1}）。被螃蟹去除的凋落叶占全年凋落叶生产

力的 33%，凋落叶去除率占凋落叶生产力的比例最高出现在 9 月（76%），最低出现在冬季（12—2 月）。因此推断随潮水输出的凋落叶占全年凋落叶的 67%，为 444.07 gDW m^{-2}。

被螃蟹去除的凋落叶大部分被螃蟹拖至洞穴内并贮存，在地面摄食的叶片只占被去除凋落叶的 12%。凋落叶的去除率、螃蟹对凋落叶的地面摄食率，以及被去除的凋落叶的比例与大气温度呈显著性正相关。

4. 褶痕相手蟹摄食凋落叶对红树林底质特性的影响

通过实验室模拟实验，研究九龙江口秋茄红树林内关键种褶痕相手蟹的活动和摄食行为对红树林土壤中营养元素和土壤酶活性的作用，以及螃蟹排泄物在叶片中营养元素的归还过程中的作用。

研究结果表明，螃蟹的活动显著提高土壤中硝态氮的含量，并且抑制土壤的脲酶活性，但是螃蟹活动对土壤中的有机碳、全氮、磷酸盐和氨态氮含量没有显著的作用，对土壤中的水解酶、蛋白酶、磷酸酶和多酚氧化酶活性也没有显著作用。通过摄食秋茄凋落叶，褶痕相手蟹显著提高土壤中有机碳和全氮含量，土壤中的蛋白酶、磷酸酶和多酚氧化酶的活性也相应地增强。褶痕相手蟹摄食 1 g 秋茄凋落叶后，分别有 154.94 mg 和 10.26 mg 有机碳和总氮转化并累积在土壤中。

在去除螃蟹排泄物后，土壤中有机碳和总氮含量降低，磷酸盐含量增加，表现出与螃蟹摄食作用相反的影响，证明螃蟹排泄物是红树林生态系统中营养物质循环的重要媒质。

关键词：红树林；秋茄；大型底栖动物；生态学关系；九龙江口

Abstract

1. Changes of macro-benthic faunal community with stand age of rehabilitated *Kandelia candel* mangrove in Jiulongjiang Estuary

Distribution properties of macro-benthic faunal communities were compared among rehabilitated *Kandelia candel* forests of different ages in Jiulongjiang Estuary, China. From July 2005 to July 2006, seasonal surveys were conducted within four representative forests: K4, K7, K19 and K43, with ages of 4, 7, 19 and 43 years, respectively. Two non-vegetated flats (NF1 and NF2) were set as the references. Numbers of faunal species in rehabilitated forests were higher than NF1 and NF2, while younger forests (K4 and K7) generally had more macro-benthic fauna species than older ones (K19 and K43). Among the total 22 species recorded, *Uca arcuata*, *Metaplax elegans*, *Phascolosoma esculenta* and *Littoraria melanostoma* were dominant. Macro-benthic faunal community structures were different among the four rehabilitated *K. candel* forests. The dominant species in younger forests was *M. elegans*, while *U. arcuata* had a higher abundance than *M. elegans* in non-vegetation flats and older forests. Gastropods were abundant in younger forests. Distribution properties of dominant species differed among rehabilitated *K. candel* forests. *U. arcuata* had the largest density in non-vegetated flats, and was infrequent in younger forests. *M. elegans* had high abundances in younger forests. High abundance of *P. esculenta* was found in older forests, while *L. melanostoma* was more abundant in younger forests. Since both macro-benthic faunal community and vegetation were similar in K19 and K43, rehabilitated *K. candel* mangrove was considered steady 19 years after being planted. That is, in the case of macro-benthic fauna and vegetation, a *K. candel* mangrove may evolve to a mature state at a stand age of about 20 years.

2. Leaf consumption by *Sesarma plicata* in a mangrove forest at Jiulongjiang Estuary

Feeding ecology of *Sesarma plicata*, the most abundant crab species in a mangrove forest dominated by *Kandelia candel* at Jiulongjiang Estuary, China, was investigated through field

and laboratory experiments. Feeding preference and consumption rates were determined on mature, senescent and decomposed leaves of *Kandelia candel*, *Bruguiera gymnorrhiza* and *Aegiceras corniculatum*. In the laboratory, *S. plicata* preferred leaves of *K. candel* over those of *B. gymnorrhiza* and *A. corniculatum*, and consumed significantly more decomposed leaves than mature and senescent ones, irrespective of crab size. Field experiments with limited power failed to reveal detectable species preferences despite more consumption of *K. candel*, but decomposed leaves of each species were again preferred. Leaf characteristics associated with preference changed with plant species and leaf state. Low tannins and high water content characterized the preferred state of leaves. Species preference was significantly and negatively related to crude fibers and C: N ratios for mature leaves, and crude fiber for senescent leaves, but significantly and positively related to water content for decomposed leaves. Leaf consumption rates averaged for all leaf categories from laboratory no-choice feeding experiments were 0.101, 0.055 and 0.017 gDW ind^{-1} d^{-1} for large, medium and small crabs, respectively. In this forest, mean density of *S. plicata* was 20.5 ind m^{-2} as assessed by a manual catching method. Leaf litter removal rate during neap tide days by sesarmid crabs was about 1.33 gDW m^{-2} d^{-1} in April 2006. The leaves removed by crabs were grazed on the sediment surface or taken into crab burrows, shredded and stored before being eaten.

3. Seasonal dynamics of leaf litter removal by crabs in a *Kandelia candel* mangrove forest in Jiulongjiang Estuary

Seasonal variability of leaf litter removal by crabs was observed from May 2006 to April 2007 in a *Kandelia candel* mangrove forest in Jiulongjiang Estuary, China. Monthly average quantities of leaf fall ranged 0.85~3.86 gDW m^{-2} d^{-1}, with high values in May, August, October and November. The whole-year leaf fall was 6.48 t ha^{-1} a^{-1} (1.81 gDW m^{-2} d^{-1}). Standing stock of leaf litter on the forest floor was 7.78 gDW m^{-2} averaged from the whole year's data, with the lowest value in December (1.23 gDW m^{-2}) and the highest in April (16.18 gDW m^{-2}). Annually averaged removal rate of leaf litter by crabs was 0.59 gDW m^{-2} d^{-1}. High seasonal variability was observed on removal rates of leaf litter by crabs. The values in the winter months (December, January and February) were 0.07~0.09 gDW m^{-2} d^{-1}, much

lower than those in other months with values of 0.59~1.18 gDW m^{-2} d^{-1}. Annually averaged percentage of leaf fall removed by crabs was 33%, with the highest values in September (reached 76%) and the lowest values in winter months (December, January and February). During the whole year, the estimated tidal export of leaf litter was 444.07 gDW m^{-2}, accounting for about 67% of the leaf fall production. In leaf litter removed by crabs, a large proportion was buried by crabs, and only 12% was consumed by crabs on the forest flood. Leaf litter removal rate, consumption rate on the forest floor, percentages of leaf fall and standing stock removed on the forest floor were significantly positively correlated with air temperature.

4. Change of soil property induced by foraging of mangrove crab *Sesarmea plicata* on mangrove leaf

The effects of mangrove crab *Sesarmea plicata* on soil chemical properties and enzyme activities were quantified in laboratory, with emphasis on crab activity and foraging *Kandelia candel* leaf. Crab activity has no significant effect on soil OC, TN and available phosphorus contents, but significantly increased soil NO_3^--N content from 131.44 μg g^{-1} in the control to 194.79 μg g^{-1}. Soil urease activities were hampered while sucrase activity was enhanced by crab activity. Foraging *K. candel* leaf by *S. plicata* presented different effects on soil properties to crab activity. Forging *K. candel* leaf significantly increased the soil OC, TKN contents, and soil enzyme activities except invertase and urease activities were significantly augmented during the foraging. Significant correlations were found among soil chemical properties and enzyme activities. By forging 1 g *K. candle* leaf, 154.94 mg OC and 10.26 mg TN contents were accumulated in soil by crab. Removing crab feces material from soil weakened foraging effect on soil properties, indicating a medium role of nutrient retention in mangrove soil.

Keywords: Mangrove; *Kandelia candel*; Macro-benthic fauna; Ecological relationship; Jiulongjiang Estuary

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