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Industrial Transformation and Shrimp Aquaculture in Thailand and Vietnam: Pathways to Ecological, Social, and Economic Sustainability?

Shrimp aquaculture in Vietnam is in the process of being transformed into a major industry around the intensification of the production system. The experiences of other countries in the region, especially in Thailand where high input production systems dominate, suggests that now is a critical time for intervention to redirect industry into pathways that are more sustainable ecologically, socially, and economically. In Thailand, years of experience with intensified systems and a complex industrial organization has not led to sustainable solutions. The challenge here is for society to regain control and then to redirect the transformation along more efficient and benign pathways. Our analyses suggest that current pathways in both countries are unlikely to lead to a sustainable industry. A complete transformation of the way shrimp are grown, fed, processed, distributed, and regulated is needed.

INDUSTRIAL TRANSFORMATION

The expansion and transformation of shrimp aquaculture in Southeast Asia has occurred in the context of rapid industrialization. Between 1970 and 1993 the contribution by industry to the Association of Southeast Asian Nations (ASEAN) regional Gross Domestic Product (GDP) increased from 25% to 40%, and industrial output increased 25 times during the same period. Energy and pollution intensities (per unit of economic activity) of most countries remain comparatively high compared to Organisation for Economic Cooperation and Development (OECD) countries, especially in the centrally planned economies like Vietnam (1). Thailand with its much larger economy and industrial sectors already has a history of air and water pollution problems.

As rapid as industrialization has been, the base remains comparatively small. Most of the investment in industrialization of Southeast Asia is still to come, and much of this will happen in coastal zones where urbanization also is a major process. With improved energy efficiency and material recycling, individual businesses and perhaps even sectors can reduce their burden on the environment. However, continuing expansion of economic and industrial activity in most countries in the region for at least the next several decades will mean that the cumulative effects on uses of energy, materials, and natural resources, and burdens on the waste-assimilation capacities of local and regional ecosystems, will continue to grow. A profound transformation in the way industry is developed, especially in coastal zones and along waterways, is required. The focus has to shift from abatement and "end-of-the-pipe" solutions to prevention, by focusing on reducing pollution and resource-use intensities, and finally toward new visions of society and its supporting systems or an "Industrial Transformation" (2).

So far little attention in Southeast Asia has been paid to what such a transformation toward sustainability would entail for food production-consumption systems. This requires understanding of the environmental consequences of activities and linkages along the commodity chain from farmers, through agri-businesses and food industries, to consumers, as well as consideration of the networks of input and service suppliers. The most problematic of these are likely to be high-value export-oriented commodities that depend on natural resources and ecosystem services like shrimp aquaculture. Changes in production and organization of the shrimp industry have been very rapid with the growth of aquaculture. In a matter of just two decades or less systems have moved, in some places, from other land-uses or cooperative harvesting of mangroves and wetlands to being a part of a fully integrated industry more akin to manufacturing than traditional agriculture or capture fisheries.

The industrialization of aquaculture has spread fairly easily among countries in Asia despite different economic and political structures and development histories. Industrial shrimp aquaculture first started and then collapsed in Taiwan (3), and from there it spread to other countries. Extensive production systems in Thailand are recorded from as early as 1957 in Nakhon-si-tammarat (4). But the industry only really began to intensify in the mid-1980s, when production from aquaculture started to increase rapidly (Fig. 1a) following the spread of successful hatcheries. The changes were facilitated by government policies on export-oriented agriculture. For example, the large Thai multinational Charoen Popkhand (CP) Group was active early, in 1986, forming a joint venture with Japanese giant company

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Mitsubishi and employing experienced Taiwanese technicians in setting up CP Aquaculture (5). The company also has a long experience and large investments in feed mills that easily were redirected toward aquaculture inputs.

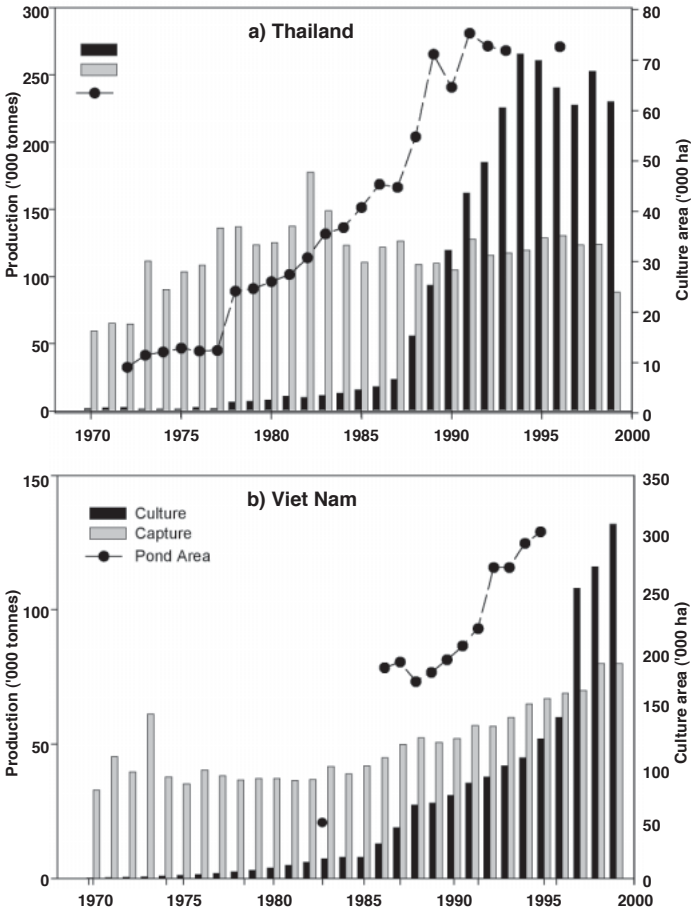
Changes to the production systems in Vietnam came later, and have been slow to spread. Much of the growth in overall production can be attributed to expansion rather than intensification until the mid-1990s (Fig. 1b). Extensive systems began to be used in the Mekong Delta soon after the end of the war with the USA (6), but it was not until the late 1980s, with development of a hatchery industry in Nha Trang, Khanh Hoa province, that intensified production systems could be developed. Today, a wide variety of systems are used in different regions of Vietnam, whereas in Thailand production methods are much more uniform. Marketing channels, organization of labor and corporations, roles played by the state, and many other factors also differ within and among countries.

In this paper the central question we address is: How can the industrial transformation of shrimp aquaculture be directed in ways that are more ecologically, economically and socially sustainable?

Our approach is to compare the well-established industry in Thailand with the new but rapidly developing industry in Vietnam, recognizing that both are linked closely to markets and consumer behavior elsewhere. Industrial transformation involves many processes apart from the techniques of managing the growth of shrimp in ponds. To assist with comparisons we have developed a general conceptual framework to describe how the effects of consumption and population processes on the environment and livelihoods are modified by a set of complex intervening structures and process (Fig. 2). The way industry is organized, the technology, knowledge and information it promotes, and the way markets develop, each have implications for the environment and livelihoods. Many of these are further mediated through politics that can change both the formal institutions and those that are actually in use. Finally, two potential feedback loops are highlighted in this framework. The first is a feedback on population through effects on livelihoods; for example, the accumulation of assets and entitlements, and how these might stimulate further migration. The second is on consumption through effects on the environment, which acknowledges that consumer awareness about environmental degradation caused in the production of a luxury commodity could alter their preferences, and thus change future consumption demand.

Intensive shrimp ponds, Nha Trang, Vietnam. Photo: L. Lebel.

Figure 1. Growth of the shrimp aqaculture industry in Thailand (a) and Vietnam (b). Production of shrimp in tonnes from aqaculture and capture fisheries are shown as solid bars, and the area under cultivation by a dashed line. (Based on Thai Department of Fisheries, FAO FishStats (2000), and (8).



METHODS

The findings reported here are based on field observations, quantitative and in-depth interviews, and analysis of secondary data.

We conducted a detailed random survey of 827 shrimp farmers in 5 regions: northern Vietnam (n = 99; Quang Ninh); southern Vietnam (n = 303; Ca Mau, Bac Lieu); central Vietnam (n = 121; Khanh Hoa); eastern peninsular Thailand (n = 239; Nakhon-sri-tammarat, Surat Thani, Songkla); and western Thailand (n = 65; Krabi and Trang). The surveys were conducted during roughly one week in each region between September and December 2000, except for Khanh Hoa, which was in August 2001. Most interviews were with the pond owners (90%), many of whom were also day-to-day managers, and the rest were with a knowledgeable pond manager (8.5%) or a senior worker (1.5%). The detailed questionnaire covered: farmers' personal and household socioeconomic characteristics; general features of the shrimp farm and its management; production costs and yields; and environmental knowledge, attitudes, and practices.

We also made extensive use of in-depth interview techniques to obtain information from other parts of the consumption-production system, and to follow-up in more detail sensitive property and political issues with farmers. Altogether, 52 noted or transcribed in-depth interviews using semistructured guides were made in Vietnam, 42 in Thailand, and one in Japan with a manager of a trading company. Interviews were made with a wide range of informants: farmers, traders, input shop owners, management in processing firms, hatchery operators, government officials, community leaders, journalists, and villagers living in shrimp areas. Observations and in-depth interviews were made at various times throughout the research period from approximately May 2000 to December 2001.

POPULATION

Indirect Population Effects in a Consumption-dominated System

The development of industrial aquaculture is dominated by consumption processes. Nevertheless, demographic changes play an

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important contextual role in most places, because of their effects on availability of labor and land.

The expansion of human settlements, tourism, and agricultural activities into coastal zones of Thailand and Vietnam has had major effects on coastal land-use and infrastructure development. In turn, these processes have constrained and interacted with other incentives for the spread and intensification of aquaculture. We are far from completely understanding these direct and indirect effects but can pose and explore some initial hypotheses.

Migration and Employment

One mechanism that could be envisaged is that rapid land-use changes and intensification bring about internal migration as spontaneous settlers move in to take advantage of new opportunities created by shrimp aquaculture. Evidence from our current study suggests that this process is not dominant. In Thailand, more than 70% of farmers at both sites were born in the village where they had their ponds, and a further 5% came there as children. In northern and central Vietnam a bit more than half were residents in place of birth, but in the south this was only one-third. In the south mean residence time of migrant shrimp farmers was 15 years, many having arrived as part of re-settlement schemes for soldiers and their families after the end of the war with the US. Thus, many of the land-use changes to aquaculture cannot be attributed directly to initial settlement.

If production is successful early, the accumulation of assets and entitlements from shrimp aquaculture may act as a stimulus for further migration of related and other connected individuals, through, for example, remittances or the ability to provide initial support. Work by Adger and his colleagues have revealed the complexity of these interactions in northern Vietnam. Aquaculture development has increased the overall wealth of coastal communities but also has increased inequities (7). The poorer households respond to rising land costs and other pressures by seasonal migration to urban and other rural areas and send back remittances to the family members who remain. In our surveys in Thailand we observed asset accumulation and increasing wealth, but have not yet gathered sufficiently detailed historical evidence to assess the effects on migration.

As the industry develops and production intensifies, there is a growth of secondary industries, for example, for feeds, water/aeration systems, and landscaping services. These provide alternative, sometimes seasonal, employment opportunities that could attract migrants or at least slow outmigration to urban centers. Shrimp cultivation itself has low labor requirements compared to paddy rice farming.

Our surveys reported here cannot really test this, but detailed secondary data on population movements and the size of the workforce employed in the industry provides an idea of the magnitude of potential effects. The Thai Department of Fisheries estimated that in 1994 the industry employed ca. 97 000 people directly and 53 000 indirectly. In Vietnam, the number of jobs created by the industry was estimated at around 277 000 in 1991 and rose to 550 000 in 1998 (8). Most positions in processing factories in both Thailand and Vietnam are given to young, unmarried women.

CONSUMPTION

Whereas the effects of population changes are indirect and arguable, growth in consumption demand has undeniably been a dominant driver of change in shrimp aquaculture. Within the global fisheries production and marketing systems,

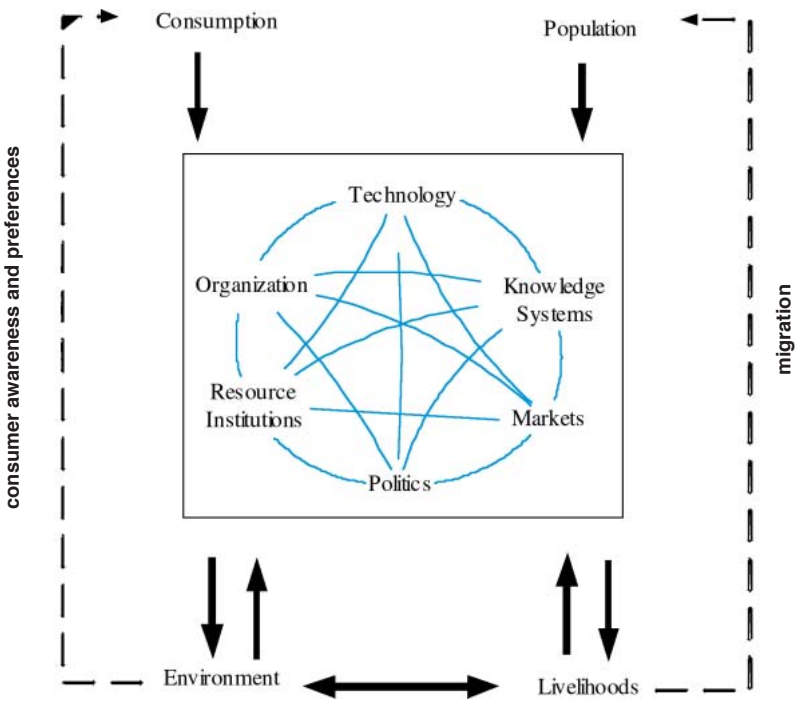
Intensive rearing shrimp ponds, Trang Province, Thailand. Photo: L. Lebel.

shrimp plays a central role as a high-value commodity. In the maturing agribusiness and food industries the emphasis is shifting to treating shrimp as a set of products rather than a single primary commodity.

The principle markets for shrimp grown in Vietnam and Thailand are the US, Japan, and EU. The potential for much growth in these high-income markets is limited. The food distribution systems are complex and highly developed, with hypermarkets, convenience stores, and many options for take-home food. High-income consumers demand convenience, are concerned with quality, want food that is varied and interesting, nutritious and healthy, and increasingly demand that it is produced in environmentally and socially ethical ways (9). Such a response already is visible, for example, in Vietnam and Thailand factories seeking International Organization for Standardization (ISO) certification for their packaging, marketing, and company management.

Consumer concern about the environmental consequences and personal health risks of consuming farm-raised shrimp has grown since 1986, when Murai Yoshinori published his influential book in Japanese on the effects of consumption on coastal environments in Southeast Asia. In the future, consumer behavior is likely to play an increasingly important role in directing changes

Figure 2. Conceptual framework for the relationship among consumption, population, and the environment for a luxury commodity such as shrimp. Not all the possible influences between intervening variables in the central box are shown, but only those important for the analysis in this paper are highlighted.



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Packaging at a shrimp processing factory in Qanh Ninh, northern Vietnam. Photo: L. Lebel.

in industry practices. An excellent foretaste is provided by the rise of the trading company Alter Trade. This was established by five consumer cooperatives servicing 1.5 million consumers in Japan in 1991. It now is importing "eco-shrimp" grown under seminatural conditions in extensive ponds in East Java, Indonesia, to supply the Japanese market. Although shelf prices in Japan are higher, the business is viable (10). We also observed factories in northern Vietnam that primarily export very large size shrimp from similar extensive systems to Japanese markets.

Demographic changes need to be considered alongside those social and economic ones that result in altered food consumption patterns and preferences. The expectation is that with rising income, domestic and intra-ASEAN demand for shrimp will once again rise rapidly as the economies recover from the 1997–1998 financial crisis. Changes to smaller families, single households, and aging populations also could affect demand, both domestic and international. In an industry largely geared toward exports, the demographic changes in consumer nations will be as important as those within their own borders.

Many of the most important consequences of consumption for environmental change and local livelihoods in the coastal zone have their effects through markets, which therefore must be examined more closely.

MARKETS

International Trade

Shrimp is the most traded seafood product internationally, with 25% coming from aquaculture. Japan, the US, and EU are the leading importers of shrimp. Thailand is the world's largest exporter of shrimp, and during the decade up to 1998 has had 18% of world market share of frozen shrimp. Vietnam has been approximately the seventh largest producer, with an average world market share around 3%. Shrimp and their products now are among Thailand's three largest exports, with earnings of more than 2 billion USD yr^{-1}. The contribution from aquaculture to total shrimp production has risen rapidly, and has exceeded that from capture fisheries for the past decade (Fig. 1a).

Competition among regions and countries for export markets is intense, and likely to lead to migration of industry between countries to take advantage of differences in costs of production and the levels of free ecosystem goods and services that can be extracted. Studies conducted in the mid-1990s showed that all Asian shrimp producers, regardless of the systems of production, have greater comparative advantage when exporting to Japan than the US and EU, because of higher prices in the Japanese market, but domestic resource costs favour Thailand, Indonesia, and Sri Lanka (11). Our analysis of trade statistics (12) for frozen shrimp exports from Vietnam and Thailand show that size and relative importance of key export markets has changed markedly during the past decade. Whereas as the total import value of frozen shrimp to Japan has remained relatively constant between 1989 and 1998, the value of exports to the US rose from 1600 million USD to 2600 million USD in 1998. At the same time Thailand's market share of US imports has risen from around 9% in 1989 to around 25% to 35% in the years since 1993. Up until 1995 Thailand's share of Japanese imports typically was 17% to 21%, but in 1998 was under 10%. Vietnam's share of Japanese imports, on the other hand, has risen steadily from under 3% to 9% in 1998. Vietnamese share of US imports is still a low 2%, but increasing in recent years. The causes of these changes in trade over the past decade are complex, but include the industrial transformation of production systems in Vietnam and other producing countries outside Thailand, especially India and Indonesia. One implication is that the consumer markets of greatest importance for bringing about changes in aquaculture practices are shifting. We still do not have a good understanding, however, of what the potential consequences of a shift from Japanese to US consumer are for environmental practices in Thailand. Another lesson is that consumption demand on Thai and Vietnamese producers has and will change over time, as competitive advantage is gained and lost, and this will indirectly influence future patterns of coastal land-use change for aquaculture.

Finally, key changes in markets and trade are resulting from changes in consumer behavior and international institutions governing trade. The supply of shrimp in the form of ready-to-eat meals and other convenience food products also is growing, as are schemes for identifying healthy and environmentally-friendly produced shrimp. Food safety issues are governed by the WTO agreements on Application of Sanitary Measures and Technical Barriers to Trade. A traceability mechanism for shrimp exported to the EU currently is being developed. Producers and processing industries in Thailand and Vietnam now are being forced to pay increasing attention to food safety issues and management because of the quality standards of importing countries.

Market Organization

Since the introduction of Doi Moi policy in the mid-1980s, market mechanisms have developed rapidly in the previously centrally-planned economy of Vietnam. Nevertheless, there are still large differences in the operation of market mechanisms between Vietnam and Thailand. In Thailand, central wholesale markets—Mahachai near Bangkok and another in Nakhon-si-tammarat-now play a crucial role in serving the processing and food industries. In our surveys, 62% of producers in western peninsular Thailand and 38% in eastern peninsular Thailand sold their shrimp directly to a central market, whereas in Vietnam most products are sold at the pond edge to shrimp traders (89% to 98%). They in turn sell directly to processing and exporting factories, many of which are owned by the state. In the complex waterways of the Mekong Delta, we observed individual traders buying largely at outlets along the main canal or from smaller traders who visit individual ponds to collect daily harvests. Without a central market, development of large processing industries is constrained, and prices and quality do not match market demand as closely.

Shrimp prices vary over time (Fig. 3), but not more than, for example, rice-a key staple crop that also is exported from Thailand. In some periods, price changes can be very dramatic: for example, during the 1997–1998 financial crisis, when the Thai currency fell rapidly in value. Export prices also depend greatly on market destinations and the quality of shrimp being sold. When quality declines, for example, due to disease, exporting companies need to look for new markets for the lower-valued shrimp (5).

The growing influence of retailers and demand for differentiation of shrimp products make it likely that initial trends to develop open markets will be replaced by more tightly coordinated vertical markets, which would allow greater quality control and specification of products down to the production techniques and stocks.

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Apart from markets for shrimp products themselves, there are also important markets for land, labor, and inputs. In the next section, we examine how enterprises are organized around these markets, and how industrialization has affected social organization .

ORGANIZATION

Commodity Chain and Input Network

Industrialization of the industry has had profound effects on both corporate and social organization. This includes: differentiation of tasks; new roles for specialist advisors and intermediaries or brokers (Fig. 4); co-evolution of institutions to regulate and collect rents; development of new products and markets; and secondary industries to supply feed, stock, equipment, and chemicals, and to freeze, store, and process seafood. In Thailand and Vietnam, some of the processing factories that earlier served exclusively capture fisheries were modified. Vertical integration and consolidation is prominent at all levels, except at the hatchery and outgrow pond stages, where large risks of failure and ownership or control of land resources by corporations has been difficult (13).

The organization of industry in Vietnam and Thailand differs in a number of features. The number of agents and linkages in Vietnam are fewer than in Thailand, but the overall structure is similar (Fig. 4). Thus, in Vietnam secondary service industries are relatively undeveloped; consulting and training services by feed and chemical companies are only just beginning and still do not reach most farmers; state agency capacity for effective extension work still is very limited; and shrimp farmer and buyer organizations are still few and weak. In Nha Trang, central Vietnam, however, where the hatchery and intensified production systems are present, many of the secondary input and services industries also are developing.

In Vietnam many of the processing factories, which also act as export-import companies, are still state enterprises. According to one senior manager, being a state enterprise has advantages and disadvantages compared to private enterprises (14). The main disadvantage is a cumbersome and inflexible bureaucracy that makes it difficult to adjust decision-making to rapidly changing market conditions. On the other hand, state enterprise employees often have more secure employment and guaranteed budgets. It also is easier for them to obtain access to credit and permits for construction, exporting, and other activities. Furthermore, as markets and market channels are less developed in Vietnam, especially in the north, the form and channels to establish supplier and export contracts and adjust prices are less flexible and open than in Thailand.

Japan has a long history of involvement in trade of frozen ocean-caught shrimp and, together with development assistance programs for fisheries in the region, was well placed for investments in the shrimp aquaculture industry. Today, Japanese firms are prominent in joint ventures in the shrimp processing industry in both Thailand (15) and Vietnam.

Industrialization tends to lengthen and complicate the commodity chain, but also creates opportunities to make profits at multiple points. The conglomerate, Charoen Popkhand, (CP), has been particularly successful in achieving vertical integration within the Thai industry (5). CP owns feed and feed input (fishmeal, flour mills); provides laboratory services to growers; has an export trade company, processing factories, hatcheries, and corporate farms; and plays a major role in research and development. CP initially even attempted, with support from the government bank, to organize growers through formal cooperatives with contracts, but a fixed price system was opposed by the farmers and had to be abandoned (5). CP aquaculture products are visible in Vietnam, though their characteristic extension and support services found in Thailand are still underdeveloped.

Social Organization

The effects on social organization also have been large, paralleling those of manufacturing and some agri-business industries. Thus, most positions in processing factories in both Thailand and Vietnam are given to young, unmarried women. Farm owners and managers, on the other hand, are predominantly male (87%) and older (average ages varied from 36 to 42 years across the 5 sites). Operations by single men were more common (12% to

Figure 3. Average monthly price in Thailand of shrimp at farm gate (baht kg^{-1}). Note effect of financial crisis and devaluation of the Thai baht in 1998.

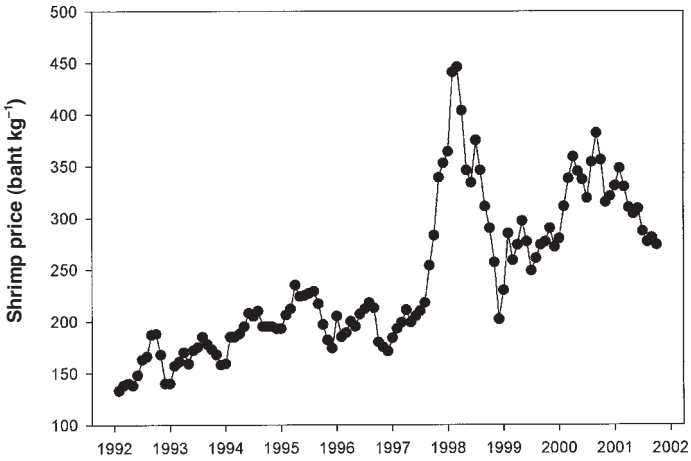
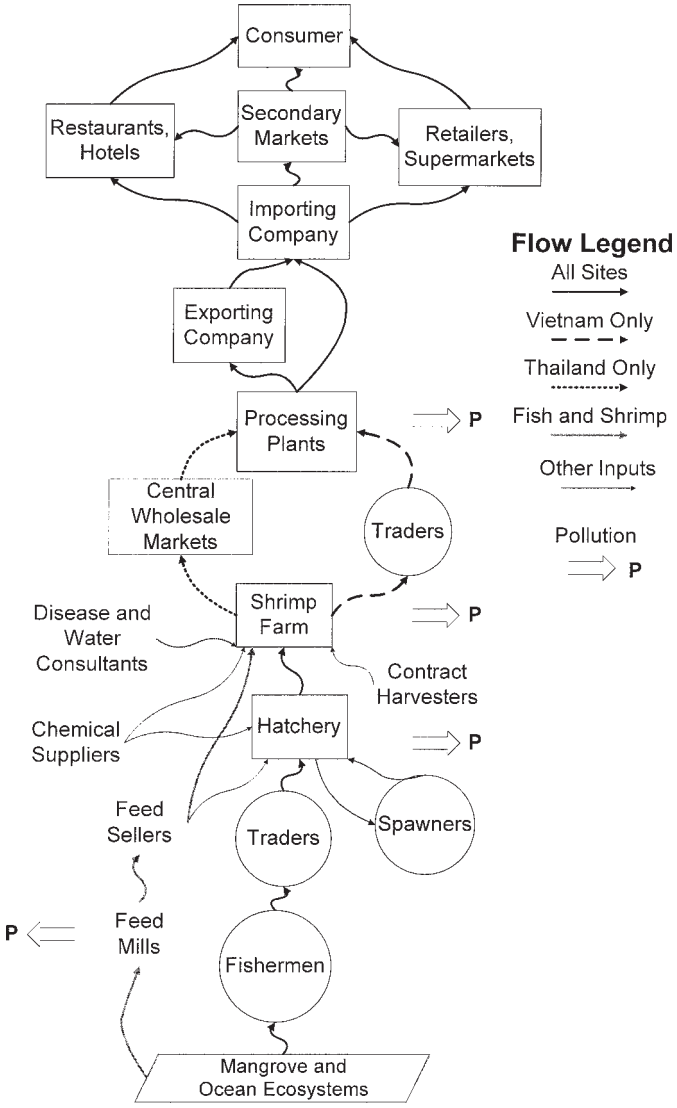


Figure 4. Effects of industrialization of the shrimp industry.



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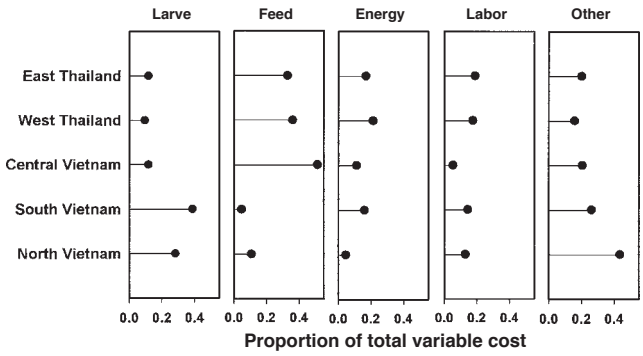
15%) in areas where systems were more intensified (Thailand and central Vietnam) than in northern and southern Vietnam sites (2% to 6%).

The introduction of aquaculture and intensification of production systems, because of the technical, labor, and managerial skills needed, undoubtedly has had other effects on social organization and cultural practices in coastal communities (16). One indicator is the past occupation of shrimp farm owners. In our survey we found substantial diversity in the prior occupation of shrimp farmers within and among sites. Among northern Vietnamese shrimp farm owners, 57% had been rice farmers. Among southern Vietnamese shrimp farm owners, 39% had been rice farmers, and among central Vietnamese shrimp farmer owners, 23% had been rice farmers. In Thailand, the proportions are lower. In eastern coastal Thailand 16% of the shrimp farmer owners had been rice farmers and in western coastal Thailand only 2% had been rice farmers. Prior fishing occupations were more likely among the Thai shrimp farm owners than the Vietnamese (25% of western coastal Thais had been fishermen, 29% of eastern coastal Thais, and among the Vietnamese sites the proportion fishermen was less than 10%). In areas where intensive production systems dominated, owners with business experience were much more common. In western coastal Thailand 20% of shrimp farm owners had prior business experience, 23% of central Vietnamese shrimp farmers had prior business experience, and 11% of eastern coastal Thai shrimp farmers. Within the least intensive shrimp farming sites, 3% of northern Vietnamese shrimp farmers and less than 2% of southern Vietnamese had prior business experience.

Differences in production systems also are reflected in labor. Although extensive systems involve much larger ponds, the amount of labor per unit area is higher when more intensive systems (ca. 3.5 to 4.3 people ha-1) are practiced than when semi-intensive systems dominate (1.8 to 2.2 people ha^{-1}).

As primary production has many risks and too few profits to attract corporate investment, there is a niche for small-scale producers to operate with some autonomy. However, with the intensified systems that come with industrialization, this is highly constrained by the need for credit, input supply, and marketing outlets. We observed relatively high rates (> 80%) of land-ownership by shrimp pond managers and owners in all sites. Land rental was most common in sites with intensified production systems: 16% in east and western peninsular Thailand, and 10% in central Vietnam, compared with 4% in northern Vietnam and < 1% in southern Vietnam. However, much more in-depth work is needed to fully explore patterns of ownership and investment in both Thailand and Vietnam. For example, some farmers in Thailand told us how they had investments in many ponds at different sites, using a mixture of their own and rented land. Moreover, because of tax requirements and regulations, the extent of these investments and *de facto* ownership are unlikely to be revealed in a one-time only cross-sectional survey.

Figure 5. Comparison of the structure of variable costs for shrimp production among 5 regions of Thailand and Vietnam. The other category includes pond preparation, maintenance, and other smaller items. Labor includes hired and family labor as a noncash cost.



Many of the observed changes in corporate organization have been closely related to technical innovations in production, handling, distribution, and marketing. Now we will consider some of the key changes with environmental and livelihood implications.

TECHNOLOGY

The transformation of shrimp aquaculture into a fully developed industry in Thailand and a nascent one in Vietnam has a number of components dependent on key innovations and technology transfers at various places along the commodity chain. The best documented changes have been in the management of grow-out ponds, and the development of hatchery techniques.

Hatcheries

In Vietnam, the critical change from extensive systems practiced since at least 1976 in Ca Mau was the beginning, in the late 1980s, of a hatchery industry in the Nha Trang district of Khanh Hoa province. The hatcheries in Nha Trang continued to dominate the industry in Vietnam for almost a decade, even though the main shrimp grow ponds are hundreds of kilometres away in Ca Mau and neighboring provinces in the Mekong Delta. Only in the past few years have hatcheries within the delta become common. The low quality of hatchery-reared post-larvae tiger prawn *P. monodon*, however, has remained a major constraint on intensification of shrimp aquaculture in the Mekong Delta. The areas in Nha Trang previously used for extensive shrimp growing and intermediate nursery ponds (a step no longer needed) now have been converted into what is probably the most intensified shrimp growing landscape in Vietnam. In part, these transformations can be attributed to the presence of an active University of Fisheries, and more recently, a number of government aquaculture and fisheries research and development centers, which organize training courses and provide consultation services for hatchery owners.

Intensification

The industrialization of shrimp aquaculture reduces the diversity of pond management systems to the designs of feed and chemical manufacturers. These replace the diversity in local practices found in extensive and semi-intensive polyculture systems. In our surveys in 2000 and 2001, we found that all farms in western and eastern peninsular Thailand and central Vietnam had adopted intensified systems, whereas those in northern and southern Vietnam continue to practice a variety of semi-intensive systems (Table 1).

In extensive and semi-intensive polyculture systems, water is exchanged as part of the tidal cycle, and this inflow also brings in the stock and natural feed. Twice a month during the low part of the big tides, harvests of a range of shrimp species and other organisms are done as water exits the impoundment. In northern Vietnam, some farmers also stock crabs and seaweed either simultaneously or alternatively with prawns. Pond sizes and overall holdings in the north are very much larger than in the south. Today, the vast majority of farmers in northern and southern Vietnam also are stocking at low rates with tiger prawns. Because of low stocking and feeding rates they are able to harvest few, but very large and high value shrimp. The more extensive systems allow shrimp farm owners to have other employment, such as rice growing.

In some parts of the Mekong Delta mixed mangrove-shrimp and shrimp-rice culture systems are being tried (17). Mixed mangrove-shrimp systems were established in state forestry-fishery enterprises to try to reduce deforestation and at the same time help alleviate poverty. Unfortunately, shrimp yields from these systems in Ca Mau province have been declining, and in 1996–1997 average annual yields were a low 286 kg ha^{-1} yr^{-1} (18).

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This study attributed the problems to a combination of poor wild seed recruitment (19), poor pond design, inappropriate management techniques, and reliance on small low-value culture species. Furthermore, losses of shrimp seed during harvesting further reduced effective stocking densities through tide action to a low of 0.15 post-larvae m^{-2}. Securing a reliable supply of more valuable tiger prawn post-larvae has been a major constraint on intensification in the Mekong Delta.

On average stocking rates in central Vietnam were half those used in Thailand, and as a consequence survival rates were higher but yields per crop lower (Table 1). A handful of farms in the south were attempting more intensified production methods. A few farms in east and western peninsular Thailand and southern Vietnam were using extremely high stocking rates of up to 150 post-larvae m^{-2}. Fully intensified systems involve high levels of initial stocking, usually with the tiger prawn *P. monodon*, complex and changing feeding regimes as the prawns grow, chemical treatment of water, addition of antibiotics, and aeration (20). In the past growers attempted to improve yields through fertilizer inputs to stimulate plankton growth and by adding trash fish or even animal carcasses. Some of these practices still are followed in Vietnam, though most growers now use commercially prepared feeds. In addition to purposefully using antibiotics, many feeds now are medicated with the antibiotic oxytetracycline. A concern is that these indiscriminate practices are likely to lead to disease resistance.

Total costs of production are much higher in the intensified systems, but profits and costs per kg of shrimp were lower. The structure of costs varied by rearing systems and location. Feed costs were the largest fraction in central Vietnam (51%), western peninsular Thailand (36%), and eastern peninsular Thailand (33%), whereas larval costs were the largest in northern Vietnam (28%) and southern Vietnam (39%). In northern Vietnam, where pond sizes are very large, pond preparation and maintenance costs contributed a much larger fraction than elsewhere.

The effects on production of the intensification trend in Thailand can be seen in the greatly increased yields per unit area (compare ratios of area and production curves in Fig. 1a). In Vietnam, as in most other countries in Southeast Asia, overall production yields generally have been much lower as many farms still use only semi-intensive systems (Fig 1b). The intention of many of these farmers, however, was to further intensify their production systems: in northern Vietnam (90%), southern Vietnam (52%), central Vietnam (45%), eastern peninsular Thailand (34%) and western peninsular Thailand (26%).

Crop Failure and Disease

The potential for high and quick returns on investments makes the shrimp aquaculture industry very attractive to national leaders, international development agencies, and private sector entrepreneurs. Production, however, is very unstable. In our surveys, 74% of farmers overall had experienced a major crop failure. Disease is probably the single most important factor limiting production in the industry. Fluctuations in market prices also may contribute to boom and bust patterns. Price increases following disease outbreaks attract new producers to try their luck. In Nha Trang, farmers indicated that land prices rose dramatically between the end of 2000 and the middle of 2001 as a result of changes in shrimp prices. In Thailand, abandonment of ponds after a few years because of disease or declining productivity is common (21), but these ponds sometimes are reused when prices are high again.

Most of the major changes in hatcheries and farms in the past decade have been directed at reducing the risks of disease devastating stock (22). Thus, there have been trends to reduce water exchange and reduce the use of trash fish. More recently, in Thailand there also has been a much wider adoption of pre-testing of larvae using genetic techniques before stocking ponds. Finally, farmers have begun moving inland and rearing shrimp for most of the cycle in much fresher water as a way of avoiding pollution and disease problems from neighbors. In Thailand, a recent innovation has been the development of low salinity rearing techniques dependent on hatcheries acclimatizing post-larvae to progressively lower salinities. This effectively has removed a key constraint to the expansion of the industry into inland delta, floodplain, and riparian areas (23).

KNOWLEDGE AND INFORMATION SYSTEMS

Research and Local Knowledge

In both countries, major technical hurdles still exist. Hatcheries still are dependent on the collection of gravid females from the ocean, diseases and water quality problems are proving hard to overcome in practice, and there still is a need to reduce dependence on wild capture fish in feed. Little effort has been made to systematically adapt technologies to better meet local environmental and cultural settings by making better use of local knowledge and the potentials of information technology.

Sound technical knowledge of production and processing methods is essential to the industry's development. The private sector in Thailand has played a much larger role in research and development than in Vietnam, in part because many of the major input supply companies are based in Thailand. Research by state supported universities and fisheries research centers also are important in both countries. However, most new knowledge is being generated to benefit corporate strategies rather than sustain local livelihoods. At the same time the expansion of aquaculture, through habitat conversion and changes in livelihoods, also has undoubtedly displaced local knowledge about use of mangroves and coastal, riparian wetlands.

Table 1. Characteristics of shrimp farms and aquaculture production in 5 regions of Vietnam and Thailand.

	North Vietnam	South Vietnam	Central Vietnam	West Thailand	East Thailand
Mean pond size (ha)	20.1	2.6	0.70	0.57	0.52
Mean total area of ponds (ha)	23.7	2.95	1.39	0.91	1.38
Mean stocking rate (ind m^{-2})	3.7	4.8	28.7	55.0	66.0
Mean survival rate (%)	25	11	76	59	51
Percentage of farms using artificial feed	78	14	100	100	99
Percentage of farms having used 14 antibiotics	9	93	83	94	
Labor inputs (people ha^{-1})	2.2	1.8	4.3	3.6	4.2
Mean proportion of total crop as tiger prawns (%)	60	57	100	100	100
Mean percentage of tiger prawn production as large individuals (< 30 ind kg^{-1})	37	71	2	1	4
Mean production of tiger prawns (kg $crop^{-1}$ ha^{-1})	142	185	2920	4760	4460
Sample size	(99)	(303)	(121)	(65)	(239)

Education and Information Sources

It often was asserted by the government officials we met that low levels of education and lack of experience are key constraints to the adoption of improved rearing and hatchery methods. The education levels of shrimp farmers varied widely, as measured by the percentage completing primary school: in western peninsular Thailand (54%), southern Vietnam (58%), eastern peninsular Thailand (72%), northern Vietnam (90%), and central Vietnam (93%). In central Vietnam (54%) more than half the farmers

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had completed a secondary degree or higher, and in northern Vietnam (39%) and eastern peninsular Thailand (39%) levels also were high. Moreover, in all areas except northern Vietnam (mean of 3 years), farmers had an average of more than 6 years' experience as shrimp farmers, with the highest average being more than 10 in southern Vietnam. It is not accurate to characterize shrimp farmers in Thailand or Vietnam as uneducated or inexperienced.

Although education and experience do not differ in a consistent way between Thailand and Vietnam, sources of information about shrimp farming do. Farmers in east and western peninsular Thailand get information from multiple sources, including friends and relatives, government extension officers, magazines and books, TV and radio, growers associations, product distributors, and training courses. On average they used 4.3 sources in comparison to 3.8 in central Vietnam, 3.0 in northern Vietnam, and only 2.2 in southern Vietnam. In part, this reflects the differences in information needs, and lack of government support for those practicing semi-intensive production methods. In Ca Mau in southern Vietnam, the lack of information appeared to be particularly acute. The only sources of information interviewees acknowledged at levels similar to those in the other areas were high reliance on friends and relatives (ca. 90%), and about half from television and radio. This is a critical point because there currently is a rush to develop nurseries and intensified shrimp ponds, but knowledge, equipment, and management systems have not yet "arrived." The mismatch in technology, industrial organization, and knowledge systems will create environmental problems.

We analyzed the association between ever having had a crop failure with number of sources of information, education, and a small set of other variables using logistic regression. After adjustment for years of practice and location, we found that farmers who obtained information from more than two sources were almost half as likely to have had a crop failure (0.56, with 95% confidence interval for odds ratio: 0.36–0.88). In contrast, levels of education, stocking rates, and pre-treatment of water were not significantly associated with the risk of having a crop failure. Access to information is important.

Finally, another important change has been the rapid increase in availability of mobile phone services. These now are widely used to link together market chains. Thus, fishing boats at sea contact intermediate traders with small fast boats when a gravid female has been captured, and then these traders, in turn, call around for offers from hatchery owners. Internet-based information systems on shrimp and their trade now are being explored.

POLITICS

Role of the State

Industrialization of aquaculture has been facilitated by changes in political structures and processes. For the most part the state in Thailand and Vietnam has served the interests of large corporations, such as feed and chemical suppliers and processing companies, rather than the needs of rural communities. The bias in aquaculture research and development and extension services has been toward shrimp as a high-value export crop requiring high levels of inputs, and not on aquaculture of fish suitable for domestic consumption or to improve livelihoods of the poorest.

The short aim has been to expand and industrialize shrimp aquaculture as rapidly as possible to earn much needed foreign exchange. After the economic crisis in 1997, the Thai Department of Fisheries vowed that the shrimp industry would help the recovery. In 2001, the Vietnamese government announced its 10-yr shrimp aquaculture development plan, which involved conversion of 60 000 ha of coastal and paddy land in 23 provinces.

The export-oriented policy of the Thai government made it possible for the industry to develop quickly, whereas many foreign markets and investment sources were closed for almost two decades to Vietnam as a consequence of US foreign policy after the war.

In both Thailand and Vietnam, centralized planning has resulted in policies on zoning to protect the environment; on extension and disease management to support producers; or to regulate control of industry by suppliers. The view of shrimp farmers in Thailand of the state's role in aquaculture development is very negative, with 83% in western peninsular Thailand and 88% in eastern peninsular Thailand stating that past support from government was poor or very poor, compared with 30% in northern Vietnam, 36% in southern Vietnam and 51% in central Vietnam. Farmers generally are most critical about land-use, environmental, and agricultural credit polices, although in central Vietnam there also was concern about control of shrimp prices.

Resistance and Social Movements

The state has not had a monopoly of power over the directions the shrimp aquaculture industry has taken. In Thailand, corporate interests have been dominant, and apart from some early facilitation, the state has for the most part been playing catch-up.

In Vietnam, decades of central planning have eliminated most alternative political voices to challenge the state. Environmental and development NGOs are relatively undeveloped, and so far have had little influence on the expansion and intensification of shrimp aquaculture. Commune structures and norms persist however, and these could facilitate strong local institutions to tackle, for example, water management and infrastructure problems, and to implement zoning schemes. Grower associations are growing in importance in Thailand, but are still virtually nonexistent in Vietnam. These are important in helping small producers resist complete control of the industry within their country from feed and other input corporations. One example of apparently successful resistance is a local growers association in southern Thailand, which has developed its own feed at a fraction of the costs of widely used commercial brands.

Land-use Conflicts

In both Thailand and Vietnam most examples of serious resistance to expansion or intensification of shrimp aquaculture hatchery or pond operations has come from local communities concerned with land-use changes or disruption of access or condition of land and water resources.

In most cases, however, the involvement of local elites in the industry, and the real benefits obtained by some local landholders, has meant that local resistance often has been small and easily swept aside (24). In addition, the perception on the ground, especially in Thailand, is that on privately-owned land, farmers can do as they please. Thus, centrally decreed zoning regulations and area bans often have had no effect on actual practices. It is possible, however, that new zoning and practice rules for aquaculture may become more successful when local communities are active in designing and enforcing them (25).

Conflicts between shrimp and paddy rice farmers have been acute in the Pak Phanang Basin, in Nakhon-sri-tammarat province in southern Thailand. Farmers have been concerned with the effects of salinity intrusion from shrimp farming operations on their yields. The effects on poor rice-growing families have been exacerbated by problems with declining productivity (due to other reasons) in what once was one of the most productive rice-growing areas in Thailand (26). One consequence of these environmental changes has been periods of net outmigration and overall relatively low population growth. Altogether, abandoned agricultural land makes up 10% of the land area. Shrimp farming is very common along the coast, and up to 70 km inland in areas bordering the Pak Phanang River. In 1997, approximately half the shrimp ponds were abandoned, but many have again been re-used in 2000. During 1999 a large tide barrier, part of a

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major Royal Development Project, became operational on the river with the intended effect of segregating activities of shrimp farmers from those of other agriculturalists dependent on fresher waters. Government agencies also have programs promoting conversion of abandoned shrimp areas inland into orchards and fish farms. To what extent the engineering and technical solutions will change land-use practices remains to be seen, as elsewhere shrimp farmers have been shown to be quite adept at culturing shrimp in low salinity systems.

A more recent and intense political conflict has arisen between inland shrimp farmers and the orchardists and rice growers in the central plains of Thailand, the traditional "rice-bowl" of the nation (27). As a result of media coverage, the National Environment Board recommended in June 1998 a complete ban on shrimp farming in freshwater areas of 10 central plain provinces under the pollution control zone legislation of the Environmental Protection Act. Shrimp farmers later successfully protested against the ban, claiming that the activity was promoted by the Department of Fisheries. A number of pro-industry agencies in government and CP in the private sector took the position that so-called closed systems with no discharge of untreated wastewater should be allowed. The National Environment Board rejected the argument, and the ban went into effect 120 days later to allow farmers to harvest their last crops. As in the case in southern Thailand, most of the concerns were about the potential for salt intrusion into rice growing areas. The potential competition for fresh water, which might be an even more serious issue, was not considered. Despite the regulations, most commentators expect circumvention because of the inability to enforce and regulate the ban, so the conflict continues.

Given the expansion in two historically important rice growing areas in Thailand, along the Pak Phanang River in southern Thailand and more recently in the central plains, the potential for similar expansion into the major rice-growing deltas of Vietnam should not be underestimated. At least in coastal areas this transition is being supported by formal government policy to change low productive rice farms to shrimp ponds.

In Thailand, social conflict also is apparent at a broader scale. The industry has recognized that aquaculture is under threat from adverse publicity—as a result of poor practices in some areas—and now is actively mounting its own counter-advertising. Some of this is damage control, but quickly has moved toward more sophisticated marketing strategies to attract environment- and health-conscious consumers. International development agencies, fisheries departments, and aquaculture-dependent research organizations also have been quick to argue the promises of new technologies and improved programs that will encourage more sustainable practices.

In our fieldwork in Vietnam, we have heard overwhelmingly positive assessments about the social development consequences of the industry. Conflicts do arise about pond boundaries and water management in landscapes dominated by shrimp, but overall these are local and mostly among shrimp farmers themselves or among state enterprises, military operations, and local communities. Government officials largely are aware of the conflicts that have occurred in Thailand, but remain confident in their ability to control land-use. The history of experiences in Thailand, however, suggests that the economic incentives and structures of power in local communities will make land-use control by central state agencies difficult. As landscapes become filled with intensified system ponds, and then start to push farther inland, more serious conflicts among different land-use and water use groups will arise.

WHO BENEFITS?

In Thailand, it commonly is perceived that local elites, some of whom are "investors," get many of the benefits, whereas the longer-term environmental and social costs are borne by disadvantaged groups. In other words, shrimp industry expansion tends to build on existing inequalities. Government often has been instrumental in facilitating land acquisition, and providing tax, credit, and import/export incentives. Although foreign investment usually does not involve ownership of land or direct control of farming in Thailand or Vietnam, the links may nevertheless be strong, particularly in manufacturing, feed, and servicing, and in processing and marketing. The distribution of benefits from industry development is an important issue that still has not been well-addressed by independent research.

The perception of producers in all locations in our surveys was that many agents are benefiting, especially those directly involved, such as traders/brokers, feed and equipment suppliers, hatchery owners, and producers themselves. In Thailand, about half the farmers felt that local government officials also were major beneficiaries, whereas very few in Vietnam thought this to be the case.

A common perception among those involved in the industry, apart from the producers and government officials, was that successful farming was deserved: "smarter entrepreneurs get richer and deserve to do so" (28). In Thailand, it is common to admire successful entrepreneurs for their ability to beat the system—to by-pass zoning laws, avoid taxes, win land disputes with the Forest Department, and so on. Many of the important political structures and processes influencing the development of shrimp aquaculture have helped drive changes in resource institutions in ways that have facilitated industrialization.

INSTITUTIONS

Surveillance, Regulation, and Zoning

One outcome of corporate dominance of shrimp aquaculture politics in Thailand is that arguments for self-regulation have been supported largely by the state. Attempts to bring in stricter legislation or bans, or actually to implement rules or decrees once they have been made into law, often have been overturned by protests from industry. In Vietnam, the role of corporations appears to be much smaller, but the economic incentives to producers have been large. Moreover, producers in most sites we studied, with the exception of northern Vietnam (74%), largely were unaware of the need for permits to carry out shrimp farming (e.g. only 10% in eastern peninsular Thailand). The role of corruption by public officials regarding acquisition of land rights for shrimp farming has been mentioned in in-depth interviews in both countries and deserves more careful study.

Institutional Lags

While technology, knowledge systems, and market institutions affecting shrimp aquaculture have changed rapidly in Thailand and Vietnam, the institutions that are supposed to govern the use of natural resources, including water, land, and mangrove and other wetland ecosystems, hardly have had time to adjust. National legislation simply has not kept pace with the rapid development of this sector. One of the favored and quicker routes has been to add new regulations within existing frameworks (such as in relation to inland capture fisheries). In Vietnam, for example, the Ministry of Fisheries has overall responsibility, but provincial and district governments are responsible for the actual planning and monitoring of aquaculture development (29). In 1995, there was no national system of registration or licensing of aquaculture farms, no control of effluents, no requirements for environmental impact assessment, and no controls on the use of hazardous substances/pharmaceuticals.

Property Rights

Key changes associated with industrialization are those in the structure and nature of property rights systems. One of the most important social consequences of the establishment of shrimp

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aquaculture in mangroves is that customary users of the mangrove are displaced. They face the double disadvantage of losing access to mangrove products, and to declines in fisheries associated with mangroves (30). Loss of access occurs easily because customary use rights are not recognized legally by the state. Obtaining permits for land-use requires good political contacts.

In Vietnam, the conversion of mangroves from common property into private and state property has accelerated the decline of mangroves. Land reclaims have accelerated human settlements in coastal areas, which leads to overuse of coastal resources. According to Adger et al. (31), privatization and state-subsidized use of mangroves not only are ecologically destructive, but also entail economic inequality among various resource users. Conversion of mangrove forests in Vietnam was made possible by changing common property rights to state property and *de facto* private property, which is contracted out to individuals for periods of 5 to 30 years. In Thailand and Vietnam, traditional uses of mangroves are disrupted by the construction of aquaculture ponds, which effectively replace the multi-use, multi-user resource with a single owner, single purpose resource (32).

In our study, virtually all the ponds surveyed in Vietnam were individually "owned" and managed, but often with special lease arrangements with state enterprises. In southern Thailand, we found that in more than 80% of farms the manager also was the owner. This contrasts with a more local, but detailed 1992 survey in the Ranot district of Songkla Province, which found that 42% of farms were corporate-owned, 19% were contract-related, and just 39% were private enterprises (33).

The previous sections of this paper demonstrate that industrialization of shrimp aquaculture involves changes in many structures and processes. The next two sections attempt to integrate the analyses presented so far to assess the implications for sustainability.

ENVIRONMENT

Mangrove and Wetland Conversion

The development of the shrimp aquaculture industry has been an important process driving changes in coastal land-use: both directly through the conversion of mangroves, other wetland ecosystems, and the secondary conversion of paddy rice farms; and indirectly through stimulating local economies and infrastructure. Various estimates suggest that conversion to aquaculture account for between 20% to 50% of the mangrove area converted in Thailand in the period up to 1986 (34–36). However, none of the studies so far reported have provided comprehensive descriptions of the spatial patterns or pathways of conversion over time, or their relationship with infrastructure development or ecological constraints such as soils (37). Even overall statistics on areas differ widely between agency reports and estimates of researchers, in part because many farms are not registered, and there can be complex patterns of use and abandonment when prices fall or disease strikes.

In our surveys, 50% of farmers in southern Vietnam, 66% in western peninsular Thailand, and 60% in eastern peninsular Thailand claimed that the land on which they now had shrimp ponds had previously been used for rice. In northern Vietnam most were previously mangrove forest, whereas in central Vietnam a substantial fraction were previously extensive shrimp ponds or nursery ponds for young post-larvae. In Thailand, some shrimp ponds were developed in mangrove areas that previously had been harvested for charcoal production and already were degraded. Understanding the pathways of conversion between different land-uses is important politically, since many disputes about the spread of shrimp farming arise because of their alleged effects on mangrove cover and conditions. In Thailand, land selection for shrimp farming is moving away from mature mangrove areas as systems have become more intensified. This is because mangroves, with their acidic soils and poor drainage, are not really that well suited to pond construction.

In the Mekong, land-use and cover changes have resulted from a combination of human settlement and infrastructure development, shrimp aquaculture expansion, and demands for firewood and construction poles. In northern Vietnam, mangrove areas in 2001 still were being cleared for shrimp farms, while at the same time, sometimes even in the same area, large efforts also were being made to replant mangroves to protect sea dikes and provide food and other ecosystem services for local communities.

Ecosystem Goods and Services

The conversion of mangroves into shrimp ponds has a number of effects on ecosystem goods and services, and biodiversity. First, mangroves can act as biofilters to assimilate waste and nutrients, but this function only can be effective if the relative area of ponds to mangroves remains low. Second mangroves are critical habitat for capture fisheries and the shrimp ultimately used to stock ponds. Based on a Malaysian study, Naylor et al. (38) estimated that the loss of one ha results in the loss of more than 100 kg of on-site fish biomass, and another 600 kg of finfish and 600 kg of shrimp in coastal waters. Based on typical yields in Thailand, this represents a reduction in fisheries biomass on the order of 400 g kg^{-1} of farmed fish because of habitat conversion alone. Using correlations between catch per unit effort and mangrove cover data, de Graaf and Xuan (39) estimated that one ha of mangrove reforest supports a marine catch of about 450 kg yr^{-1} in the Mekong Delta. They also found strong associations between total catch and mangrove area after adjustment for the capture effort. Ronnbach (40) calculated for some regions in India that between 0.2 to 7.5 ha of mangrove were needed just to provide the gravid females necessary for hatchery produced larvae to support intensive shrimp ponds in the area. By making various assumptions, the size of various estimates and their economic value can be made to vary by an order of magnitude or more with different studies (41–43). The crucial conclusion remains, however, that the ecosystem services provided by mangroves are numerous, large, and critical for capture fisheries and the long-term sustainability of the shrimp industry itself.

Pollution

Most reported negative environmental effects of shrimp farming have been attributed to intensive culture systems. Detriments include: nutrient and organic enrichment potentially leading to anoxic sediments; changes in benthic communities; and eutrophication, salinization of freshwater, and pollution from illegal pond sediment disposal and the growing use of a variety of chemical products (44, 45). In terms of human waste equivalents, Briggs and Funge-Smith (46) estimated that the 40 000 ha of intensive shrimp ponds in Thailand in 1992 produced N-waste equivalent to 3.1 to 3.6 million people and P equivalent to 4.6 to 7.3 million people. Taking into account the amount of dry sediments (16.2 mill. t yr^{-1}) and biological oxygen demand (35 000 t yr^{-1}) this is clearly a very large contribution to the overall waste loading in the Thai coastal environment. In our surveys, shrimp farmers using intensified systems in eastern and western peninsular Thailand were aware that waste-water from shrimp aquaculture posed a threat to local fisheries, but in central Vietnam much fewer had this concern. In northern and southern Vietnam, where semi-intensive systems predominate, almost all farmers felt their water discharges were inconsequential.

From inland shrimp farms the water and soil pollution are likely to be more severe than from farms along the coast, due to the difference in volumes of water available for exchange and dilution of organic and salinity loadings (23). Moreover, the potential for effects on other downstream users, including rice farm-

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ers and orchardists, is likely to be much higher. Freshwater consumption by inland shrimp ponds is similar to that for irrigation of rice fields (47).

Resource Inputs

Although the effects of shrimp-pond construction and operations on the environment have attracted the most attention, there also are significant implications of other parts of the commodity chain and supply network. Wild fish, as meal or oil, comprise 50% of the composition of shrimp feeds (48). Naylor et al. (38) estimated that 2.8 kg of wild fish are needed to produce each kg of shrimp. In the Southeast Asia region harvesting wild fish for feed production reduced supplies of small pelagic fish, like mackerel and anchovy, that could be consumed by people in coastal communities. Harvesting of gravid female shrimp, and in Vietnam, of post larvae seed, also could have significant consequences for other fish species if by-catches are large. Finally, the energy required for processing, storage, and distribution is likely to far exceed that used in farm production.

So far there have been no analyses of the full environmental costs of producing shrimp. Another issue of great importance to Vietnam is a more careful assessment of the environmental costs and benefits of alternative technologies, especially semi-intensive *versus* highly intensive systems. Semi-intensive systems require much more mangrove land to be disturbed, but if done appropriately may be able to maintain many of the ecosystem's functions. Intensive systems on the other hand require much less land to be converted. They now are developed usually in nonmangrove areas, but the resources required to support them are large.

LIVELIHOODS

Sustainability

A livelihood can be defined as the capabilities, assets or resources, entitlements, and activities required for living. The livelihoods of the poor in coastal zones and inland agricultural areas often are dependent directly on maintenance of the local ecosystem goods and services of wetlands and mangroves. Rice fields and irrigation channels themselves were observed to be sources of food. The expansion and intensification of shrimp aquaculture already has degraded and altered many of these ecological services, and threatens others. How have livelihoods of different groups of people been affected by the industrialization of shrimp aquaculture? To what extent, and for how long, can some of the immediate economic benefits of industry development offset or be used to substitute for the losses in these ecological services? How do people cope with boom and bust production swings as a result of disease outbreaks? These kinds of questions are crucial to understanding what is required for an industrial transformation toward sustainability, with technical and organizational efforts to reduce resource use and pollution. A livelihood is considered sustainable when it can cope with and recover from stresses and shocks (i.e. is resilient), and maintain or enhance its capabilities, assets and entitlements without undermining the natural resource base (49).

When asked directly whether they thought the shrimp aquaculture industry would ever be sustainable, the almost 70% to 80% of farmers in our sites in Vietnam and Thailand said they did not think so. This perception of farmers combines both ecological and economic reasoning. A similar proportion of farmers believed they could pursue shrimp aquaculture with practices similar to what they were using for no longer than 10 years.

Assets, Entitlements, and Income

The industrialization of shrimp aquaculture affects the livelihoods of various groups of people. Unfortunately, those who are most disadvantaged by the changes wrought by aquaculture are difficult to identify as a group for study, because they are not involved and may have already been displaced.

Among those surveyed, 90% or more at all sites said that shrimp farming had helped improve their standards of living. Many farmers had recently purchased major assets. For 96%, overall shrimp farming was more profitable than their previous primary occupation. Farmers, however, acknowledged that the levels of risk were higher, especially in areas where intensified production systems dominated. About one third of farmers had other regular sources of income than shrimp farming.

Access to credit and the ability to pay back loans were comparatively bigger issues in Vietnam than in Thailand. In all three areas of Vietnam about one third (32% to 29%) of farmers were having difficulty paying back loans, compared to only 12% to 15% in Thailand. In northern Vietnam, almost 95% had taken loans, but of this 42% were from friends or relatives. Elsewhere approximately one half (40% to 57%) had obtained loans, most frequently from banks or agricultural cooperatives. Annual interest rates on loans varied substantially (group averages: 0.4% to 7.5% per year) and in a complex way between locations and types of lending institutions, with rates generally higher from private credit sources.

Adaptive Capacity

The maintenance of local capacities to adapt to disease, price, and other shocks in local communities are crucial to the sustainability of the overall industry. This adaptive capacity is found in both the ecological as well as social systems, and industrial re-organization has changed both.

The specialization and dependencies required to participate in mainstream industrialized shrimp aquaculture by reducing the diversity of income sources reduces the adaptive capacity of households. However this effect can be offset by the ability to purchase assets and make other investments when the producer has been successful. The risk of crop failure from disease outbreaks creates serious difficulties for small investors with poor access to credit. After one failure, many farmers do not have sufficient capital to recover. Although in our survey sample, more than 70% had experienced a crop failure, we must remember that the group of current producers is a biased sample of those who have tried—they are the survivors. In the shrimp consumption-production system suppliers and retailers are much more powerful actors than the producers, and are able to push for increases in costs of inputs as well as keeping down the farm gate prices for shrimp.

ALTERNATIVE PATHWAYS

This paper has argued that the industrial restructuring of shrimp aquaculture in Vietnam and Thailand has involved a complex suite of changes in organization, technology, institutions, knowledge and information systems, markets, and politics. Shrimp aquaculture in Vietnam is on the verge of adopting wholeheartedly the intensification and industrialization model that Thailand has struggled with for the past decade. We already have observed in central Vietnam, as in Thailand earlier, how the commitment to industrialization results in entire regional landscapes with relatively uniform production methods and dependency on high levels of inputs and services, and the assumptions that coastal and aquatic ecosystems will be able to continue to assimilate and convert wastes. Current practices in Thailand are not ecologically sustainable. We are concerned that the consequences of such a transformation in the Mekong River Delta and along the coasts and major deltas of the north would be even more serious.

Nevertheless, we acknowledge that industrialization does not inevitably lead down destructive, non-sustainable pathways, but can be harnessed to improve efficiencies, the profits to producers, and environmental management through standards and shar-

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ing of best practices.

Intensification of shrimp pond production systems reduces the resilience of the larger ecosystem base upon which production depends for resistance to disease, water pollution, and other challenges. Ultimately, it also threatens the sustainability of the shrimp aquaculture industry as options to relocate operations and substitute resources from elsewhere decline because of rising costs and the regional scarcity of key input resources. This may not be a major concern for some of the larger corporate interests, as they have the capacity, given time, to shift the focus of their factories or retail outlets to other commodities and products. The industrialization of shrimp aquaculture has been driven by the strategies of large corporations to maximize profits at various points along the commodity chain. They have had a willing and growing market of wealthy consumers to supply. They have had the governments of developing countries, strapped for cash and desperately needing foreign exchange, more than willing to sacrifice "uncounted" natural resources and ecosystem services. They have been able to take advantage of a large supply of small-scale producers desperate for opportunities to lift their incomes. Some producers have succeeded and others have failed, but the overall machine has marched on, oblivious to the cumulative effects on ecosystem conditions.

Cumulative environmental degradation is an underrated issue in the debate on shrimp aquaculture. Three examples are: *i*) the progressive deterioration in water quality sources for ponds, and accumulation of nutrients in coastal sediments, as a result of wastewater and pond sediment; *ii*) the progressive removal of coastal mangrove strips, which when too small no longer provide effective protection against coastal storm surges (50); and *iii*) the diminishing natural stock of gravid females with which to supply hatcheries and, in the future, complete cycle systems.

At the landscape scale there appears to be a critical threshold. At very low densities of farms, disease and water problems are rare even when physical infrastructure and institutions for shared resources are limited. However, as the landscape is filled with shrimp ponds a threshold is eventually reached after which the remaining natural habitat no longer can cope with nutrient inputs. Water quality starts to decline rapidly, and the risks of disease increase quickly. Moreover, as environmental quality deteriorates due to the accumulation of pollutants, the need to use chemicals to pre-treat water and guard against disease outbreaks increases in a positive feedback that ends when the system is no longer profitable. Industrialization pushes landscapes nearer such thresholds.

Barriers to a Transformation

An industrial transformation that would support the development of a sustainable aquaculture industry in Vietnam and Thailand has not yet begun, for a couple of key reasons. First, effective institutions that could guide this transformation along sustainable trajectories have not matched the rapid and large-scale development of the industry in Thailand. In Vietnam, central planning has been active in setting production goals, but local authorities are left with the challenge of implementing them and attempting to control land-use without adequate resources. Vietnam is in the early stages of environmental regulation systems and policies (51), and there is not much of an environmental social movement to push for such changes. In both countries, resource management planning and institutions have worked at cross-purposes. Aquaculture production falls under the responsibility of one ministry, whereas land and water resources are handled by other ministries. In the absence of good coordination and analysis of cross-sectoral effects and needs, the results are contradictory policies and inconsistent implementation. Second, the emphasis on technological solutions, while promising to decrease the dependence on local aquatic ecosystems such as mangroves to provide services to clean water and so on, tends to rely on higher levels of external inputs. These include various chemical agents and require extra resources procured from elsewhere, such as fossil fuels or fish for feed. Also, these solutions often are not enforceable or adopted because not enough attention has been paid to constraints on access to the technologies. These arise because of the poor state of knowledge systems, and limited or preferential access to resources like credit permits and land. Finally, most research and development is geared to solutions that rarely go beyond tinkering with current production systems, whereas sustainable solutions will require much more radical changes, such as revisiting poly-culture systems with reduced input costs, and finding more efficient ways of organizing business and information. This is why an approach that emphasizes the full commodity chain and supply network, or life cycle, from gravid female to the shrimp in the cocktail, is appropriate (Fig. 4).

Third, because the commodity chain and supply network is long, most consumers still have little idea about the consequences of their consumption behavior. Even producers depend on a supply chain that is remote from their pond. The feedback loops and opportunities for learning available to a farmer-harvester in his extensive polyculture system simply do not exist in the industrialized version.

Finally a transformation will be difficult during the current time of fast growth in the industry because political, market, labor, and consumer forces all are pushing the industry to the limits of intensification and expanded production. Moreover, the bigger players now have substantial investments in infrastructure that they would not willingly abandon or re-direct. Thus, it probably will take a major ecological disaster, a very serious disease outbreak, or a health scare from eating farm-raised shrimp before a major change in the way business is done can take hold in the industry. This makes research and development of alternatives important now, because what options are available when the crisis arrives can have a big effect on the way the system will evolve.

At the beginning of this paper we posed the question: How can the industrial transformation of shrimp aquaculture be directed in ways that are more ecologically, economically, and socially sustainable?

Our comparisons of the development and current state of the shrimp aquaculture industry in different regions of Thailand and Vietnam lead us to conclude that facilitating local innovation and adaptation, and more generic institutional, social, organizational, and educational changes, are important.

Given the great variation in current land-use and aquaculture practices among regions; availability and cost of land and clean water; the state of, and threats to, supporting ecosystems; and cultural factors, the most appropriate trajectory for the industry will vary from place to place. Thus, in Ca Mau, with complex internal waterways and large areas of mangroves, extensive or seminatural farming systems are feasible, whereas such options no longer exist in most parts of eastern peninsular Thailand or central Vietnam.

Shrimp aquaculture should be seen as an optional part of a community development strategy. In both Vietnam and Thailand most policy-making regarding the development of aquaculture has been highly centralized, driven by corporate interests, and insensitive to differences in social and ecological contexts. As a consequence it has been ineffective in guiding environmental practices of shrimp farmers or associated industries. Local institutions have great potential to help improve collective decisions regarding water, land and coastal resource use, but they will struggle to do so without the resources and recognition of an accountable state and cooperation with the private sector. This will require flexibility in policy instruments, implementation, and even the way goals are stated, that is not typical of central governments in Thailand or Vietnam.

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CONCLUSION

Our analyses suggest that current pathways are unlikely to lead to a sustainable industry. In the short term, improvements in management can help reduce environmental damage, and structural changes to improve access to knowledge, credit, and other resources for the poor could help glean some of the potential social development benefits. In the longer term, or next couple of decades, however, nothing short of a complete transformation in the way shrimp are grown, fed, processed, distributed, and consumed is needed. This would change the way profits and costs are shared, and have to be guided by new institutions and environmentally aware consumption demands that provide a better mix of incentives for good environmental practices by industry. In some favorable locations this will imply de-intensifying production, whereas in many other places, the solution will be finding alternatives to growing and eating shrimp.

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