PROFILE

‘‘Low-Salt’’ Shrimp Aquaculture in Thailand: Goodbye Coastline, Hello Khon Kaen!

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ABSTRACT / Intensive shrimp culture has been confined to relatively narrow bands of land along the seashores of tropical developing nations due to the need for large volumes of saltwater for water exchange during the culture period. Recent developments in Thailand suggest, however, that this close association could soon be a thing of the past. Large numbers of Thai farmers are adopting low-salinity culture systems that rely upon sea or salt pan water that is trucked inland. This development greatly increases the potential for establishing shrimp cultivation much further from the coast than previously believed possible. The migration of intensive shrimp farming into freshwater environments, however, raises serious concerns over the disposal of pond effluents and the impact of saltwater intrusion on surrounding agricultural activities. In the absence of effective government regulation of the expansion and operation of the shrimp culture industry, supporting local nongovernmental organizations (NGOs) and community initiatives may be the only means of minimizing the negative impacts of shrimp farming on rural communities.

Black tiger shrimp[1] (*Penaeus monodon*) is the most widely cultured shrimp species in the world. World cultured production reached 758,000 mt in 1994, with most major producers registering a double-digit growth over 1993 (*Asian Shrimp News* 1995). To date, the establishment of intensive shrimp culture has been confined to relatively narrow bands of land along the seashores of tropical developing nations. This concentration has primarily been due to the need for large volumes of saltwater for water exchange during the culture period. Recent developments in Thailand suggest, however, that this close association could soon be a thing of the past. Over the past few years, Thai farmers have discovered that it is both feasible and profitable to grow tiger shrimp in former wet rice fields at distances much further inland from the coast than previously believed possible. The key to their success is the adoption of low-salinity culture systems that rely upon sea or salt pan water that is trucked inland. Given the widespread concern among shrimp farmers in Thailand’s coastal areas over production losses due to outbreaks of disease and virus, and the low profitability of wet rice production, Thailand could well experience an inland ‘‘shrimp rush’’ rivaling the boom and bust diffusion of intensive production along the coast during the past ten years.

This paper examines the development and ongoing adoption of low-salinity production systems for black tiger shrimp. We believe that this trend poses a major new land and water resource management challenge for Thailand, as well as for other countries with established or fledgling culture industries throughout Asia. To set the context for this discussion, the growth of cultured shrimp production in Thailand is first examined, followed by a review of the factors that have contributed to the development and adoption of low-salinity shrimp culture. We then consider the types of problems that low-salinity culture brings to rural areas whose economies presently depend on rice and freshwater fish cultivation, and we examine possible approaches for ameliorating the social, economic, and environmental impacts.

Cultured Shrimp Production in Thailand

Shrimp culture has been practiced for decades in Thailand. Like their counterparts in other Asian nations, Thai farmers in low-lying areas whose land would flood with seawater during certain parts of the year often practiced a rotation of rice culture and aquaculture (Ling 1977, Tiensongrusmee 1970). With rice yields being relatively low due to soil salinization, aquaculture was a welcome windfall as it provided low-cost protein for domestic consumption, and the sale

[1]Despite some confusion over the popular names ‘‘shrimps’’ and ‘‘prawns,’’ the convention in the literature is to use prawn for freshwater forms of palaemonids and shrimp for the others, particularly the marine species (Pillay 1990).

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of fish and shrimp at local markets helped supplement household incomes. As traditional aquaculture relied on tidal action for stocking and natural feeds, it was necessarily a polyculture because of the inability to control the composition of the seed stock. Shrimp usually made up a small percentage of the harvest in such systems as the species trapped in the paddy fields were incompatible or environmental conditions were not suitable for high survival rates. The shrimp species raised were banana shrimp (*Penaeus merguiensis*), school shrimp (*Metapenaeus ensis*), and a small volume of black tiger shrimp (*Penaeus monodon*) (Saisithi 1989).

The low productivity associated with extensive forms of shrimp rearing, combined with the ready availability of catch from the open sea, meant that few people were interested in investing in shrimp culture. This situation changed dramatically in the 1980s with the development of new mariculture technologies that enabled the propagation and raising of tiger shrimp in captivity. Of critical importance was the development of specially formulated artificial feeds that stimulated growth and facilitated high stocking densities, thereby opening the door to intensive culture on a commercial scale (Csavas 1993). Consumer demand for shrimp also began to soar at a time when the wild catch was stagnating (Weber 1994). Although virtually unknown to consumers in Japan, Europe, and North America prior to the 1980s, black tiger shrimp quickly became the most widely cultured shrimp species in the world. Their domination of the world market has come about largely due to the facts that they grow rapidly to commercial size, have a low mortality rate when favorable conditions are provided throughout rearing, and there is no cannibalism. They are also exceptionally tolerant of fluctuations in temperature and salinity (Laubier 1990).

Thailand's intensive shrimp culture industry first established itself in the upper Gulf of Thailand provinces of Samut Sakhon, Samut Prakan, Samut Songkhram, Chachoengsao, Phetchaburi, and Bangkok (Figure 1). High market prices fueled by international demand offered the potential of high profit rates, which attracted a throng of investors, few of whom were familiar with aquaculture. Although startup costs were high, investment could be recouped from less than two crops of shrimp, which was easily managed by the majority of growers in under one year (Chong 1990). In just two years, (1987–1989) some 5000 ha of what was previously salt pans, extensive shrimp ponds, and wetlands were converted to intensive culture, so that by 1989 cultured shrimp production exceeded Thailand's wild catch for the first time (Kongkeo 1994). Shrimp exports grew from 28,063 MT in 1986 to 202,000 MT by 1995 (Figure 2). As a result of the intensification of methods and expansion of culture area, Thailand by 1995 had established itself as the world's largest producer of cultured shrimp.

In terms of Thailand's national balance of payments, shrimp culture has been an unimagined success. Growers have benefited from high investment returns and an expanding market. Aggregate economic and production statistics, however, provide little indication of the large-scale social, economic, and environmental disruptions that the industry has wrought within coastal communities. The widespread proliferation of intensive culture systems has contributed to the loss of habitat and nursery area for aquatic species owing to the removal of mangrove forests; the discharge of particulate and dissolved nutrient-laden effluent from shrimp ponds has adversely affected coastal water quality; and groundwater aquifers and domestic water supplies have been contaminated by saltwater intrusion, as have abutting paddy rice areas (Baird and Quarto 1994, Dierberg and Kiattisimkul 1996, Flaherty and Karnjanakesorn 1995, Thailand Development Support Committee 1990, Yadfon Association 1996).

Several problems have also arisen within the culture industry itself. The much touted financial successes have increasingly been tempered by growing problems with outbreaks of disease and virus. Shortly after the introduction of intensive culture, many farms began to experience high mortality rates. This has been attributed to a variety of factors, many related to inadequate regulation of the operation and expansion of the industry by government. Owing to a lack of coordination of pond construction and water supply infrastructure, water quality along the coast quickly deteriorated due to the discharge of pond effluents (Philips and others 1993). Poor water quality contributed to outbreaks of diseases, which were quickly transmitted between the densely concentrated farms. In addition to self-pollution of culture areas, the siting of ponds near urban, agricultural, and industrial developments made them vulnerable to external contamination of water supplies (Lin 1992). Poor farm management owing to limited technical skills within the pool of new entrants to the culture industry also created problems. Overfeeding, overblooming of phytoplankon, and poor water circulation contributed to self-pollution of the culture ponds (Kongkeo 1994). The rush to cash in on the promise of instant wealth led many new farmers to stock their ponds at extremely high densities, often exceeding 90 postlarvae (PL) per square meter (Miller 1996), which is three times the recommended level of 30 PL/m^2 (see Chanratchakool and others 1995). The slump in international shrimp prices during 1989 also provided incentive for farmers to attempt ever higher

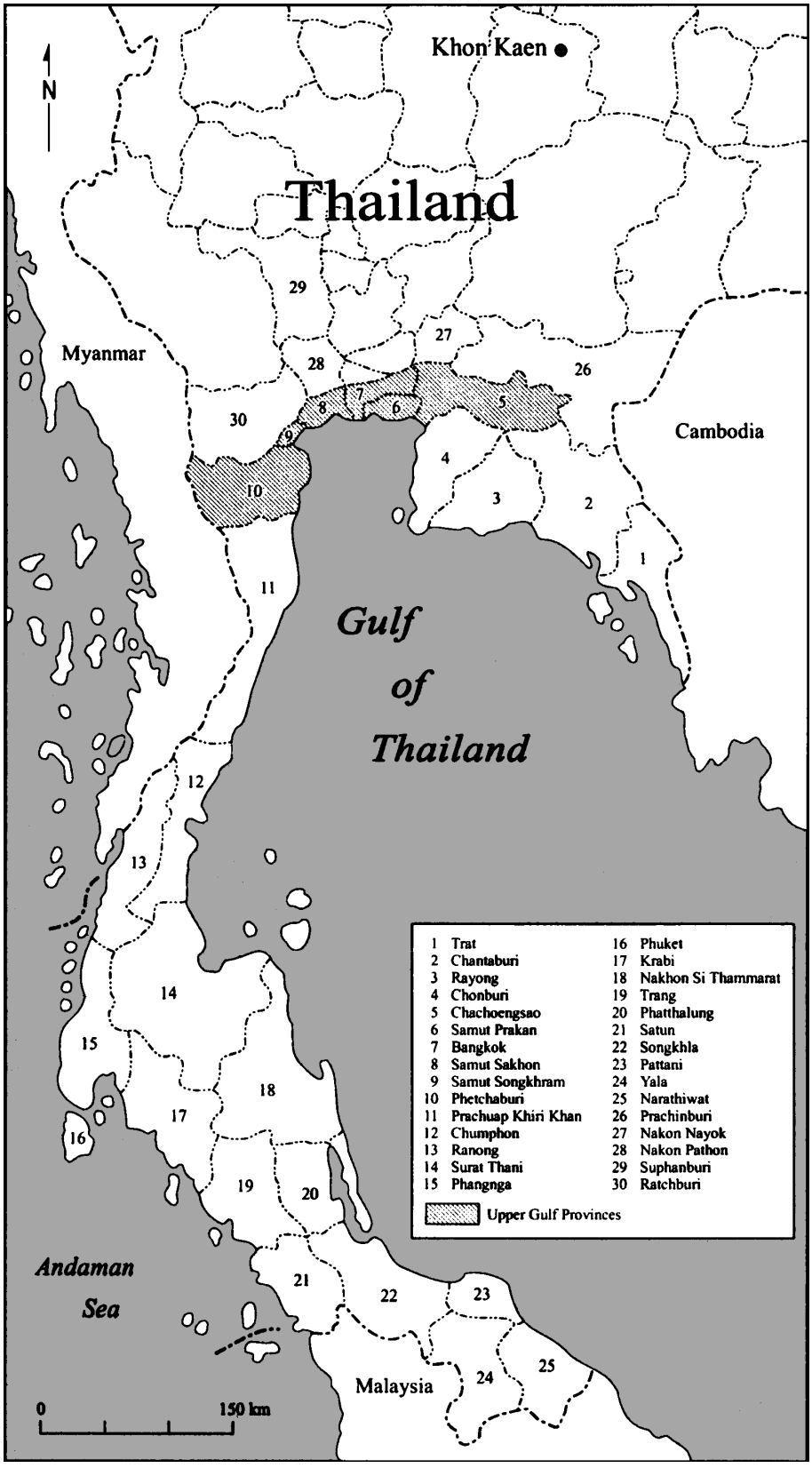

Figure 1. Thailand's central and southern provinces.

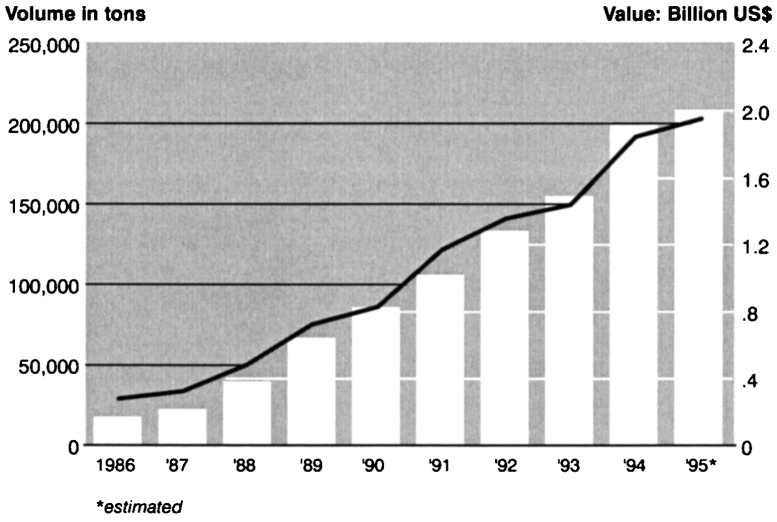

Figure 2. Shrimp production in Thailand, 1986–1995.

stocking densities in order to maintain profit levels. High stocking densities, however, greatly increase the risk of crop failure as larger amounts of waste are produced in the pond, which then poison the system (Lin 1993). With growing numbers of ponds succumbing to disease, farmers began to make heavy use of antibiotics as a prophylactic measure. Unfortunately, there is evidence that this practice actually has detrimental effects on shrimp health, as it breaks down the immune systems of the shrimp, thereby increasing their susceptibility to viruses (Brown 1989).

The deteriorating environmental conditions in the upper gulf provinces resulted in significant reductions in growth and survival rates, as well as contributed to episodes of large-scale mortalities. The high cost and risk associated with trying to reestablish production in areas hit by disease led to the large-scale abandonment of culture areas in Central Thailand, leaving behind a legacy of abandoned and deteriorating culture ponds and water supply canals that now lie idle. In the province of Samut Sakhon alone, 3,555 ha of shrimp ponds were abandoned (Office of Environment Policy and Planning 1994). Many small-scale farmers were squeezed out of business by crop failures, a few reverted to extensive shrimp culture methods, while others switched to lower value, and much less risky, fish and crab culture (Miller 1994). The domino effect of crop failure and pond abandonment in Thailand's upper gulf provinces was of sufficient magnitude to have effected a dramatic reduction in total shrimp production. Two factors, however, have been operating to offset these production losses.

The first factor is that as farmers came to realize how vulnerable their operations were to water pollution, they changed their culture strategies. The most widespread adaptation was a movement away from open culture systems, based on high rates of water exchange during the culture period, to semiclosed recycling systems in which pond water is treated after each crop and then reused (Wanuchsoontorn and others 1993). This system helped protect farmers from the activities of surrounding growers who continued to discharge pond effluent into shared waterways or who had encountered problems with disease. Farmers have also improved their management techniques, having taken note of the problems associated with using high stocking densities, failing to allow sufficient time for proper cleaning and drying of pond bottoms, and the risk involved in using expensive antibiotics to control disease. Many are now willing to settle for two crops per year rather than three, which provides time for their ponds to rest. The second factor that has helped maintain aggregate production levels is that new culture areas were developed, primarily along the southern Gulf of Thailand coast and the Andaman Sea, by both local farmers and larger absentee operators who migrated from the central region (Lin 1995). Unfortunately, these areas are also beginning to experience major outbreaks of disease and virus. Local informants in the south indicated that 50% or more of coastal shrimp farms were idle in June 1996 owing to problems with disease, and aggregate statistics suggest that shrimp production dropped roughly 10% between 1995 and 1996, to 205,000 tonnes (Khao Kung 1997).

The increased incidence of disease and declining yields has generated a large research effort aimed at improving the long-term sustainability of the industry. Improved farm management, better treatment of effluent, and technological advances in feeds and disease control are all heralded as ways of making intensive

shrimp culture sustainable (Chen 1993, Phillips and others 1993, Tookwinas 1996). Support for this research effort may also be driven, in part, by the fact that the option for farmers to simply abandon their ponds and move to new areas along the coast is not as viable as it once was. The amount of Thailand's coastline that has yet to be exploited for one use or another is quite limited. Wet rice paddy land close enough to the sea for direct access to salt water or indirectly through canals constitute the ideal sites, but most of these sites are now occupied. In addition, land prices in Thailand's coastal areas are becoming prohibitively expensive for shrimp culture owing to strong demand for tourism, residential, and other ocean-based developments.

The initial wave of shrimp farming removed large areas of Thailand's mangrove forests. Although the exact contribution of shrimp culture to mangrove destruction is a matter of some dispute, with some observers arguing that shrimp farming is not the major cause (see, for example, Tookwinas 1996), the majority of analysts believe that shrimp farming has been the largest single agent (Onchan 1990, Raine 1994). An important factor that helped facilitate the conversion of mangroves to shrimp farming was that these areas were typically demarcated by the forest department as reserved forest. However, the forest department had neither the internal capacity nor the external support necessary among other government agencies to effectively control this land (Vandergeest 1996). In practice, mangroves have for many years been treated by local inhabitants as an open-access or common property resource that provided direct benefits in the form of fuelwood, building materials, charcoal, and other household needs, as well as the indirect benefits of maintaining water quality, preventing shoreline erosion, and providing fish habitat. With the advent of shrimp farming, however, some resident and many outside investors were able to occupy this land without having to purchase it from local people and without much interference from the forestry department. The only exception was when this incursion occurred in the more closely guarded national parks or wildlife sanctuaries. Even here, however, government agencies have often been unable to counter the powerful interests promoting the expansion of shrimp farming (Enright 1995).

The most recent wave of intensive shrimp culture development appears to be avoiding mangroves for several reasons. First, further expansion into mangroves has been made more difficult by the public controversies over rapid deforestation in Thailand, including the loss of mangroves. The Thai government has now undertaken several steps to conserve and rehabilitate mangroves (see Nissapa and Charoenchiratrakul 1995). Although enforcement of the laws and regulations covering mangrove use continues to be a problem, the remaining mangroves, mostly along the Andaman Sea, are also being monitored by NGOs as well as government departments that are increasingly mindful of further public criticism. Second, farmers may be avoiding mangroves because of the now widespread realization among growers that while the intertidal zone is well suited to traditional extensive culture systems, it is not well suited to intensive culture. Mangroves often contain acid sulfate soils that must be treated with lime, deep ponds cannot be built because they are difficult to drain, drying the pond bottoms is impossible, and construction costs are high (*C.P. Shrimp News* 1994). On the west coast, new shrimp ponds are currently being excavated at higher elevations on the back edges of mangroves, leaving most of the mangrove untouched. Pond effluents, however, continue to be released into the mangroves. Although mangroves can act as natural filters, the point at which their carrying capacity would be overloaded is as yet unknown (Robertson and Phillips 1994).

Despite the increased incidence of disease, declining yields, saturation of potential sites along the coast, and growing public and scientific concern over the social and environmental consequences of shrimp farming, total shrimp production in Thailand continued to rise through 1995. Although production declined by 10% between 1995 and 1996, this is considerably less than that suggested by the large area of idle and abandoned ponds. Many analysts believe that the industry has peaked and will continue to decline as there are few sites left to exploit (Dierberg and Kiattisimkul 1996, Lin 1995). This assessment, however, may prove to be premature. Although the location of culture ponds has in the past been confined to areas close to the sea owing to the need for large volumes of saltwater, during the past two years many new farmers have been adopting low-salt culture strategies. This development greatly increases the potential for establishing shrimp cultivation much further inland than previously believed possible, thereby opening up vast new tracts of land to the industry.

The Low-Salt Innovation

Conventional intensive shrimp rearing begins by mixing salt or brackish water with freshwater in culture ponds in proportions calculated to obtain the desired salinity level. In coastal and estuarine areas seawater salinity undergoes marked fluctuations because of the input of fresh water, which varies according to runoff from the land and also with tidal changes. The salinity

of natural seawater in the Gulf of Thailand falls in the range of 29–31 ppt (Network of Aquaculture Centres in Asia Pacific 1994). The recommended salinity level for optimal growth of tiger shrimp varies, however. Some analysts suggest a range of 15–25 ppt and cite slower growth and problems with shell development in low-salinity water (Lymsuwan 1992). Others recommend salinities in the 10–30 ppt range (Chanratchakool and others 1995). Black tiger shrimp, however, are very tolerant of variations in salinity and can be grown outside of these ranges. The migration of shrimp farming from central Thailand to the east coast of the peninsula was facilitated by the development of techniques permitting the use of full-strength seawater, since the volume of available fresh water on this coast is very low. On the Andaman sea some farmers prefer to use full-strength seawater in low water exchange systems, which can bring salinity levels up to the 40–45 ppt range (Kongkeo 1994). The growth rate of shrimp, however, is slow in high-salinity water (Tookwinas 1996).

In conventional systems the incentive for locating culture ponds near the coast was accentuated by the need for high water exchange rates. In order to maintain water quality throughout the culture period, uneaten food and other waste products were removed through water exchange. Recommended water exchange rates range from a low of 5%–10% volume per day at the beginning, increasing to 30%–40% in the final stage (Lin 1993). For each crop of shrimp, then, the volume of salt water required was quite large. Low water exchange systems have reduced rather than eliminated the need for seawater.

This account of the factors that have led to the concentration of shrimp farming along Thailand's coastline is now being rendered out of date by the migration of shrimp farms into wet rice growing areas many kilometers from the coast. During a survey of shrimp farms and hatcheries conducted throughout Thailand's coastal provinces in June 1996 and 1997, we found that inland shrimp farmers are starting culture with pond salinity levels that range between 10 and 15 ppt, although some operations begin growout at 5 ppt. By the time of harvest, pond salinity levels have usually fallen to zero. All the farmers interviewed use low water exchange systems both as a means of protecting themselves from external sources of water pollution as well as to maintain salinity levels in their ponds. Salt water is trucked in at the beginning of the culture period, and fresh water is added during grow out to offset water losses due to evaporation and seepage. The feasibility of low-salinity culture, combined with high market prices for shrimp, has made it economically viable to truck salt water in from the coast. Intensive shrimp farming is now diffusing into many areas of central Thailand that have previously been considered part of Thailand's rice bowl.

The introduction and expansion of low-salinity shrimp culture hinges upon the availability of suitable *Penaeus monodon* postlarvae. Thailand has over 1500 small backyard shrimp hatcheries scattered along its coast, most of which are family owned and operated (Kongkeo 1994). While some hatcheries have adjusted their operations so as to supply PL directly to inland farmers, the diffusion of low-salinity culture into rice growing areas is largely being facilitated by the establishment of small-scale nurseries that specialize in acclimatizing PL to lower salinity levels. Nursery operators purchase PL10 from the hatcheries and transport them to their inland ponds. There the salinity level is stepped down over a three- to five-day period from 30 ppt, which is the minimum salinity level maintained in the hatcheries, to 10 or 15 ppt, depending upon the requirements of farmers in the area.

In other ways, low-salinity culture is very similar to conventional intensive culture strategies that have developed along the coast, in that it relies upon artificial feeds, aerators, and a wide variety of drugs and chemicals (see Tonguthai 1996). Farmers indicated, however, that the shrimp grow slower and stay in the ponds for a shorter period of time, which results in a smaller harvest size. Low-salinity farmers typically had harvests of 55 pieces/kg which sells for US$5.90/kg, while coastal farmers can achieve 35 pieces/kg which sells for US$7.50–7.90/kg. Local consumers find, however, that the flesh of shrimp reared under low-salinity conditions is not as firm as that of shrimp reared in more saline water, and some observers suggest that the taste of shrimp improves with increasing salinity (Csavas 1993). The rapid reshaping of overseas consumer tastes in favor of black tiger prawn during the 1980s, however, suggests that these characteristics are unlikely to pose an insurmountable obstacle for marketing low-salt shrimp. Differences in taste and texture could prove difficult to detect, as shrimp from inland and coastal operations are thrown into the same product mix by processors.

Although the rapid growth of low-salinity culture is a recent phenomenon, the technique appeared relatively early in the establishment of Thailand's intensive culture industry. It was not, however, developed or promoted by researchers associated with academic institutes or large corporations. Rather it came about through the efforts of innovative small-scale farmers who were endeavouring to deal with practical problems and who tried techniques that trained researchers might have dismissed. Unlike Central and South America, where most cultured shrimp production comes from a relatively a small number of large private or

corporate farms (Lester 1992), about 70% of the shrimp farms in Thailand are small, owner-managed operations with a few ponds covering less than 1.6 ha, while some 90% own no more than ten ponds (*Asian Shrimp News* 1994, Gronski 1997). Respondents indicated that the first field trials for low-salinity culture were undertaken by farmers in the upper gulf provinces roughly eight or ten years ago. These farmers were situated several kilometers in from the sea along streams and canals that contained brackish water owing to tidal action. Salinity levels in these areas, however, varied greatly depending upon the season. As their ponds were idle during the wet season, their response was to work with local hatcheries to develop culture techniques that would allow them to recoup their investment costs faster, by growing black tiger shrimp year around by using low-salinity water in their culture ponds. Once it was established that shrimp could survive under low-salinity conditions, farmers soon determined that it was economical to excavate culture ponds in rice paddies well inland from the coast, and simply truck sea or salt pan water to the site. Shrimp farms are now pervasive in the province of Chachoengsao, which is renown for its high-quality rice production, and are now being developed in excess of 75 km from the coast. Respondents indicated that a 2-h drive from the sea is the current upper limit within which it is economically viable to transport saltwater. Although low salinity culture first appeared in the central region, we found that shrimp farmers situated several kilometres inland along the peninsular east coast, have also adopted similar methods.

The exact number of ponds or the culture area devoted to low-salinity production is not known. Production is scattered throughout many provinces in a band that stretches many kilometers in from the sea. As most small-scale farmers, coastal and inland, do not register their ponds, it is difficult to assess how far from the coast shrimp farming has moved or the amount of area involved. Fisheries Department officials, however, estimate that it could be as high as 2400 ha in one of the major producing areas: the combined provinces of Nakorn Nayok, Prachinburi, and Chachoengsao. Our investigation revealed that it is also of growing importance in the provinces of Nakorn Pathom, Supanburi, Samut Songkram, and Rachburi.

Given the limited amount of information available about the area and extent of low salinity shrimp aquaculture, it is also difficult to assess precisely its contribution to total shrimp production in Thailand. If, however, we assume a low yield of 4 MT/ha, one crop per year instead of the two that many farmers now achieve, and apply this to a conservative estimate of 3000 ha of ponds in the country, this gives an annual production in 1996 of at least 12,000 MT, which would comprise about 4% of total Thai production. While this estimate is obviously very rough (and in our view, conservative, given the rate at which new ponds are being developed) the general conclusion is nevertheless clear: low-salinity shrimp farming is making a substantial contribution to Thailand's total shrimp production. Its importance is also poised to increase in the future should production in coastal areas decrease or as increasing numbers rice farmers looking for more profitable activities switch to shrimp.

Factors Underlying Adoption

The adoption of low-salt shrimp culture has been facilitated by the convergence of a series of conditions, a convergence that may also hold in other Asian countries. First are the vested interests of aggressive ancillary industries that depend upon shrimp rearing. Intensive shrimp farming requires enormous quantities of artificial feeds, chemicals, and capital equipment. As the shrimp culture industry has grown, so too has the demand for services to the industry. The manufacturing and sales activities that support the culture industry now represent a major economic force. It is estimated that in 1995, the shrimp culture industry and supporting businesses in Thailand directly employed up to 190,000 laborers, with more workers employed by supporting businesses (Gronski 1997). As shrimp farmers experience problems with water quality and disease, these companies have invested heavily into research programs designed to overcome them. Technical remedies include new water treatment chemicals, vaccines, and medicated feeds. These companies also have a strong incentive to promote the expansion of the industry into new areas by providing credit and extension services to prospective farmers. Feed company representatives in Chachoengsao, for example, frequently visit rice farmers who are adjacent to shrimp growing operations to talk about the economic benefits of shrimp production, provide seminars on the methods of culture, and offer free water quality diagnostics for those who enter the industry. Some even offer to check the PL for disease prior to shipment. The expansion of low-salinity culture also comes about by word of mouth among farmers. Most of our respondents learned how to grow shrimp from friends and neighbours, with some additional technical assistance from agents selling feed and other inputs. Nothing, of course, promotes the industry more effectively than word of successful harvests and high profits. Although shrimp farming is now recognized as a highly risky venture, the farmers we interviewed had no difficulty raising investment capital.

A second important economic factor underlying the adoption of low-salinity shrimp farming is the squeeze on profitability in rice farming. In contrast to grains such as maize and wheat, for which prices have risen substantially in the past five years, the price of rice rose only marginally during 1990–1993, and stagnated during 1994–1996 (United Nations Conference on Trade and Development 1994, 1996). At the same time, rapid economic growth in Thailand has produced a labor shortage and driven up the cost of labor. Villagers throughout the south central plains can easily obtain wage labor in factories or construction, and studies of rural economies in other parts of Thailand now routinely find that villagers are obtaining the bulk of their income from off-farm labor (Pearson 1996, Rigg 1996, Richie 1996). Presently, Thai agricultural laborers are paid a wage of about US$4.00 per day, several times more than the prevailing wages of a decade ago. In response, many farmers are deemphasizing rice cultivation and, where possible, shifting toward less labor-intensive crops like fruit, or high-value crops that provide sufficient income to pay for the rising cost of labor. The ongoing restructuring of agriculture to capital-intensive, high-value crops is exemplified by the shift to intensive shrimp farming.

The lower central plains have long been characterized by relatively high land inequalities and landlessness (Rigg 1991a) and thus include a strata of relatively large landowners who need to either hire expensive labor or rent out their land. In our interviews, most landowners in the central plains reported that they were growing rice at a loss. These landowners are also the group best able to obtain access to the capital necessary to take advantage of a shift to more capital-intensive shrimp farming. In some cases, respondents began their move away from rice by converting their rice paddies to freshwater aquaculture. Once they had invested in culture ponds, shrimp farming was simply a second step in the process of intensification.

Although there are some absentee owners among the inland shrimp farmers interviewed, most are owner-operators. The majority have only a few ponds located on land close to water supplies and grow shrimp using only household labor. Labor for harvesting is often provided by the purchasing agent or even mobilized as exchange labour. In contrast, larger operations that rely on hired rather than household labor for their day-to-day operation are much more sensitive to the rising cost of labor. In Ranong and other provinces close to the border with Myanmar, labor shortages have led to widespread use of undocumented foreign workers in shrimp farming as well as in other activities such as construction, restaurant work, or on fishing boats. In Ranong, Burmese laborers on shrimp farms are paid a mere US$2.00 per day. However, they are only permitted to work within designated areas of Thailand not far from the border with Myanmar. In other coastal areas the rising cost of labor, as well as conflicts with local farmers who enter into contracts on company schemes, have helped undermine the competetiveness of operations that are dependent on hired labor or contract farming.

The case of one successful farming family in Samut Songkram aptly illustrates the attraction of low-salt shrimp farming for inland landowners looking for an alternative to rice. When the authors interviewed this family in June 1996, they had recently excavated three small ponds from their paddy land—two for shrimp culture covering just over 0.3 ha, and one for sedimentation. As their land was located 3 km inland from the coast, and there was no tidal based movement of seawater into this area, they purchased salt water from the operator of a local salt pan. For each crop, two truckloads of salt pan water (with a salinity level around 100 ppt) costing US$90 each were required. Together with other production costs for feed, chemicals, labour, etc., they had invested US$3160 for their current crop. With a stocking density of 30 pieces/m^2, the level recommended by the Department of Fisheries but less than half of what some farmers in the area use, they had just harvested 1 MT. This had been sold for US$6000, giving a profit of US$2840. The US$180 investment for trucked saltwater represented less than 10% of the total production costs for one crop and did not dig deeply into their profit margin. They anticipated growing three crops of shrimp this year. Had they continued to grow rice, gross income from this land would probably not have exceeded US$200 and, given the prevailing cost of labor and other inputs, their profit would have been negligible.

A third factor that is crucial to the spread of shrimp farming into rice growing areas is that the water infrastructure needed to support shrimp culture is already in place. Wet rice cultivation in river deltas is usually based on continual supplies of fresh water delivered via canals. As with other rice-growing river deltas in Asia, the Thai Central Plains are criss-crossed by an intricate network of canals that supply and drain water, some of it built 100 years ago as Bangkok elites organized the commercial production of rice for the world market (Feeny 1982). This infrastructure can easily be turned to servicing shrimp farms. The importance of this infrastructure is illustrated by comparing the central region with the Ranot/Hua Sai area on the east coast of southern Thailand, where water infrastructure is poor and rice farmers had previously depended

on the heavy rains not available further north. The government is currently making huge investments in water infrastructure in these districts. One project in Hua Sai has a budget of close to US$10 million (according to one Department of Fisheries official) just for building the facility. These systems are intended to carry seawater to shrimp farmers, carry away waste water, and reduce conflicts with rice farmers by keeping the saltwater infrastructure for shrimp separate from canals used for agriculture. In effect, these investments were made a long time ago in the central plains, when these areas were first opened up for commercial rice production. Unfortunately, shrimp production in the Hua Sai–Ranot area may collapse before the projects are finished, while many small-scale operators will be unable to access these services.

Fourth, associated with the declining profitability of rice is the fact that land costs are lower inland they are along the coast, where prices and rents have soared owing to the demand generated by shrimp farmers and other land uses. In the south, for example, land rents for shrimp farming in coastal areas average US$2000/ha/yr. Land rents for shrimp farming in areas removed from the coast typically fall in the range of US$500–750/ha/yr. Although these rents are low in comparison to that paid by shrimp farmers in coastal areas, they are very high for areas that are predominantly rice growing. The low profitability of rice, combined with the easy availability of off-farm work, has provided a strong incentive for many small landowners who do not wish to undertake shrimp farming themselves to rent out their land to local or nonlocal shrimp farmers.

Fifth, the rapid expansion of low-salinity culture into freshwater areas has been facilitated by the lack of institutional control over shrimp farming operations in Thailand. Historically, the government has promoted shrimp culture both as a means of generating foreign exchange and of improving rural income levels (Flaherty and Karnjanakesorn 1995). More recently, faced with a outpouring of concern from community groups, academics, and NGOs over the adverse environmental and social effects of shrimp farming, a variety of measures to control the expansion and operation of the industry have been enacted. Indeed, one of the regulations for shrimp farming announced by the Department of Fisheries in November 1991, forbids draining salt water into public freshwater systems or farming areas. A general lack of enforcement and coordination between government agencies, however, means that shrimp farms can be established in rural areas with little fear of government intervention. Small-scale rice-growing households, therefore, have very limited means of protecting themselves from the deleterious environmental impacts that may be generated by shrimp culture operations.

Sixth, the prevailing view is that farmers who are practicing low-salinity shrimp culture well in rice growing areas have a lower risk of crop failure due to disease than farmers who are located in congested shrimp farming areas along the coast. It is extremely difficult to generalize about the risks involved, however, as water quality, both fresh and sea, varies so much from one location to the next. There are also many different pathogens that affect Thailand's shrimp industry (see Flegel and Sriurairatana 1993). Although Kongkeo (1994) argues that major pathogens of tiger shrimp such as yellow head virus (YHV) and white spot baculovirus (WSBV) hardly occur in freshwater, there is no reason to believe that these pathogens will not move to freshwater environments.

On the one hand, inland farms have the advantage of being more dispersed than the tightly concentrated culture operations along the coast. This helps to reduce the risk of water contamination by adjacent operations and the transmission of disease between ponds. However, this advantage is offset by other factors. As the density of inland culture ponds increases, farmers may encounter the same problems with freshwater quality deterioration as those being experienced by growers who are located along the coast. Furthermore, in many parts of the Gulf of Thailand, seawater contains high levels of domestic, agricultural, and industrial wastes. Contaminated seawater has already been identified as a critical problem for shrimp farmers in coastal areas (*Bangkok Post* 1995). Although the use of hypersaline water from local salt pans may contain fewer pathogens, not all farmers rely upon this source. Finally, one source of viral pathogens that coastal and inland shrimp farmers are equally vulnerable to is the seed stock. A significant incidence of infection is being discovered in wild brookstock and postlarvae (Browdy 1996). In June 1996, all the coastal farms we visited reported serious problems with disease, while the inland farmers reported few if any problems. In June 1997, however, inland farmers indicated that they too were having serious problems with disease.

Discussion

The adoption of low-salinity culture has received relatively little attention in the literature, although Dierberg and Kiattisimkul (1996) and MIDAS Agronomics (1995) both note its existence and briefly comment on the problem of saltwater intrusion. Nevertheless, the prevailing view appears to be that this type of culture is quite localized and of negligible consequence both in terms of production and its environmental impact (see

Kongkeo 1994). We believe, however, that the growing popularity of this method has important implications for rural communities in Thailand. The low returns available from rice cultivation have helped create an economic environment in which there is no shortage of fresh culture sites available for purchase or short-term lease. The migration of intensive shrimp farming into freshwater environments raises serious concerns over the disposal of pond effluents and the impact of saltwater intrusion on surrounding agricultural activities. Conflicts arising from the contamination of freshwater canals by pond effluents have already emerged. In response to criticisms about the deteriorating quality of surface water, many inland shrimp farmers blame other agricultural operations such as piggeries and slaughterhouses, which release effluents into freshwater canals, as being the main problem (Miller 1996). They maintain that inland shrimp farming is more benign environmentally than culture that is concentrated along the coast and are also fearful of any attempt to regulate their activities. However, while a variety of activities are contributing to the deterioration of water quality in rural areas, there can be little doubt that the discharge of toxic effluents and the importation of salt into freshwater areas by shrimp farmers will have long-term and perhaps irreversible impacts on rural land and water resources, much to the detriment of the people in surrounding communities. Salt not only leaches directly out of the culture ponds, but farmers remove sediments from the pond bottoms after harvest and typically dump them nearby. These piles of sediment contain large amounts of salt that can be leached out by rainfall. This leachate, in turn, can contaminate both surface and subsurface bodies of freshwater by increasing their salinity (Boyd 1995). The problems of soil and water contamination in rural areas are further augmented by the large volumes of salt water that are brought in to support the operation of the shrimp nurseries.

To date, efforts to control the expansion of the shrimp culture industry in Thailand have been largely ineffective. Large areas of mangrove forest have been lost, estuaries polluted, and agricultural areas rendered near useless after massive abandonment of degraded shrimp ponds. The ability of the Thai government to regulate the expansion of shrimp farming is hindered by a sectoral approach to resource management. As in other states, the Thai bureaucracy is complex and hierarchical. Agencies with overlapping responsibilities are as likely to compete as cooperate with each other. No single national agency in Thailand is responsible for coastal management or has jurisdiction over both marine and land areas. Indeed, many of the agencies involved in the regulation of coastal areas have conflicting interests and mandates. At present, six ministries comprised of 21 departments have some form of responsibility for activities dealing with coastal zone management (Boromthanarat and Chaijaroenwatana undated). Fishery resources are protected and managed by the Department of Fisheries, while the Royal Forestry Department has responsibility for mangrove areas. Other agencies such as Ministry of Commerce Affairs and the Board of Trade are empowered to regulate the import and export of fish commodities. The Ministry of Interior has jurisdiction over civil affairs as well as land not claimed by other government agencies. Rivalry among these ministries often results in policies that are promoted by one agency being ignored and/or undermined by others (Rigg 1991b, Vandergeest 1996). As a result, one agency often promotes an activity that contradicts the mandate of another.

The Department of Fisheries has the most direct and extensive involvement with shrimp farmers. However, the department's extension mandate means that it is often more interested in promoting shrimp aquaculture and providing technical assistance to growers than in facilitating greater cooperation among farmers in managing shared water resources or in resolving the conflicts over resource use between growers and local communities, which are crucial to the survival of this industry in the future. To them, the expansion of shrimp farming may well represent a welcome expansion of jurisdiction. Local Ministry of Interior officials are left to deal with the conflicts resulting from environmental degradation, but these officials are not highly motivated to do so since they often cannot resist participating in the high short-term profits available from shrimp farming themselves. Some may simply not appreciate how damaging shrimp culture operations can be to rural communities. The Royal Forestry Department claims jurisdiction over mangroves but until recently did not have the capacity or will to monitor and protect these important ecosystems. More importantly, there is no equivalent agency for monitoring the environmental impacts of shrimp farms locating in agricultural areas, except perhaps for the Department of Irrigation, which is concerned with water infrastructure. Other agencies simply do not have the capacity to become closely involved with the thousands of small shrimp farm operators, nor are they willing to oppose the major companies involved directly or indirectly in shrimp farming. As a result, limited attention has been given to ensuring that aquacultural development proposals comply with Thailand's existing environmental laws (Sainate and Wongphiromsan 1992). Many of the early developments were started by large investment loans (Gronski 1997), and the rush into an activity providing quick profits soon overwhelmed the regulatory capacity of concerned agencies.

Dierberg and Kiattisimkul (1996) suggest that a more comprehensive and integrated approach to dealing with the problems surrounding the shrimp culture industry is urgently needed. Their suggestions include less centralized planning and more local involvement, more cooperation between government agencies, and devising a coastal zone map to identify areas appropriate for new pond construction. While we certainly agree that a more comprehensive and more decentralized approach is desirable, we also believe that these reforms are not sufficient for addressing the problems generated by the shrimp culture industry in the short-term. Even if a national program of decentralization were to be adopted, it is likely to encounter problems due to strongly held views regarding encroachment of other departments into the mandate of the various agencies involved (Vandergeest 1996). Such a program would also fail to address the lack of agency capacity to monitor and regulate a highly mobile and quickly established activity that is carried out by thousands of small-scale operators throughout the nation's coast. Zoning areas as suitable for pond development has considerable intuitive appeal. However, this implies that areas outside the zone would not be developed for shrimp culture. Such a scheme, taken on its own, is unworkable in the Thai context. Even the status of ''national park'' has not been sufficient to protect Khao Sam Roi Yot from extensive encroachment by shrimp farmers (Enright 1995). Indeed, the emphasis placed on regulating new pond construction by mapping out appropriate coastal areas not only seems to work against decentralization, but also misses the emerging new trend in shrimp farming in Thailand: the move inland.

The social and environmental problems being generated by the shrimp culture industry are very much here and now. The lack of institutional control and bureaucratic inertia suggest that other means must be developed quickly in order to avert or at least minimize the direct impacts of shrimp farming on the environment and the subsequent indirect impacts on the welfare of rural people. International environmental groups have proposed a variety of strategies, including boycotts, certification and consumer labelling programs, and green taxes, as possible means of compensating for weak government control over the shrimp farming industry not only in Thailand, but throughout tropical developing nations that are host to the industry (Mangrove Action Project 1996, Natural Resources Defense Council 1996). There is no consensus among these groups, however, over either the feasibility or desirability of implementing these initiatives. Apart from the many technical and practical issues inherent in the establishment and monitoring of such programs, there is also concern about the impact these measures would have on the many rural households that rely on the industry, directly or indirectly, for employment (Nixon 1996).

We believe that the most promising area for regulating the migration of shrimp farming into freshwater environments, at least in the short-term, is through support of local NGOs who are actively trying to raise levels of awareness in rural communities about the many social and environmental consequences of shrimp culture. Up to now few rural communities have been aware of the detrimental effects that shrimp farming could have on their communities until after the industry has been established. Shrimp farmers that lease land often do not explain to the landowners the long-term impacts that shrimp cultivation can have. This leads to conflict when the landowner reoccupies the land only to find that it has been rendered unsuitable for growing rice or other agricultural crops. At the same time, some village leaders are too involved with shrimp farming themselves to lead a village movement for greater regulation. In our survey we encountered only one case where a local community had organized to impose strict regulations on the operation of large shrimp farm that had been developed by an absentee owner. This suggests that NGOs could play an important role by raising awareness of the potential environmental consequences of shrimp farming and by assisting local communities to supplement ineffective government regulation with local controls. A few NGOs have initiated this approach in villages on the Andaman Sea. The government could assist local regulation through laws and policies improving the legal rights of communities to engage in local resource management.

Supporting local NGOs, however, is only a partial solution and is certainly no panacea for solving the many problems associated with intensive shrimp farming. Indeed, only a few NGOs are active in the intensive agricultural areas most affected by shrimp farming, because most Thai NGOs prefer to focus their efforts on more appealing issues like forest conservation in the north, or small-scale fisheries in the south. With only a few exceptions, NGOs have limited their involvement in shrimp farming conflicts, since the problems seem so difficult. The intensity of NGO activity required to implement this solution probably exceeds the current capacity or interest of Thai NGOs. Thus a solution relying on community regulation would also need to work through local government, which has the problems noted above.

Community regulation facilitated by NGOs and local government could be supplemented by working through shrimp farmers themselves, especially where the majority of shrimp culture farms are locally owned. Despite their often individualistic and short-term focus, shrimp

farmers have powerful incentives to engage in collective self-regulation, given their dependence on common property water resources and mutual vulnerability to the questionable practices of other operators. In this context, the recent establishment of shrimp grower associations in the south is encouraging: some of these associations have taken on the function of cooperative self-regulation. Government agencies could use their limited resources more effectively by working through these associations rather than by trying to impose and enforce regulations.

In addition to facilitating community and self-regulation, the as yet unknown potential for inland shrimp farming suggests a need for studies of the social, economic, and environmental impacts of introducing shrimp culture into rice-growing communities. We might note that international environmental groups concerned with shrimp aquaculture have often focused their concern on mangrove destruction, while this study suggests that the new areas being opened up to shrimp farming are intensive agricultural areas, where the livelihoods of many rural people could be affected by resource degradation. In addition, the human health aspects of low-salinity shrimp culture also require attention. Generally, there is growing awareness and concern over the presence and level of antibiotic residues in cultured shrimp (Saitanu and Amornsin 1994). The industry sees its own interest in having standards on allowable levels of residue, similar to those in poultry and livestock, and seeks to educate consumers that some residue is acceptable and safe for human consumption (*Asian Shrimp News* 1992). Critics of the widespread use of antibiotics in aquaculture as prophylactics to prevent the occurrence of disease, however, argue that this practice should be completely abandoned (Brown 1989, Bratten and Hektoen 1991). In addition to concerns over the use of antibiotics, however, the establishment of shrimp farms in rice-growing areas opens the door to contamination from agricultural residues. Miller (1996) found that ponds that drew water from irrigation canals subsequently contained high levels of organochlorine pesticides. These residues can only be detected using sophisticated laboratory equipment. Presently, they go undetected by farmers who are primarily concerned with the basic water quality parameters, such as temperature, pH, and salinity, that affect shrimp mortality. This situation may change in predominantly rice-growing areas, as shrimp are among the most susceptible animals to pesticide toxicity (*Asian Shrimp News* 1994). Until shrimp mortalities can be traced to these residues, however, it is unlikely that much monitoring will be conducted. There is also cause for concern over the presence of heavy metals such as cadmium, zinc, mercury, and other industrial pollutants (Phillips 1993). The siting of shrimp farms in areas characterized by industrialization suggests that the detection of heavy metals, organic solvents, and petroleum hydrocarbons needs immediate attention.

Conclusions

The conversion of coastal environments to shrimp aquaculture is emerging as one of the most important environmental challenges facing tropical developing nations. Growing numbers of environmental analysts and NGOs are now depicting intensive shrimp farming as a short-term, unsustainable, ''rape and run'' industry that results in wanton degradation and destruction of coastal resources (Rosenberry 1993). While some investigators believe that changes in pond management and technical advances have considerable promise for making the industry sustainable, skepticism remains high. There is little doubt, however, that the high profit potential associated with the industry will continue to make it attractive to investors and provide impetus for the development of new culture areas. Many analysts believe that Thailand's shrimp culture industry has peaked and will continue to decline, as there are few undeveloped coastal areas left to exploit. The development of low-salinity shrimp culture, however, opens up vast new tracts of land that may help offset production losses, at least in the short term.

The rapid diffusion of low-salinity shrimp culture into freshwater areas arises from the convergence of several factors. These include the vested interests of ancillary agribusiness, stagnant prices for rice and rising costs of agricultural labor, an available water infrastructure, low land prices relative to the coast, and a lack of institutional control and regulation. These conditions are not unique to Thailand, although the particular mix may differ. Rigg (1996), for example, notes that other parts of Southeast Asia have seen an increase in the amount of productive agricultural land lying idle, for reasons similar to those found in Thailand. We believe that future discussions of shrimp farming need to consider the possibility of rapid expansion away from the coast into the irrigated river deltas of Southeast Asia.

The migration of intensive shrimp farming into freshwater environments raises serious concerns over the disposal of pond effluents and the impact of saltwater intrusion on surrounding agricultural activities. In the absence of effective government regulation, there is potential for serious and even more recalcitrant environmental problems than those being experienced in culture areas along Thailand's coast. With only very limited attention having been given to the movement of shrimp culture into rice-growing communites, several aspects of this inland shift merit further investigation.

These include the potential for community and self-regulation of shrimp farming, the ecological and social impacts of shrimp culture in agricultural areas, and the human health effects that arise from siting ponds in areas that are proximate to chemical-intensive farming and heavy industries.

The future of low-salinity shrimp culture is difficult to predict. The pace of new pond construction in Thailand suggests that the area devoted to this activity is increasing rapidly. Indeed, if the international demand for shrimp drives market prices higher, the prospect of Western consumers dining on tiger shrimp raised near Khon Kaen is not completely farfetched. We cannot help but be pessimistic that the shrimp aquaculture juggernaut is stoppable through a consumer-focused approach that fails to differentiate among different shrimp culture techniques. Instead, we believe that the most promising approach to reducing the social, economic, and environmental impacts would be to supplement government regulations with local monitoring and regulation by communities and local shrimp farmer organizations, who are, after all, the people who have the most at stake.

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