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Environmental performance of brackish water polyculture system from a life cycle perspective: A Filipino case study

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ABSTRACT

Life Cycle Assessment (LCA) was applied to assess the environmental performance of brackish water polyculture of black tiger prawn, mud crabs, tilapia and milkfish in a pond aquaculture system. The study was conducted on 15 production sites, located in Pampanga Province of the Philippines. The scope of analysis covered the hatchery or capture of juveniles from the wild up to the delivery of products to auction markets. Impact categories included eutrophication, acidification, climate change, land occupation, net primary production use, total cumulative energy demand (TCED), and total human labour. Life cycle impact indicators were calculated for one tonne of product (total production or that of individual species) using both energy-based and economic allocations. The results indicated that the main impacts from farming operations were eutrophication, land occupation, acidification and human labour. Feed (molluscs harvested from aquatic ecosystems) mainly influenced net primary production use, TCED and climate change, and harvesting and delivery mainly influenced climate change and TCED. Differences in farm practices and yields induced high variability in impacts. Production site size had no significant effect; however, its distance from the sea appeared to affect its efficiency and, consequently, impacts. Changing the allocation method changed the ranking of species' impacts within each impact category, milkfish having the highest impacts with energy-based allocation and prawn and crabs having the highest impacts with economic allocation. The lack of differences in impacts between intensive monocultures of prawn and tilapia recorded in the literature and the same species in Pampanga's polyculture suggests that the degree of intensification is not a relevant concept for distinguishing impacts of aquaculture systems.

1. Introduction

Polyculture is an approach of culturing multiple species in the same space (Milstein, 2005). Though it originated in agricultural systems, it also has been applied in aquaculture systems, mainly to efficiently increase utilization of natural foods in ponds with multiple trophic levels of cultured species. It is dominant mainly in Asia, especially for local communities, to provide a sustainable livelihood and sources of nutrition (FAO, 2012). The Philippines developed aquaculture along its coast more than 300 years ago. Aquaculture production in the Philippines reached 744,000 tonnes in 2010, ranking 9th in the Asiatic region (FAO, 2012), and plays a significant role in the country's economy (BFAR (Bureau of Fisheries and Aquatic Resources), 2004). In the Philippines, Pampanga Province is one of the main production areas for brackish water polyculture based on a pond aquaculture system. This brackish water polyculture system is located in an estuary that opens onto Manila Bay (Luzon Island) and occupies more than 16,000 ha of ponds in the province. Three to four species are associated with this system: tiger prawn (*Penaeus monodon*), mud crabs (*Scylla serrata* and *Scylla olivacea*), milkfish (*Chanos chanos*) and, in areas further from the sea, tilapia (*Oreochromis niloticus*). Native and introduced wild fish (detailed later) are also part of the polyculture. The rationale for this polyculture system is the combination of complementary species that use different habitats in the pond ecosystem, such as the bottom (tiger prawn and crabs) or the water column (milkfish and tilapia). These species, despite being opportunistic omnivores, also feed on different trophic levels, tiger prawn and crabs focus more on detritus and milkfish and tilapia focuses more on plankton. Moreover, these species meet different market demands: milkfish and tilapia supply the local market, while tiger prawns and crabs are marketed in large cities (mainly in the Philippines).

Performance of polyculture systems is debatable in terms of sustainability, particularly when compared to the results of monoculture. The Life Cycle Assessment (LCA) method has been previously applied to assess the environmental performance of intensive fish-production

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systems, especially for salmonids (Aubin et al., 2009; Boissy et al., 2011; d'Orbcastel et al., 2009; Papatryphon et al., 2004a,b; Pelletier and Tyedmers, 2007; Pelletier et al., 2007; Samuel-Fitwi et al., 2012). However, there are few available studies on pond systems (Bosma et al., 2011; Cao et al., 2011, 2013; Mungkung, 2005; Pelletier and Tyedmers, 2010) and even fewer on extensive polyculture systems (Casaca, 2008; Efole-Ewoukem et al., 2012; Phong et al., 2011). However, no studies have been performed on polyculture systems in Asia. Therefore, this study aims to: (1) estimate environmental impacts of this type of polyculture system, (2) define the principal sources of the impacts, (3) discuss their allocation among the species, and (4) compare impacts of this polyculture system to those of intensive fish farming systems.

2. Materials and methods

2.1. Production system

A sample of farms, representative of common practices, was surveyed to conduct the environmental study. Three tiger prawn hatcheries were studied in Zambales, Pangasinan and Quezon Provinces in the east, northeast and west of Luzon Island, respectively. The main difference among them concerns the feed, which is based either exclusively on diatoms (*Skeletonema* spp.) or on diatoms supplemented with concentrated feeds or brine shrimp (*Artemia* spp.). Broodstock are fished from the sea with small trawlers. Tiger prawn larvae in Pampanga come mainly from Luzon Island, and also from Mindanao and the Visayas islands. Two tilapia hatcheries were studied in Pampanga, the main production area for tilapia fingerlings on Luzon Island. Milkfish fingerlings are either fished from the sea or provided by Indonesian or Taiwanese hatcheries. When fished, they are caught by hand using a 15-metre-long net. The main fishing area is at Iba, Zambales Province. Once caught, they are transported to Bulacan Province (next to Pampanga Province) and are fed in pre-growing ponds for two months before being sent to Pampanga. About 50% of the fingerlings are fished and 50% are purchased from foreign hatcheries. For the LCA, capture of milkfish fingerlings from the sea was assumed. Crab larvae are collected by hand in the river and mangrove (using a landing net) in two main locations: Aparri Estuary (north of Luzon Island) for the orange mud crab (*S. serrata*) and Sorsogon Bay (southeast of Luzon Island) for the king mud crab (*S. olivacea*).

Fifteen production sites were surveyed in Pampanga. Each production site is a pond with its surrounding area depending on a farm, which is defined by its surface area, location and production practices. The ponds range in size from 1 to 101 ha. In this area the mean pond size is 19.4 ha (Grandmougin, 2003). Depending on the size, one or more employees manage the production site and live on the dykes permanently. Several ponds can be operated by the same farmer. Since tiger prawn is the most profitable species in the polyculture, farm activity is mainly organised around its production cycle, which lasts 3–4 months (Fig. 1). Crabs, representing the second most valuable product, are produced in six months. The production cycles of tiger prawns and crabs are independent, as crabs can be harvested without draining ponds. Tilapia and milkfish are sorted at each tiger prawn harvest into large fish that can be sold and small fish that are transferred into another grow-out pond. Consequently, fish are produced in 3–9 months depending on their growth rate and farmers' decisions. Infrastructure is generally limited to the wood or concrete house of the permanent caretaker, motorised boats (made of epoxy resin and fibreglass) and concrete water gates of the pond. The main tiger prawn feed consists of horn snails (*Cerithium tenellum*), considered a pest (Bagarinao and Lantin-Olaguer, 2000), and mangrove whelk (*Telescopium telescopium*), collected either from a river by the farmers or, for farmers operating several production sites, from Manila Bay (60 km from Pampanga), from where it is transported by truck. Depending on farmer practices, other feeds are distributed in limited quantities during the first weeks of the production cycle as a supplement; for example, trash fish from the previous harvest or the local markets, or in rare cases, frymass. Chemicals and fertilisers commonly used are lime and urea (16–0–0), respectively.

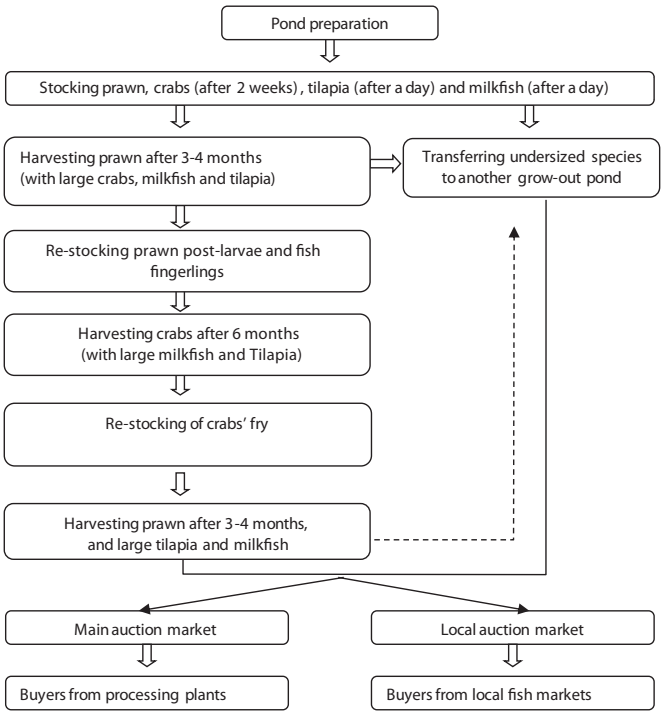

Fig. 1. Production cycle of the brackish water polyculture system of Pampanga, Philippines.

One of the main concerns in the polyculture system is an extremely high mortality rate (up to 95%) of tiger prawn post-larvae (Table 1). Several factors may be responsible, including water pollution, interspecies competition (especially with crabs) and insufficient river flow due to Mt. Pinatubo's eruption, in 1991. Nevertheless, the commonly held cause is the presence of white-spot disease in the ponds, a viral syndrome, which caused major abandonment of tiger prawn monoculture in the Philippines in the 1990s (FAO, 2005). It also must be noted that the fishponds of Pampanga were historically adapted for milkfish culture, not for shrimp. Survival rates of the other three species range from 50 to 68%.

As previously mentioned, some native and introduced species from the wild are found in Pampanga fishponds. Native species include silver perch (*Bidyanus bidyanus*), snakehead murrel (*Channa striata*), goby (*Callogobius tanegasimae*), and Indian white shrimp (*Penaeus indicus*), while introduced species include blue tilapia (*Oreochromis aureus*) and white leg shrimp (*Litopenaeus vannamei*). These "wild fish" harvested from ponds can represent up to 10% of the gross income of a production site. This was included in the inventory by estimating a mean mass of wild fish per ha.

Table 1
Mean stocking densities, mortality rates and annual production of the brackish polyculture system of Pampanga, based on a 30-production-site sample in a previous survey from April to July 2006.
Baruthio (2006).

Species	Initial stocking density (per m^2)	Whole-cycle survival rate (%)	Production (kg/ha/year)
Tiger prawn	5.61	5	218
Mud crabs	0.51	50	191[a]
Milkfish	0.70	68	269
Tilapia	0.64	61	563

[a] Individuals/ha/year.