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Comparing nutrient budgets in integrated rice-shrimp ponds and shrimp grow-out ponds

Luu Duc Dien[a,b,*], Le Huu Hiep[b], Nguyen Van Hao[b], Jesmond Sammut[c], Michele Astrid Burford[a]

[a] Australian Rivers Institute and Griffith School of Environment, Griffith University, 170 Kessels Road, Nathan, Queensland 4111, Australia
[b] Research Institute for Aquaculture No. 2, 116 Nguyen Dinh Chieu Street, District 1, Ho Chi Minh City, Viet Nam
[c] Centre for Ecosystem Science, The School of Biological, Earth & Environmental Sciences, The University of New South Wales, Sydney 2052, Australia

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ABSTRACT

Saltwater intrusion has become a severe issue for the Mekong Delta in Vietnam, especially near the coastline. This issue has led to farmers diversifying from exclusively growing rice to adopting a mixed rice-shrimp system with rice only cultivated in the wet season. However, the nutrient (nitrogen, phosphorus and carbon) cycling and nutrient use efficiency of this system remain poorly understood. To address this knowledge gap, we examined nutrient budgets across 12 farms using integrated rice-shrimp ponds, and in some cases semi-intensive or intensive shrimp grow-out ponds (*Penaeus monodon* or *Penaeus vannamei*), over a two-year period (2014–2015). In terms of nutrient budgets, the main nutrient input (92% of the N input, 57% P and 95% C) in the integrated rice-shrimp ponds (IRSPs) came from intake water (excluding C from primary production), while water discharge accounted for the highest output (75% of N output, 41% P, 57% C, excluding C from respiration). The study showed that IRSPs had low dissolved oxygen and high nutrient concentrations which may affect shrimp production. Conversely, salinity levels in the wet season were too high for rice plants thereby affecting rice production. Shrimp survival in the IRSPs was low over the two years (6.3 ± 2.2%), which resulted in the low proportion of nutrients exported from the ponds as harvested shrimp (6% N, 5% P and 10% C). In contrast, the shrimp grow-out ponds (SGOPs), had much higher survival (77.1% for *P. vannamei* and 59.2% for *P. monodon*) in three of the six farms where the shrimp survived through to harvest. In these ponds, formulated feed was the highest nutrient input (*P. vannamei*: 82% N, 75% P and 85% C; *P. monodon*: 75% N, 55% P and 77% C) with approximately a third of the nutrients being in the shrimp harvest. In our study, nutrients in the IRSPs were used less efficiently than in SGOPs, hence mechanisms to improve shrimp survival and production in IRSPs are urgently needed.

1. Introduction

Farmed shrimp are the most valuable commodity for Vietnam and account for 42% of the country's earnings from seafood production, and approximately 76% of Vietnam's shrimp production occurs in the Mekong Delta (ADB, 2013). The Mekong River and its tributaries are also critical areas for rice production, and the river system and its farmlands are known as the "Rice Bowl" of Vietnam (Dang and Danh, 2008). However, in recent decades, sea level rise, river flow regulation and increased water consumption have increased water salinity to the point where it is becoming a serious problem for rice production (Tho et al., 2013). Hence, in some regions, the canals and farms have freshwater in the rainy season but higher salinity in the dry season; consequently, rice is increasingly difficult to grow in the dry season. Integrated rice-shrimp farming has been promoted given that dry season conditions are suitable for shrimp production when rice crops might struggle or fail under higher salinities. This farming system involves farming rice in the wet season with shrimp culture in the same system during the dry season. This practice has increased from around 40,000 ha in 2000 (Brennan et al., 2002; Preston and Clayton, 2003) to 160,000 ha in 2016 and has been speculated a rise to 250,000 ha by 2030 (Tuan et al., 2016). Despite this, there have been few studies on the sustainability of these systems (Leigh et al., 2017).

An understanding of the nutrient budget, by quantifying nutrient inputs and outputs, and hence the efficiency of nutrient utilization, is critical to determine the sustainability of rice-shrimp farming systems. However, to date, this has not been addressed. There are many studies of nutrient budgets in a range of aquaculture systems, especially for shrimp ponds. For example, nutrient budgets have been determined for intensive shrimp ponds in Thailand (Briggs and Funge-Smith, 1994;

* Corresponding author at: Griffith University, 170 Kessels Road, Nathan, Queensland 4111, Australia.
E-mail address: ducdien.luu@griffithuni.edu.au (L.D. Dien).

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Thakur and Lin, 2003), extensive shrimp ponds in Bangladesh (Rouf et al., 2012; Wahab et al., 2003), semi-intensive shrimp farms in Mexico (Paez-Osuna et al., 1997; Paez-Osuna et al., 1999; Miranda et al., 2009), and semi-intensive shrimp farms in Australia (Jackson et al., 2003). These studies have found that feed was the primary source of nitrogen (N), phosphorus (P), and carbon (C) in these ponds with $<$ 17% being assimilated by shrimp (Briggs and Funge-Smith, 1994; Islam et al., 2004; Jackson et al., 2003; Miranda et al., 2009). In culture systems with low water exchange, waterborne loss of nutrients is less important than loss into the bed sediments of the pond due to the rapid accumulation of sludge (Audelo-Naranjo et al., 2010; Kittiwanich et al., 2012; Qi et al., 2001; Thakur and Lin, 2003). Hence, a significant proportion of nutrients received in ponds ends up settling on the pond bottom and being discharged (Huy and Maeda, 2015; Sun and Boyd, 2013; Xia et al., 2004).

Nutrient budgets provide a means to quantify potential impacts of pond management strategies to improve the efficiency of production. There remains a gap in our knowledge of nutrient budgets for integrated rice-shrimp ponds (IRSPs). Therefore, in this study, we compared nutrient budgets in shrimp grow-out ponds (SGOPs) with adjacent IRSPs to determine dominant nutrient inputs and outputs, and the relative effectiveness of nutrient utilization by shrimp. This information is a fundamental step in improving food utilization efficiency, water quality and biogeochemical processes of the farming practices.

2. Materials and methods

2.1. Study area

The study focused on 12 farms along a canal in the Cai Nuoc District, Ca Mau Province, Vietnam from February 2014 to January 2016 (Fig. 1). There were six farms (C1–C6) using only IRSPs, with a platform (70–80% of area) for rice growing, and surrounding ditch (20–30% of area) for water management and shrimp farming. An additional six farms (M1–M6) were used to trial a combination of the IRSPs, plus newly constructed SGOPs with shrimp grown from semi-intensive to intensive conditions. IRSPs ranged in size from 1.2 to 3.5 ha, with water depth in the ditch typically 1.0–1.4 m, and for the platform 0.1–0.4 m. The SGOPs were 0.2–0.3 ha in area, and 1.1–1.5 m deep (Fig. 2).

There are two main seasons in the region: the dry season from December to April, and the wet (rainy) season from May/June to October/November (Leigh et al., 2017). The hottest period is typically between April and May, while the wettest period is from September to October/November. During the rainy season, water salinity in this region drops gradually from around 20 to 4, and may become fresh (Hoanh et al., 2016). The area experiences annual flooding due to its low elevation. The air temperature ranges from 24 to 34 °C, and the average monthly rainfall ranges from 0 mm in the dry season to 250 mm in the wet season, with annual rainfall around 2300 mm (ADB, 2013).

2.2. Pond management

The first steps of preparation for the IRSP included cleaning and reinforcing the pond bank, discharging the water in the ditch through a sluice gate, and transferring sludge in the ditch to the platform. After that, lime was added to the pond (using calcium oxide, a dose of 1 t ha^{-1} $ditch^{-1}$ and 500 kg ha^{-1} $platform^{-1}$), then the platform was dried for 5–7 days. Approximately 15–20 days later, water was added from the canal via a filter bag if the salinity of the supply channel was suitable ($>$ 10) or via a settling pond. Unwanted fish were killed using Rotenone, and water was disinfected using iodine added at 0.5 mg L^{-1}.

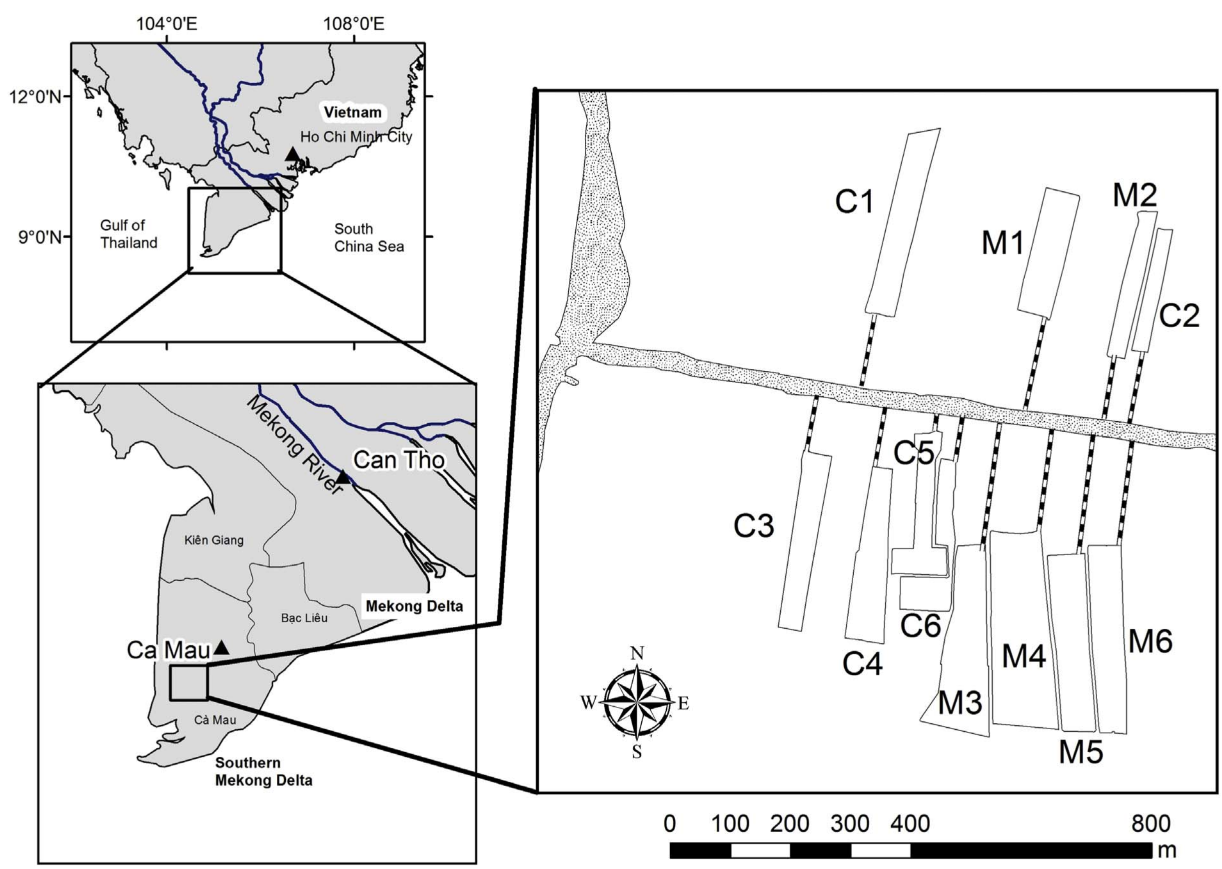

Fig. 1. Map of 12 farms and the adjacent canal in Ca Mau province, Vietnam.