A REGIONAL APPROACH TO ASSESSING ORGANIC WASTE PRODUCTION BY LOW SALINITY SHRIMP FARMS

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The need for large volumes of brackish water to fill pond enclosures has traditionally limited the cultivation of marine shrimp to a relatively narrow band of coastal land in Thailand[1]. This was certainly the case during the first wave of intensive shrimp aquaculture development in the Upper Gulf of Thailand during the late 1980s. Farm expansion during this period was concentrated in the estuaries of major rivers such as the Bangpakong, Chao Phraya, Tha Chin, and Mae Khlong. Intrusion of saline water during the dry season is a common characteristic of these low gradient river systems, and this permitted the construction of a second generation of tiger shrimp farms along natural stream channels and irrigation canals some distance from the coast[2]. However, brackish water is unavailable in upstream areas when higher stream flows counteract tidal influences during the wet season[3]. Low salinity shrimp culture techniques were developed to overcome this seasonal limitation, and shrimp farming expanded inland rapidly during the second half of the 1990s. The low salinity culture system spread from seasonally brackish areas, to freshwater areas that never experience salt water intrusion[4]. Low salinity shrimp farms that draw freshwater from existing rice irrigation infrastructure now exist over 100 kilometers from the coast in areas such as Prachinburi and Nakhon Nayok. Approximately 18,530 hectares of low salinity shrimp ponds have been identified in the Bangpakong River Basin as part of our study, and as much as 40 percent of Thailand's total cultured shrimp production could come from shrimp farms located in freshwater or seasonally brackish areas throughout the country[5].

The rapid emergence of low salinity shrimp farming within inland freshwater areas has, however, raised concerns regarding potential water quality impacts[6]. The main concern is usually the disposal of organic-rich effluent from shrimp farms into freshwater streams or irrigation canals. Water quality impacts associated with an individual low salinity shrimp farm are typically quite limited because of their small size (0.5 - 5 hectares). However, the simultaneous operation of a large number of these farms within a river basin could produce a serious cumulative impact on regional water quality[7]. Given the proliferation of shrimp ponds within freshwater areas of Thailand, it is imperative to obtain a better understanding of the regional organic waste production characteristics of this activity. Unfortunately, most previous investigations have been site-specific case studies[8,9] or have focused on brackish water shrimp farms located in coastal environments[10,11,12,13]. Few broad-scale environmental studies have been undertaken assessing the regional water quality impacts associated with low salinity shrimp farming.

Figure 1: The Bangpakong River Basin study area

Study Area

The Bangpakong River Basin is approximately 18,758 km^2 in area (Figure 1). Two major tributaries (Nakhon Nayok and Prachinburi Rivers) join in northern Chachoengsao Province to create the Lower Bangpakong River (Figure 2). This major watercourse then flows 122 kilometers through a flat alluvial plain before empting into the Upper Gulf of Thailand. The lower Bangpakong sub-basin is a highly productive agricultural region with fertile clay soils and an extensive man-made irrigation network dating back over one hundred years[11]. Irrigated rice is the most common crop, but fruit and field crops such as tomatoes and corn are also produced. Intensive animal husbandry (chicken, pig and cattle) has also developed with many large farms located in Chonburi and Chachoengsao provinces. A substantial industrial complex and numerous towns and cities are located along the lower Bangpakong River.

Regional assessment techniques

Shrimp farming can develop very rapidly in suitable areas. This rapid pace of development places on a premium on the availability of farm inventory data and can render time consuming management approaches such as basin planning or integrated coastal zone management largely ineffective[15]. Given these characteristics, a technique that combines the use of satellite imagery, geographic information systems (GIS), and organic waste modeling was developed to study aquaculture-related water quality impacts in the Bangpakong River Basin.

Shrimp farms in the study area were identified by a recent survey of low salinity shrimp farms in the Central Plains Region of Thailand4. This survey utilized LandSat 5TM (level 8) satellite images obtained on March 10 and March 17, 1998. Interpretations of these images were later ground-truthed to produce 1:50,000 base maps identifying individual shrimp ponds. These base maps digitized, and entered into a geographical information system with other data (e.g., hydrology, soils, land use). This process identified the location of individual low salinity shrimp ponds, and provided a calculation of total pond area within individual sub-basins (Figure 3). A field reconnaissance of the study area was also conducted during the latter half of 2000. No new low salinity shrimp farms were found outside of the areas surveyed in 1998, but a substantial number of new ponds were found to be under construction within existing development zones. This may have been in response to the rise in world shrimp prices that occurred as a result of disease-related crop failures in Ecuador[16].

Shrimp farm organic waste production was evaluated using biological oxygen demand (BOD) loading estimates. BOD is one of the most commonly applied indicators of both organic waste production and overall water quality in Thailand[17]. BOD provides a measure of the potential for aquaculture wastewater to cause pollution by "de-oxygenation"[18]. Three scenarios for farm-level BOD production estimates, based on farm level studies[8,9,10,11,13,14,19] were combined with the shrimp farm locational data to estimate organic waste loads within individual sub-basins. Shrimp farming BOD production was also compared to other sources of agricultural, industrial and municipal organic pollution to assess the relative significance shrimp farm effluent discharges.

Figure 2: The Bangpakong River is rises from the fusion of the Nakhon Nayok and Prachinburi Rivers in Chachoensao Province

Existing Water Quality in the Bangpakong River

Water quality and hydrological conditions in the Bangpakong River Basin were recently investigated as part of a Water Quality Management Plan for the Eastern Region of Thailand[14]. Streamflows in the Bangpakong River Basin are extremely seasonal as a result of the monsoon which creates a distinct dry season (November - April) and wet season (May-November).

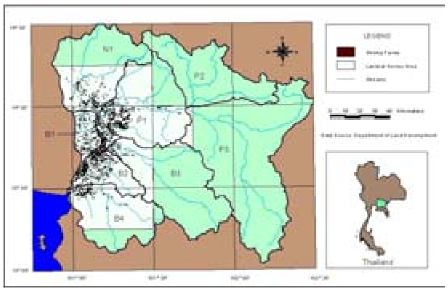

Figure 3: Pond area within sub-basins

Threshold levels for key parameters identified by the Pollution Control Department (dissolved oxygen – DO; biological oxygen demand – BOD; total coliforms and ammonia – NH_3) were used to create water quality classes representing the needs of beneficial water uses in the Bangpakong River. Class 1 water quality essentially corresponds to natural conditions, while Class 5 water quality is very poor and only suitable for navigational purposes. Water quality meeting the Class 2 level has been targeted for most reaches of the Bangpakong, Prachinburi and Nakhon Nayok Rivers. Currently, only the most distant headwaters of the Prachinburi and Nakhon Nayok Rivers comply with the Class 2 target for dissolved oxygen (6.0 - 7.6 mg/l). Most of the Prachinburi River and all reaches of the lower Bangpakong River above kilometer 82 possess a Class 3 designation (4.0 – 6.0 mg/l). The lower Bangpakong River and several reaches of the Nakhon Nayok River were rated as Class 4 (2-4 mg/l).

Several important points are highlighted by this water quality

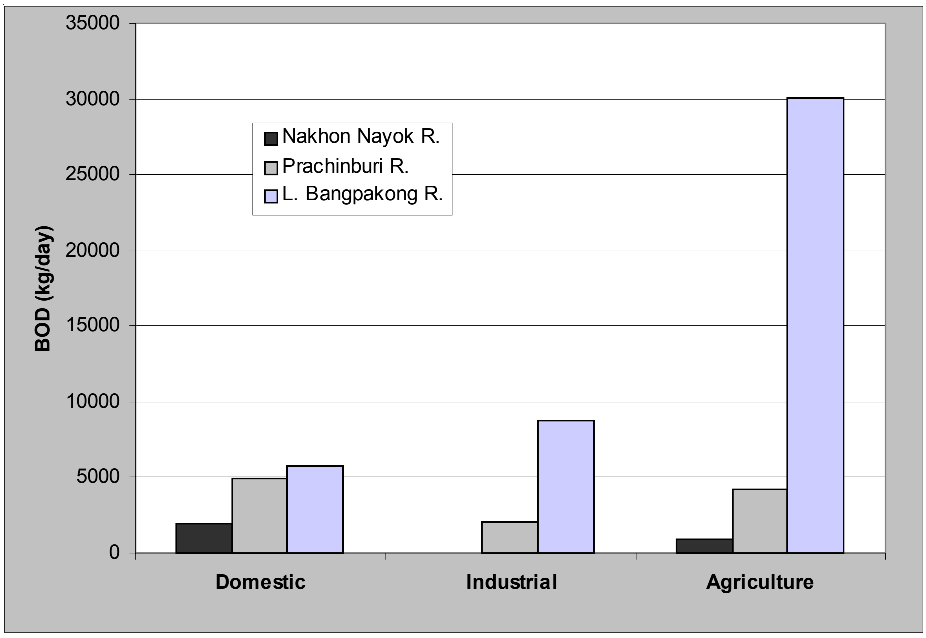

Figure 4: Total pollution load from the industrial, domestic and agricultural sectors

assessment. Low dissolved oxygen and high BOD levels suggest that many portions of the Bangpakong River Basin are heavily loaded with organic wastes to the severe detriment of water quality. The lower Bangpakong River receives the largest total pollution load from the industrial, domestic and agricultural sectors (Figure 4). Agricultural BOD inputs from intensive animal husbandry (pig, chicken and cattle farms) are significant in each of the three major rivers, but exceed 30,000 kg/day in the lower Bangpakong River. Substantial industrial and domestic pollution loads were also identified in the lower Bangpakong River as a result of effluent produced by major industrial estates and urban centers located within this sub-basin[20]. Population growth and economic development will likely result in a further degradation of water quality unless municipal wastewater treatment facilities are constructed, industrial effluent discharges are controlled, and the flow of untreated agricultural pollutants is greatly reduced[14].

Figure 5: Small waterways have limited assimilative capacity

Shrimp Farm Organic Waste Production

Low salinity shrimp farm effluent production and water exchanges are modest during the first 60 days of the grow-out cycle because the juvenile shrimp are small and require little supplemental feeding[21]. Larger shrimp require substantial feed inputs and more frequent water exchanges to maintain a suitable growing environment. Uneaten food pellets, faeces, and eroded pond soil tend to accumulate at the center of the pond enclosure due to the action of mechanical aerators. This "sludge" is enriched in nitrogen, phosphorus and carbon relative to sediments in the surrounding environment. The organic waste load of shrimp farm effluent is determined by the quantity and rate of waste production, feed nutrient levels, feed conversion ratios, and site-specific conditions[10].

Untreated liquid effluent discharged during the early to mid grow-out period typically contains organic nutrient loads only slightly higher than many receiving waters in Thailand[8,17]. This effluent is also generally within a range acceptable to native freshwater and marine organisms and complies with aquaculture effluent quality standards such as those proposed by the Thai Pollution Control Department[17]. The nature of untreated effluent released during the late grow-out period and at harvest is quite different with significant concentrations of nutrients, solid organic matter, and salt.

Larger shrimp farms typically treat pond sludge using on-site settling ponds. Small-scale low salinity shrimp farms in Thailand generally do not possess either adequate land or the experience to apply this even basic form of waste management[22]. Many shrimp farmers simply flush pond sludge directly into adjacent water bodies[17]. Accumulated pond sediments may be removed with high-pressure water sprays. A second disposal technique involves simply allowing pond outlets to remain open over several tidal cycles[19].

Sludge disposal is problematic in all shrimp farming areas, but this issue is particularly important within inland regions containing low salinity shrimp farms[6]. The small streams and irrigation canals that support shrimp farms within inland areas may have little assimilative capacity (Figure 5) and water quality can be significantly degraded by sludge dumping. The disposal of pond sludge into any water body is illegal in Thailand, but this practice is not uncommon due to a lack of farmer awareness and difficulties in enforcing regulations[19,17].

Regional Impact of Shrimp Farming on Water Quality

Water quality in the Bangpakong River Basin is affected by a number of pollutants, but organic nutrient loading is the biggest concern[17]. Given the degree to which husbandry practices affect organic nutrient levels within shrimp farm effluent, three BOD scenarios were developed to estimate regional water quality impacts. Scenario A represents a "best case" situation in which shrimp farms apply efficient husbandry procedures and basic waste management practices. Effluent discharges in Scenario A comply with the existing Thai standard for aquaculture wastewater of 10 mg BOD^5 per litre or less throughout the production cycle[17]. It is assumed that no effluent discharge occurs during the early grow-out period and pond bottom sediments are stored on-site. Based on these assumptions, BOD production in Scenario A is estimated at 163 kg/ha/crop or 326 kg/ha/year.

BOD Scenario B presents a "worst case" situation. Poor husbandry and waste management practices result in effluent that exceeds Thai aquaculture standards for BOD during the mid-late grow-out period and at harvest. BOD production figures for these stages of the production cycle were drawn from a recent study of low salinity shrimp culture within freshwater areas of the Thai Central Plains Region[8] which corresponds to the findings of other recent studies[12,13,17]. BOD production in Scenario B is estimated at 2,768.5 kg/ha/crop and 5,537 kg/ha/year.

BOD Scenario C represents an intermediate case. It assumes that 50 percent of existing low salinity shrimp farms comply with effluent discharge standards, while the remaining 50 percent utilize poor management practices that results in non-compliance and sludge dumping.

The magnitude of water quality impacts associated with low salinity shrimp farming in the Bangpakong River Basin was estimated using shrimp pond area calculations (Figure 2), effluent production estimates[19], and the three BOD production scenarios outlined above. Assuming a shrimp farm wastewater outflow of 16,300 m^3/ha/crop, the operation of 18,531 hectares of low salinity ponds would generate approximately 332,613,500 m^3 of effluent per crop or 665,227,000 m^3 per year (assuming 2 shrimp crops per year are produced). A substantial proportion (59 percent) of the total effluent flows originate from shrimp farms located in the lower Bangpakong River (Table 1). High organic pollution loads in the Bangpakong East and West Bank sub-basins are associated with dense concentrations of low salinity shrimp farms in the Muang, Bang Khla, Ban Pho, and Khong Khuain districts of Chachoengsao Province. Effluent volumes are relatively smaller in the Prachinburi sub-basin (26 percent of the basin total), but are almost completely concentrated within the Ban Sang district located near the confluence of the lower Prachinburi and Nakhon Nayok Rivers. Only 15 percent of the total effluent flow is produced by shrimp farms in the Nakhon Nayok sub-basin, mostly located along the lower Nakhon Nayok River or operating within irrigation projects in the Ongharak and Muang districts.

Total annual organic pollution loads in the three BOD scenarios range from approximately 6 million kg/year (Scenario A – best case situation) to over 102 million kg/year (Scenario B – worst case situation). BOD production in Scenario C (a combination of good and poor shrimp farm effluent management practices) is estimated at approximately 54 million kg/year. The extreme difference in BOD production rates provided by the three scenarios is largely attributable to sludge handling practices. Shrimp farm effluents that contain sludge removed by wet flushing possess very high suspended sediments loads and are heavily enriched in both nitrogen and phosphorus. In the "worst case" management scenario (BOD Scenario B), slightly less than 90 percent of the total BOD load associated with each hectare of shrimp pond is attributable to pond sludge disposal. Only approximately 10 percent of the total BOD load within Scenario B reflects late grow-out period water exchange or effluent disposal at harvest.

A comparison of annual estimated organic pollution loads for other forms of intensive animal husbandry suggests that low salinity shrimp farming represents a large new source of agricultural BOD in the Bangpakong River Basin (Table 2). Depending on which BOD scenario is applied, low salinity shrimp farming could produce somewhat less or considerably more BOD per year than the intensive chicken or pig farming sectors. A more accurate estimate of shrimp farm BOD production is not possible because detailed data on sludge handling practices in the Bangpakong River Basin are unavailable. Given the explosive growth of low salinity shrimp farming in eastern Thailand, and the widespread prevalence of poor waste management practices, BOD loads are likely at least as large as those produced by intensive pig or chicken farming and could reach the levels described in BOD Scenario C.

Table 1: Estimates of BOD under different scenarios

Sub-Basins	Pond Area (hectares)	Effluent Volume[1] (m^3 / year)	BOD Scenario 1 (kg / year)	BOD Scenario 2[2] (kg / year)	BOD Scenario 3 (kg / year)
Nakhon Nayok River	2,861	93,268,600	932,686	15,841,357	8,387,022
Nakhon Nayok Sub-Basin	**2,861**	**93,268,600**	**932,686**	**15,841,357**	**8,339,815**
L. Prachinburi River	4,746	154,719,600	1,547,196	26,278,602	13,912,899
Hanuman River	0	0	0	0	0
Phraprong River	0	0	0	0	0
Prachinburi Sub-Basin	**4,746**	**154,719,600**	**1,547,196**	**26,278,602**	**13,834,590**
Bangpakong (west bank)	4,039	131,671,400	1,316,714	22,363,943	11,840,329
Bangpakong (east bank)	4,494	146,504,400	1,465,044	24,883,278	13,174,161
Khlong Luang	1,613	52,583,800	525,838	8,931,181	4,728,510
Khlong Thalat	777	25,330,200	253,302	4,302,249	2,277,776
L. Bangpakong Sub-Basin	**10,923**	**392,135,700**	**3,200,439**	**60,480,651**	**32,020,775**
Total Bangpakong Basin	**18,530**	**665,227,000**	**6,040,780**	**102,600,610**	**54,320,695**

Management implications

Existing water quality in many portions of the Bangpakong River Basin is not suitable for aquatic life or for water uses that involve human contact such as fishing, swimming, bathing[14]. The situation is particularly serious in the lower Bangpakong River during the dry season when nutrient loading from agricultural, industrial and municipal sources produce algae blooms and low dissolved oxygen levels. Construction of the Bangpakong Diversion Dam has also affected dry season water quality conditions, and it appears unlikely that this facility will operate as planned until organic pollution levels in the lower

Table 2: Annual estimated organic pollution loads for animal husbandry

SUB-BASIN	CHICKEN (BOD kg/year)	PIG (BOD kg/year)	LOW SALINITY SHRIMP (BOD kg/year)		
			Scenario A	Scenario B	Scenario C
Nakhon Nayok	7,651,875	1,030,778	932,686	15,841,357	8,339,815
Prachinburi	7,574,130	3,003,158	1,547,196	26,278,602	13,834,590
Lower Bangpakong	13,468,946	14,777,968	3,200,439	60,480,651	32,020,775
TOTAL BASIN	**28,694,952**	**18,811,904**	**6,040,780**	**102,600,610**	**54,320,695**

Bangpakong River are dramatically reduced[22].

Achieving the water quality targets outlined in the Action Plan to Improve Water Quality in the Eastern River Basins will require a major reduction in organic nutrient loads within the lower Bangpakong and Prachinburi Rivers (Pollution Control Department, 1998). Proposed remedial actions include limiting industrial waste flows, constructing municipal water treatment faculties, and reducing organic waste flows from intensive chicken and pig farms. However, a large number of low salinity shrimp farms have been constructed in the Bangpakong River Basin since these remedial actions were proposed. This additional source of organic pollution has undoubtedly increased total agricultural BOD production and placed further stress on water quality. The dry season also represents the main production period for shrimp. Given the likely contribution of shrimp farm waste to total annual agricultural pollution loads, and the implications this has for meeting BOD reduction targets, it is reasonable to conclude that low salinity shrimp farming is having a significant impact on the water quality in the Bangpakong River Basin.

Confidence in the assessment is affected by several factors. Firstly, water quality monitoring data are limited to the main channel reaches of the Prachinburi, Nakhon Nayok and lower Bangpakong Rivers. Information describing environmental conditions in tributary streams are unavailable, but given the more limited assimilative capacity of these systems, water quality impacts could be even more severe than those identified in the main river channels. Dry season water quality effects within irrigation districts could be particularly acute because outflow from areas are limited to prevent the intrusion of saline tidal flows from the main channel of the Bangpakong River. Assumptions concerning average annual shrimp crop production are also based on a relatively small data set, and very little information is available concerning sludge management practices. The latter issue is particularly critical given the influence of sludge on the overall production of organic pollutants by low salinity shrimp farms.

Controlling the regional water quality impacts associated with low salinity shrimp farming will be difficult, but eliminating the illegal disposal of pond bottom sediments into freshwater streams or irrigation canals is critical. Management actions that could reduce the prevalence of illegal sludge disposal include increased environmental monitoring, more stringent enforcement practices, and extension programs for shrimp farmers that focus on waste management techniques. Imposing a requirement for all shrimp farmers to construct and utilize waste treatment ponds could also reduce water quality impacts. Addressing waste management issues in the shrimp farming sector does not, however, guarantee regional water quality improvements. A wide range of agricultural, industrial and domestic activities produce organic pollutants in the Bangpakong River Basin, and a multi-sectoral pollution reduction strategies is required. In the absence of a broad-based approach, improved waste management practices introduced by shrimp farmers will have a limited effect on regional water quality.

Acknowledgments

Financial support for this study was provided by the Canadian Social Sciences and Humanities Research Council, and the International Development Research Center. Logistical support was provided by the Department of Aquatic Sciences at Burapha University in Bang Saen, Thailand. Digital and non-digital data sets were supplied by the Thai Land Development Department, Pollution Control Department, and Department of Fisheries. Maps were prepared by Ole Heggen of the Department of Geography, University of Victoria.

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