博 士 学 位 论 文

海水养殖生态环境系统演化机制研究

——以半精养虾蟹混养系统为例

Ecosystem Evolvement Mechanism in Mariculture Environment: A Case Study from Semi-intensive Shrimp-crabs Mixing Culture Ecosystem

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海水养殖生态环境系统演化机制研究
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摘　要

人口与海洋渔业资源之间的供需矛盾，促进海水养殖业的快速发展，同时也引发了海洋生态环境的退化。可持续海水养殖系统成为解决这一矛盾的研究主题。

为此，本研究以地处泉州湾的半精养虾蟹混养系统作为案例，采用析因法，对该系统进行了群落生态学研究。从2003年10月至2004年5月，共采集10批次的样品，对系统的理化环境因子、微生物群落、浮游生物群落、底栖生物群落进行了调查，分析了不同群落的随养殖时间推移的数量及生物量、群落结构及优势种变化，并对新、旧虾池中不同生物群落及其环境因子进行了相关性分析、多样性分析、相似性分析和聚类分析。

1. 通过案例研究，从群落生态学研究结果，揭示出半精养虾蟹混养系统存在以下动态演绎规律：（1）半精养虾蟹混养系统的水体亚系统受自然与人为干扰影响大，其群落结构体现系统对干扰的响应；表层沉积环境较为稳定，其群落结构适宜反映系统的生长发育状况；稳定的环境孕育相对稳定的群落结构，反映于不同粒径的生物类群；（2）环境理化因子反映系统即时的代谢状况；不同粒径生物的群落结构可表征相应时间尺度上系统的稳定性；（3）多样性与系统的稳定性并无必然的联系，反映在多样性较为丰富的水体环境更为动荡，而多样性相对简约的表层沉积环境则相对稳定；

2. 为弥补群落生态学研究的不足，本研究又从综合法入手，从系统生态学角度对海水养殖系统的生长发育趋向进行了理论研究，取得以下研究结果：（1）提出的新生态归趋假设认为，生态系统的生长发育是物质与能量的存贮量增长，及其在信息与环境作用下，通过内部重组，而使该贮备在系统内滞留时间延长的综合结果；生态系统总是朝着能耗最低和功率最大的方向生长发育；（2）提出3个生态模型：1）生态量模型，认为特定粒径种群的生态量，是其信息在时空二维尺度上的综合

表达量，定义为生物量与代时的乘积；生态系统生态量为特定系统中不同粒径生物种群生态量的总和；它描述系统远离热力学平衡态的程度，反映系统的稳定性；2）平均滞留时间模型，定义为生态系统生态量与生态系统生物量的比值，表征系统的生长发育程度；3）生态系统平衡模 型，定义为即时状态下与平衡状态下生态系统生态量的比值，表征系统生长发育的平衡程度。

3. 综合群落生态学的定量分析与系统生态学的定性分析结果，提出海水养殖系统不可持续生态格局形成的根源在于：(1) 养殖动物自身及其与较小粒径生物的比例不合理，是系统不可持续的结构根源。养殖动物在不同生长发育阶段切割系统食物链的不同粒径生物环节，导致系统富余的物质和能量逐渐积滞于粒径较小的生物类群，系统氧债增大，体现为水体环境中微藻的爆发和表层沉积环境中厌氧微生物的优势地位； (2)以饲料形式从外源输入的物质与能量不能完全为养殖动物所利用，从而倾注于粒径较小的生物进行代谢，是系统氧债与生态危机的物质根源；(3) 系统生态位配置不合理，导致外源输入的物质和能量不能被不同粒径的生物有效地捕获，进而导致系统的熵增高，海水养殖系统朝着不可持续的方向发展，是系统不可持续的功能根源。

4. 基于海水养殖系统不可持续的根源，又从系统生态学角度提出海水养殖系统建构与调控趋向为：（1）须加强适应其营养代谢需求的配合饲料的研究；（2）应根据地区环境特点与经济状况，确定养殖系统的营养结构，再根据不同粒径生物的异速代谢原理、系统的临界自组织原理和正负反馈平衡原理，以及不同粒径生物的种群密度法则，合理配置不同粒径、不同营养层次生物的密度与比例，既不使系统的熵超越养殖目标种群耐受的临界值，也不使物质与能量积滞于粒径较小的较低营养层次，而使其以粒径较大的不同营养层次生物的产品形式输出；（3）应在不同粒径适度配置生态位互补的多样性资源物种；对于粒径较大、代时较长的资源物种，不仅应配置依赖于饲料的养殖目标种群，还应同时配养不依赖饲料，而可统摄粒径较小的低营养层次生物所含的物质与能量的资源物种，提高系统的输出效率与稳定性；对于粒径较小、代时较短的资源物种，建议从其他生态系统进行移植与重组，发挥其在地质历史进化过程中形成的生态位协同作用，提高系统中物质与能量的再循环利用率，降低其腐殖化的比例。

5. 在系统微生物生态学研究过程中，取得了以下方法学研究成果：（1）在微生物群落结构研究中，解决了困扰沉积物总 DNA 提取效果的腐殖酸问题，遴选出了脱腐效果较好的单一配位剂，阐释了脱腐原理，配制了脱腐性能优越且经济适用的脱腐缓冲液，建立了操作简便的脱腐方法；（2）为克服微生物 16S rRNA 基因的多拷贝序列不一致现象对微生物群落结构研究造成的困扰，对单拷贝的看家基因 rpoB 进行了研究，筛选出了可应用于细菌群落结构研究的引物和 PCR 方法。

上述研究结果将有助于人们认识与理解自然与人为干扰对养殖系统影响及其响应，阐释海水养殖系统生态格局的成因机制，追溯其不可持续的深刻根源，明确海水养殖系统结构与功能调控趋向，并为推进海水养殖系统可持续研究的发展提供理论模型与技术工具，具有重要的理论意义与应用价值。

关键词：海水养殖；系统演化；微生态

Ecosystem Succession Mechanism in Mariculture Environment: A Case Study from Semi-intensive Shrimp-crabs Mixing Culture Ecosystem

Abstract

The paradox between population increment and marine fishery resource accumulate the rapid development of mariculture and the degeneration of marine environment. Therefore, many research aim to sustainable aquaculture.

In order to understand the growth and development tendency of mariculture ecosystem, the study conduct to semi-intensive shrimp-crab mixing culture system as a case. On the view of reductionism，we carry on the research basing on the community ecological methods. From October in 2003 to May in 2004, 10 batches of ecosystem sample was collected. The investigation was conducted to the physical and chemical environment factors, microbial community, phytoplankton community, zooplankton community, macrobenthos community and microbenthos community, focused on the quantity or biomass of different community and their predominant species and community structure dynamics. Meanwhile, the correlation analysis, diversity analysis, similarity analysis and cluster analysis was carried out for different community and environment factors.

1. Basing on the case study, some dynamic rules of shrimp-crabs mixing culture ecosystem was deduced by the community research:（1）The community structure on water body is influenced greatly by naturally and man-made disturbance which embodies the response of ecosystem to disturbance. The community structure in surface sediment is more stable than water body which is fit for imaging the ecosystem growth and development status. The stable environment gestates the conservative community structure which is reflected on different body size organisms.（2）The environmental physical and chemical factors reflect the prompt metabolic status of ecosystem；The community structure of different body size organisms exhibit the stability at the corresponding generation time scale; （3）The biodiversity is not correlative with the

ecosystem stability which is reflected by the reality that the abundant biodiversity exist in dynamic water column while the comparative simple biodiversity take on surface sediment.

2. In order to evade the limitation of the community research, in the light of integration methods, this study was conducted to the growth and development of the mariculture ecosystem. Basing on the system ecology research, the following theoretical outcomes was obtained:（1）A new ecosystem tendency theory was proposed that the ecosystem growth and development is not only the increment of matter and energy saving, but also the lag time prolong as a result of the inner saving reorganizing due to the interaction of information and environment. The ecosystem growth and development is always towards minimum energy cost and maximum power.（2）Three ecological model was proposed: 1) Ecosystem ecomass model which define the ecosystem ecomass is the sum of product of different body size organism's biomass and generation time. The ecosystem ecomass describe the extent of ecosystem far from thermodynamic equilibrium which could reflect the stability of ecosystem; 2) The average lag time model which define the average lag time as the ecosystem ecomass/biomass ratio. The model could exhibit the extent of ecosystem growth and development; 3) Ecosystem equilibrium model which define the ecosystem equilibrium parameter as ratio of ecosystem ecomass in the temporal status and in the equilibrium status. The ecosystem equilibrium parameter reflect the equilibrium degree of ecosystem growth and development.

3. Combining the quantitative analysis of the community research result and the qualitative analysis of the system ecology research outcome, the following root and evolvement mechanisms was put forward for the unsustainable mariculture ecosystem: (1) The mariculture ecosystem is unsustainable which is originated from the irrational proportion of different body size organisms. The breeding animal feed on the different body size organisms within their different growth and development stage which lead to the redundant matter and energy accumulate into the small body size organisms that the ecosystem oxygen debt increase, the micro-body size algae proliferate explosively in water column and the anaerobic microbes dominate in surface sediment. (2) The root of the oxygen debt and crisis of mariculture ecosystem are also derived from the matter and

energy as feed imported from outside which can not be used completely by the breeding animals and pump to the smaller body size organisms to metabolize.(3) The functional origin of unsustainable mariculture ecosystem is the disharmonious niche match which lead to the input matter and energy can not be fixed by different body size organisms efficiently so that the entropy of mariculture ecosystem increase and tend to develop towards the unsustainable orientation.

4. Base on the unsustainable mechanisms and ecosystem growth and development tendency, the construction and regulation tendency of mariculture ecosystem was proposed as:（1）The formula feed research must focus on the suitability for the nutrient metabolism requirement of breeding animal.（2） The trophic structure of mariculture ecosystem should confirm according to the regional environment characteristic and economic status. The density or proportion of different body size or trophic level should be adjust according to the general ecological allometric principles of body size, the critical self-organization principle, the equilibrium principle between the positive and negative feedback and the density law of different body size organism. The entropy of the mariculture ecosystem should not go beyond the critical value. There is no redundant matter and energy accumulating at small body size organism which were output as biomass of biggish body size organism. （3）The mariculture ecosystem should prepare the resource species with interdependent niche. The bigger body size and the longer generation time resource species should include not only the goal breeding organism which depend on the feed, but also the match breeding organism which ingest on the smaller body size organism. The moderate match breeding organism will improve the output efficiency and the ecosystem stability. It is suggested that the smaller body size and shorter generation time organisms should be transplanted from other ecosystem to reorganize to make use of their collaborative niche evolved from geological history so as to enhance the recycle efficiency and reduce the humification proportion of the matter and energy.

5. In the process of microbial ecology research of shrimp-crabs pond, the following methodology outcome was acquired:（1）In the preliminary research of microbial community structure, the problem was overcome that the humic acids(HAs) coextract with sediment microbial DNA. The specific reagent was screened out to put up the