Economic and Water Quality Evaluation of Intensive Shrimp Production Systems in Thailand

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ABSTRACT

Economic feasibility of five intensive shrimp production systems are evaluated using farm survey data for 20 contract farms and 31 independent farms in the Ranot District of Songkhla Province in southern Thailand. Generalized stochastic dominance (GSD) is applied to net economic returns to determine the rank order of the five production systems for farmers with different risk preferences. Water samples drawn from growout and sedimentation ponds and the ocean are tested for 12 water quality indicators. A production system used by independent farms is the most profitable system for all risk preferences evaluated. However, the system generates highly polluted wastewater. One production system used by contract farms provides the best overall quality of water, but has a low economic return. Not all production systems that improve water quality result in lower economic returns. Getting shrimp producers to adopt production systems that improve water quality will require effective regulations and/or economic incentives. Copyright © 1996 Elsevier Science Ltd

INTRODUCTION

During the past 7 years, Thailand’s marine shrimp culture, especially culture of the black tiger prawn (Penaeus monodon), has been growing very rapidly. Prior
to 1984, Thailand harvested as much as 90% of its shrimps from natural sources in the Gulf of Thailand and the Indian Ocean. From 1985 to 1993, the area in shrimp production increased significantly from 40 768 ha to 71 887 ha. Production of farm-based shrimp rose from 15 840 metric tons to 225 514 metric tons during this same period. Shrimps from capture fisheries has been stable or declining since 1987 (Department of Fisheries, 1995). Shrimp production has increased much more rapidly than the area devoted to shrimp farming because capital intensive production methods have replaced more traditional capital extensive methods. Currently, over 70% of the shrimp culture areas are farmed intensively.

The shrimp culture industry is an important source of foreign exchange earnings, employment and protein. Thailand is one of the top five major suppliers of frozen shrimps in the international market (Suwanrangsi, 1992). The value of frozen shrimp exports increased substantially from US$8.32x10^6 in 1981 to about US$1.2x10^9 in 1992 (Krishnasamy, 1993). More than 90% of shrimp exports in 1992 was from aquaculture. Piumsomboon (1993) indicated that Thailand's shrimp production industry employs at least 134 000 people, excluding workers in the related industries of hatcheries, cold storage, feed manufacturing, construction and others.

Rapid expansion in shrimp production is responsible for major social, economic and environmental problems. Intensive shrimp production occurs in a relatively small area. Crowding of farms in these areas results from inadequate planning and regulation. There is no comprehensive plan which takes into account the relationship between the total area in shrimp ponds at a particular site and the carrying capacity of the supplying/receiving water bodies at that site. It is common for the water discharged to the ocean by one farm to be subsequently utilized by a neighboring farm.

Currently, farmers interested in maximizing short-term profit utilize intensive shrimp production methods that are not environmentally sustainable. In pursuing this profit objective, farmers dispose of untreated waste-water from culturing ponds into natural waterways, nearby ecosystems and coastal areas. This practice has had an adverse impact on Thailand's coastal beaches and marine ecosystems. This pollution problem has two elements. First, there is a ‘commons problem’ in the sense that no one farmer is willing to reduce waste emissions to receiving waters because there is free access to the waste assimilative capacity of those waters. Second, there is an externality because the waste emissions from one farm pollute the water supplies used by other farms. This pollution has a significant negative effect on shrimp production (Boyd and Musig, 1992).

Culturing activities in the central and southern regions face extinction because cultured shrimps are being threatened by either serious diseases or mass mortality triggered by water-borne organisms. The high stocking and
feeding rates used in intensive shrimp production increase the dissolved organic matter from metabolites and decomposed uneaten feed in the pond which results in highly polluted wastewater from the pond. Most shrimp farms use very high stocking rates because, in previous years, this practice has boosted production levels. For shrimp farming to be sustainable, it must provide an adequate farm income, generate export earnings and protect the long-term productivity of natural resources and the environment.

The objective of this paper is to evaluate the economic feasibility and water quality impacts of five intensive shrimp production systems used by contract and independent farms in southern Thailand and to discuss public policies for enhancing the sustainability of shrimp production. The major hypothesis to be evaluated is that production systems which generate less water pollution are less profitable. If this hypothesis is supported, then reducing water pollution from shrimp production is unlikely to occur unless farmers have an economic incentive to reduce pollution.

METHODS

Study area

The Ranot district of Songkhla province is located on the east coast of southern Thailand. This district was selected for analysis because of the heavy concentration of shrimp farms and associated water pollution. The district is about 3200 hectares in size and accounts for about 11% of the total area in shrimp culture in southern Thailand. Southern Thailand accounts for about 40% of Thailand shrimp culture. There are three main types of shrimp farms in the Ranot district: independent or small farms, contract farms and company-owned farms.

Farm sizes varies greatly, from 0.16 to 1.6 ha. Independent farms make up approximately 50% of the total number of shrimp farms in the Ranot District. They are generally owned by small operators and utilize family and hired labor. Contract farms are those under contract with one of the biggest companies in the district, a Thai company with American shareholders. This company was established in 1985 and uses a concept known as franchised contract shrimp farming which combines the energy, dedication and resourcefulness of small farmers with the organizational, planning and industrial skills, and financial and marketing resources of a multinational company (Rosenberry, 1993). The contract farmer is responsible for the shrimp rearing operation and the company handles planning, financing, pond construction, research and development, feed manufacturing, shrimp harvesting, processing and marketing. Company-owned farms have played an important role
in the development of the shrimp industry in the Ranot district and other areas of Thailand. There are 22 contract companies registered in the Ranot district (Ranot Fishery Office, 1994). This paper focuses on independent and contract farms.

Current management of shrimp farms

The major inputs used in intensive shrimp production include land, labor, seawater, capital, fry, feed and management. Each cycle consists of pond preparation, filling and stocking followed by feeding, aeration, water quality monitoring and water exchange (replenishing water in the pond). Shrimps are harvested at 16–18 weeks and typically marketed at the farm gate. Intensively managed shrimp ponds vary from very small with an area of 0.08 ha to very large with an area of over 1.6 ha. Pond depth varies from 1.0 to 1.8 m.

Maintenance of water quality is important to the success of shrimp farming. Salinity, temperature, dissolved oxygen, pH, hydrogen sulfide, biochemical oxygen demand, ammonia, nitrite, nitrate and chlorophyll levels have to be optimized because of high biomass content in the form of shrimp stock, excess feed, feces and other organic wastes. Key management variables are stocking rate, feeding rate and water management.

In an intensive production system, a stocking rate of 15–30 fry/m² or 4000–7680 fry/ha is normally recommended. In practice, most farmers stock at rates in excess of 60 fry/m² (Chaiyakam et al., 1993; Thongrak, 1993). All fry are hatchery-reared. Thongrak (1993) found that shrimp farmers who stocked at very high rates harvested shrimps at a smaller size. In contrast, a lower stocking rate allows shrimps to be harvested at a later date which increases shrimp size and profits (Asian Shrimp Culture Council, 1992a) and reduces risk (Tookwinas and Ruangpan, 1993).

Since there is almost no natural food production on intensive farms, shrimp farmers depend exclusively on commercial feeds. Overfeeding is common. A survey conducted in southern Thailand indicated that 60% of the shrimp farms had a feed conversion ratio (FCR) greater than 1.6. FCR is the weight of the shrimp produced divided by the weight of the feed. Only 2.2% achieved a FCR as low as 1.2 (Asian Shrimp Culture Council, 1992b). Overfeeding not only reduces the efficiency of feed conversion, but pollutes pond water. The tens of thousands of metric tons of shrimps produced in the Ranot district result in large accumulations of waste in coastal water. Since seawater is pumped into ponds during the water exchange operation, the risk of shrimp disease and mortality is high.

Maintenance of water quality is essential for the survival and optimum growth of shrimp because the capacity of the pond to support shrimps is
determined by water quality (Asian Shrimp Culture Council, 1991). Water quality maintenance requires that uneaten food and other waste products be continually removed from the pond through exchange with clean water. Water exchange and waste removal are critical processes in intensive pond management. Individual farmers decide when to exchange water based on past experience. Some farmers are reluctant to exchange water for fear that the new water might introduce diseases into the pond. This fear is supported by Boyd and Musig's (1992) finding that water sources contaminated by effluent from other shrimp ponds can spread shrimp disease.

Water management significantly affects shrimp production and the quality of wastewater. A number of practices can be used to improve the quality of discharged pond water and reduce production risk in shrimp farming. These practices include the use of a sedimentation pond or reservoir and the use of a treatment pond. A sedimentation pond is a reservoir used to settle out suspended sediments in water before the water is pumped into growout ponds. The reservoir should cover an area of about 30-50% of the total area of the growout pond. Water exchange should occur as needed, but especially during emergencies such as an outbreak of disease (Rosenberry, 1991; Limsuwan, 1992). Presently, very few farms use sedimentation ponds because it requires converting a growout pond to a sedimentation pond which reduces production. A sedimentation pond is not feasible for small farms that have only one pond.

A treatment pond is another practice for improving the quality of wastewater discharged into the ocean. This practice is costly because it requires setting aside a pond for water treatment. Yoo and Boyd (1993) argued that it may not be practical or economically efficient to treat wastewater by using it in the production of other aquacultural species.

Factors influencing the decision to introduce a treatment pond differ from those influencing the installation of a sedimentation pond. A sedimentation pond for inflow water directly benefits the shrimp farmer, whereas a treatment pond does not necessarily benefit an individual farmer unless treatment ponds are widely adopted. If farmers have adequate capital and land, they are more likely to install a sedimentation pond than a treatment pond. This paper focuses on water management practices prior to the time water is pumped into the growout pond and during production.

Risk analysis

It is widely recognized that production of black tiger shrimp is extremely risky because of substantial annual variation in net returns due to wide fluctuations in yield. There is substantial evidence from Taiwan, Thailand (including the Ranot district) and Indonesia that adverse environmental
effects of shrimp production, notably water pollution, have contributed to higher variability in crop yields and, in some cases, major financial loss.

To date, shrimp farmers have demonstrated little interest in understanding and managing the production risk from poor water quality. However, experienced farmers are beginning to implement practices that decrease production risk such as water-quality monitoring and a lower stocking rate.Managing production risk is crucial to the continued success of shrimp farming in Thailand.

This study evaluates the economic feasibility of five shrimp production systems by applying generalized stochastic dominance (GSD) (Meyer, 1977) to the distributions of net returns for these production systems. GSD theory states that if net return for system 1 has a probability distribution \( f \) and net return for system 2 has a probability distribution \( g \), then system 1 dominates system 2 whenever the expected utility of net return for \( f \) exceeds the expected utility of net return for \( g \). Mathematically, \( f \) dominates \( g \) when

\[
\int_0^1 [f(x) - g(x)]u(x)dx > 0, 
\]

where \( x \) is net return, \( f(x) \) and \( g(x) \) are the probability distributions of \( f \) and \( g \), respectively, and \( u(x) \) is the utility function. For simplicity, the domain of \( x \) is normalized to fall in the interval [0, 1] and is equivalent to

\[
\int_0^1 [F(x) - G(x)]u'(x)dx < 0, 
\]

where \( F \) and \( G \) are the cumulative probability distributions of \( f \) and \( g \), and \( u'(x) \) is the first derivative of the utility function with respect to \( x \).

Meyer (1977) derived conditions where the dominance of one distribution over another occurs for all decision makers who have a Pratt risk aversion coefficient (RAC) which falls in the following interval:

\[
r_1(x) \leq -u''(x)/u'(x) \leq r_2(x),
\]

where \( r_1(x) \) and \( r_2(x) \) are upper and lower bounds on the RAC, respectively. The bounds depend on \( x \) (net returns or wealth). Negative values of \( r(x) \) indicate risk proneness, a zero value indicates risk neutrality and positive values indicate risk aversion.

GSD for two distributions can be evaluated using the following optimal control problem:
Maximize \( \int_{0}^{1} [F(x) - G(x)]u'(x) \, dx \) 

subject to

\[ [u'(x)]' = u'(x)\frac{u'(x)}{u'(x)} \]

\[ r_1(x) \leq -u''(x)/u'(x) \leq r_2(x) \]

with the initial condition \( u'(0) = 1 \).

In this problem, the dominance condition given in eqn 1 is maximized with respect to \( x \). The first restriction is the equation of motion and the second restriction requires \( r(x) \) to fall in a particular interval. If the value of the objective function for the solution to this problem is negative, then the maximum value of the expression given by eqn 1 is negative over all RACs within the interval \([r_1(x), r_2(x)]\), and \( f \) dominates \( g \) for all RACs in this interval.

The optimal control problem given in eqn 2 was solved using the Meyeroot computer program developed by McCarl (1989). The GSD analysis was done in the original units of measurement which were baht (US$ 0.04) for currency and rai (0.16 ha) for area. Three risk aversion intervals were selected as the starting point: \((-0.000032, 0.000032)\) for risk neutrality; \((0.000032, 0.00016)\) for moderate risk aversion; and \((0.0016, 0.0032)\) for strong risk aversion. These intervals were obtained by rescaling the intervals used by Donald and Prato (1992) for currency differences (US$ to baht) and areal units (ha to rai) using the procedure indicated by Raskin and Cochran (1986). The Meyeroot program was then used to determine the solution to eqn 2 which gives the largest risk aversion interval for all pairs of production systems. Intervals were added until utility was too small or solutions could not be obtained. The resulting risk aversion intervals for the RACs are given in Table 1.

Net return per hectare equals gross return minus variable cost of production per hectare. It represents the return to land, capital and management. Since net return per hectare depends on production and prices, it is stochastic. Gross return per hectare equals shrimp yield per hectare times average shrimp price. Shrimp prices are the average market prices received by farmers for various sizes of shrimp during July–August 1994 period. The variation in shrimp price was quite small because of the shortness of the study period. Therefore, most of the variation in gross return is due to variation in production.

Production cost is estimated based on shrimp production activities within the cycle. Only variable cost per hectare is considered. Variable cost includes the cost of fry, feed, labor, fuel, water, fertilizer, lime, chemicals, interest on operating capital and maintenance. For farms that use family labor, cost of
TABLE 1
Upper and Lower Bounds for Risk Aversion Coefficients

<table>
<thead>
<tr>
<th>Risk preference category(^b)</th>
<th>(r_1(x))^(c)</th>
<th>(r_2(x))^(d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk preferring to risk neutral</td>
<td>-0.00064</td>
<td>0.000032</td>
</tr>
<tr>
<td>1</td>
<td>0.000032</td>
<td>0.00016</td>
</tr>
<tr>
<td>Moderately risk averse</td>
<td>0.00016</td>
<td>0.00032</td>
</tr>
<tr>
<td>3</td>
<td>0.00032</td>
<td>0.00064</td>
</tr>
<tr>
<td>Strongly risk averse</td>
<td>0.00064</td>
<td>0.00256</td>
</tr>
<tr>
<td>4</td>
<td>0.00256</td>
<td>0.006</td>
</tr>
</tbody>
</table>

\(^a\)These coefficients were used to solve eqn 2. \(x\) is in baht/rai (one baht equals $US0.04 and one rai equals 0.16 ha).
\(^b\)Category 1 represents the most risk-preferring farmers and category 6 represents the most risk-averse farmers.
\(^c\)Lower bound
\(^d\)Upper bound.

family labor is included in variable cost. Inputs levels are assumed to be determined at the beginning of the production cycle (Anderson et al., 1977). Input prices were obtained from an informal survey of input suppliers in the Ranot district. They reflect 1994 average prices. Fixed cost is not considered because the evaluation is short run.

Farm survey

Since Taborn is the only sub-district of the Ranot district that supports shrimp farming, it was selected for the farm survey. A preliminary survey of both contract and independent farmers was conducted to identify farm structure and production practices. The preliminary survey of independent farms gathered information on the number of growout ponds on the farm, the stocking date for the current crop, stocking rate and presence or absence of sedimentation ponds. The date of stocking was used to schedule water sampling.

In the preliminary survey, 65 independent shrimp farms were randomly selected from the Taborn sub-district. All 65 farms used very high stocking rates (over 75 fry/m\(^2\)). Thirty-seven of the independent farms had multiple ponds and the rest had single ponds. Of the 37 multiple-pond farms, only seven had sedimentation ponds. Based on the preliminary survey, three systems were selected for evaluation on independent farmers (Table 2). Of the 57 contract farmers interviewed in the preliminary survey, 13 stocked at a rate greater than or equal to 60 fry/m\(^2\) and the rest stocked at 50 fry/m\(^2\).
Therefore, only two systems were identified for contract farms, those with high (≥60 fry/m²) and those with low (50 fry/m²) stocking rates. Only single ponds were found on contract farms.

The final sample consisted of 51 farms representing five production systems. The sample included 20 contract farmers, 11 with low stocking rates and nine with high stocking rates, and 31 independent farmers, seven with sedimentation ponds, 13 with multiple growout ponds, and 11 with a single growout pond.

**Water quality monitoring and analysis**

Water samples were taken from three shrimp growout ponds for each system, three sedimentation ponds in system IMUSEH, three locations for sedimentation ponds in contract farms and three locations from coastal water. Water samples drawn from growout ponds were collected at the outflow every week during the fourth month of the production cycle in July 1994. Other samples were collected in the same period. Samples were collected at a 50 cm depth in the ponds in front of the outflow and at a 100 cm depth in coastal water. Coastal water samples were taken at approximately 100–150 m from the coast where most shrimp farms pump seawater into the ponds.

Water samples were tested for indicators generally used in aquaculture (Chaiyakam and Songsangjinda, 1992; Chaiyakam and Songsangjinda, 1993; Songsangjinda et al., 1993). The indicators included ammonia, biological oxygen demand, chlorophyll a, dissolved oxygen, hydrogen sulfide, nitrite-nitrogen, orthophosphate, pH, temperature, total suspended solids, salinity and silicate levels. Single-factor analysis of variance was used to test whether production systems had significantly different effects on water quality. Where differences were significant (P<0.05), comparisons between means were made using Duncan’s Multiple Range test.
RESULTS

Survey

Production characteristics
Production characteristics for sample farms are summarized in Table 3. The crop being raised at the time of the survey is the 10th crop for most contract farms while it varies from the first to the 10th crop for independent farms. Among all the crops raised by sampled farmers, 19 contract farms (95%) and one-half of the independent farms experienced crop failure. Pond sizes are much smaller for independent farms than for contract farms. Independent farms are located much closer to the coast than contract farms because it is difficult and costly for independent farmers to construct water supply facilities.

The average length of the culture period is 4 months for the current crop and 4-6 months for the previous crop on contract farms, and 3-7 months for the current crop and 4-2 months for the previous crop on independent farms. Shrimp health problems appear to be the main reason for a shortening in the production cycle. When health problems occur, continuation of production is risky. Shorter production cycles is the main reason for the smaller size of harvested shrimp.

Ninety-five percent of the contract farms and 52 farms of the independent farms reported at least one crop failure. The number of crop failures varies

<table>
<thead>
<tr>
<th>Item</th>
<th>Contract farm (n = 20)</th>
<th>Percent</th>
<th>Independent farm (n = 31)</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crops per pond</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-3</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>32</td>
</tr>
<tr>
<td>4-6</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>7-9</td>
<td>3</td>
<td>15</td>
<td>11</td>
<td>36</td>
</tr>
<tr>
<td>10</td>
<td>17</td>
<td>85</td>
<td>6</td>
<td>19</td>
</tr>
<tr>
<td>Culture period for current crop (months)</td>
<td>3-4-5 (4)(^b)</td>
<td>—</td>
<td>2.5-4-5 (3-7)</td>
<td>—</td>
</tr>
<tr>
<td>Culture period for last crop (months)</td>
<td>4-5 (4-6)</td>
<td>—</td>
<td>3.5-4.5 (4-2)</td>
<td>—</td>
</tr>
<tr>
<td>Farms reporting crop failure(^a)</td>
<td>19</td>
<td>95</td>
<td>16</td>
<td>52</td>
</tr>
<tr>
<td>Causes of crop failure:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water exchange</td>
<td>4</td>
<td>21</td>
<td>4</td>
<td>25</td>
</tr>
<tr>
<td>Disease</td>
<td>9</td>
<td>47</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>Unidentified</td>
<td>6</td>
<td>32</td>
<td>7</td>
<td>44</td>
</tr>
</tbody>
</table>

\(^a\) At least one crop failed since respondent started raising shrimps in that pond.
\(^b\) Values in parentheses are means.
from one to four per farm, averaging 25% of the total number of crops raised. Failures result from a combination of factors, but poor water quality is the major cause. Eight of the 51 farms experienced crop failure due to water exchange and several farms experienced disease outbreak.

**Water management**

Contract farms only use seawater to raise shrimp whereas 20% of the independent farms use a blend of seawater and freshwater. A blend is preferred because tiger shrimps grow much faster in blended water than in seawater. Freshwater can only be obtained from groundwater which is very limited in the Ranot district. Moreover, pumping of groundwater for shrimp culture is prohibited in the Ranot district.

All contract farms use water from sedimentation ponds which is distributed to farms by small canals. The percentage of area in sedimentation ponds per area of growout ponds is very low; 4% compared to the recommended value of 30–50%. A low percentage does not allow suspended solids to settle out. This result is corroborated by water samples taken from sedimentation ponds on contract farms which contained high concentrations of total suspended solids.

The area of sedimentation pond on independent farms accounts for 50% of the area of growout ponds, which is an acceptable proportion. All sedimentation ponds in the survey use single-step sediment removal. Among the seven independent farms having a sedimentation pond, five farms allow water to settle out naturally without any treatment. The other farms use chemicals, aerators and lime to accelerate sedimentation and maintain an optimal pH level. However, water in sedimentation ponds has a low residence time due to the stochastic nature of farmers’ decisions regarding water exchange.

All sampled farms exchange water during the production cycle. Farms tend not to exchange water during the first month of the production cycle. Rates and frequency of exchange increase as shrimps become larger. For example, in the second month, water is exchanged twice at a replacement rate of 30%. Exchange is more frequent in the third and fourth months; twice per week at 30% replacement. Most farmers are reluctant to exchange water unless the shrimps exhibit symptoms of poor health. This reluctance arises because pumping new water into a pond might increase the risk of health problems, particularly when the incoming water is contaminated.

Since none of the independent farms have a sedimentation or treatment pond for wastewater, they all discharge pond wastewater directly to the coast or through discharge canals or natural waterways. All contract farms discharge wastewater to the coast through a discharge canal and sedimentation pond. Since sedimentation ponds are very small relative to the quantity of
water flushed, there is not sufficient settling of suspended solids or organic matter in wastewater.

**Stocking rate**
Independent farms stock at a much higher rate than contract farms. For example, farms using system IMUH stock at more than twice the rate as farms using system CONL (110 vs 50 fry/m², respectively). Nearly all farms increase their stocking rate over time as survival rates decline. System IMUSEH has the highest survival rate (82.2%) and system CONH has the lowest survival rate (8.9%). As a whole, independent farms realize higher average survival rates than contract farms; 41.1% vs 18.8%. Current survival rates are much lower than previous rates which get as high as 95% (Asian Shrimp Culture Council, 1991). Since current management practices are similar to those employed in the past, low quality of fry and the deterioration of water quality are the likely causes of lower survival rates.

**Feed and feeding**
The use and cost of feed affects profitability and water quality. Nearly all contract farms use only formulated feed provided by the contract company. In contrast, about 20% of the independent farms utilize both formulated and fresh feeds. The average FCR is lower for systems used in independent farms than for systems used in contract farms. This implies that independent farms use their feed more efficiently which partly explains why independent farms are more profitable than contract farms. Results do not indicate that lower FCRs improve the quality of discharged water. There is considerable opportunity for contract farms and independent farms to significantly improve their FCR.

**Costs, yields and returns**
Table 4 summarizes the estimated variable cost for alternative shrimp production systems. Two types of costs are reported: (i) the cost per hectare for individual inputs such as fry, feed, fuel, labor and other items, and total variable cost (TVC) which is the sum of the costs of the variable inputs; and (ii) average variable cost (AVC) which equals TVC divided by production. TVC is much higher for independent farms than for contract farms. TVC is more than twice as high for system IMUSEH than for systems CONH and CONL. This difference is explained by higher variable costs for feed, fuel and labor on independent farms. Feed cost under system IMUSEH accounts for about 50% of TVC. In contrast, total feed cost is only 28% of TVC for systems CONH and CONL. Cost of fry is the second highest variable cost for independent farms and the third highest variable cost for contract farms, accounting for between 15 and 21% of TVC. Reducing stocking rate to attain maximum survival rate would substantially reduce variable cost.
### TABLE 4
Variable Cost for Alternative Shrimp Production Systems$^{a,b}$

<table>
<thead>
<tr>
<th>Item</th>
<th>IMUSEH</th>
<th>ISIH</th>
<th>IMUH</th>
<th>CONH</th>
<th>CONL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fry</td>
<td>6155</td>
<td>5925</td>
<td>6099</td>
<td>3976</td>
<td>3241</td>
</tr>
<tr>
<td>%$^c$</td>
<td>15.4</td>
<td>20.8</td>
<td>19.7</td>
<td>20.8</td>
<td>17.3</td>
</tr>
<tr>
<td>Feed</td>
<td>19903</td>
<td>13303</td>
<td>14705</td>
<td>5296</td>
<td>5283</td>
</tr>
<tr>
<td>%$^c$</td>
<td>49.8</td>
<td>46.7</td>
<td>47.4</td>
<td>27.7</td>
<td>28.2</td>
</tr>
<tr>
<td>Fuel</td>
<td>3597</td>
<td>3020</td>
<td>3808</td>
<td>1199</td>
<td>1611</td>
</tr>
<tr>
<td>%$^c$</td>
<td>9.0</td>
<td>10.6</td>
<td>12.3</td>
<td>6.3</td>
<td>8.6</td>
</tr>
<tr>
<td>Labor</td>
<td>2758</td>
<td>2080</td>
<td>2508</td>
<td>760</td>
<td>843</td>
</tr>
<tr>
<td>%$^c$</td>
<td>6.9</td>
<td>7.3</td>
<td>8.1</td>
<td>4.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Other</td>
<td>7554</td>
<td>4159</td>
<td>3900</td>
<td>7876</td>
<td>7756</td>
</tr>
<tr>
<td>%$^c$</td>
<td>18.9</td>
<td>14.6</td>
<td>12.6</td>
<td>41.2$^d$</td>
<td>41.4$^d$</td>
</tr>
<tr>
<td>TVC</td>
<td>39967</td>
<td>28487</td>
<td>31020</td>
<td>19107</td>
<td>18734</td>
</tr>
<tr>
<td>SD</td>
<td>19269</td>
<td>6605</td>
<td>7331</td>
<td>2033</td>
<td>2402</td>
</tr>
<tr>
<td>AVC$^e$</td>
<td>3.74</td>
<td>4.06</td>
<td>3.73</td>
<td>8.28</td>
<td>6.88</td>
</tr>
</tbody>
</table>

$^a$US/ha.
$^b$Variable cost for each input is averaged over all farms utilizing the indicated system.
$^c$As a percentage of total variable cost.
$^d$Includes cost for water supply and facilities which averages about 28% of total variable cost for systems CONH and CONL.
$^e$US/kg.

AVC behaves quite differently than TVC. Systems IMUH and IMUSEH have the lowest AVC at $US 3.73/kg, and system CONH has the highest AVC at $US 8.28/kg. Independent farms have lower AVC than contract farms for two reasons. First, yield is much higher for systems used by independent farms. Second, contract farms have to pay for water supply facilities which do not directly enhance production.

The quantity of shrimp harvested per hectare per crop (yield) varies across systems (Table 5). For all systems, average yield is much higher for independent farms than for contract farms; 8666 vs 2510 kg/ha/crop. System IMUSEH (independent farm with sedimentation pond and high stocking rate) has the highest yield, namely 10679 kg/ha/crop. As evidenced by the high standard deviations, there is higher variation in yields for systems used on independent farms than for systems used on contract farms. This finding could result from variation in quality of fry, water quality and other factors.

Net returns are reported in Table 6. System IMUSEH has the highest average net return. The mean net return for system CONH is negative and the minimum net returns for systems ISIH, IMUH, CONH and CONL are negative. Hence, contract farms are only marginally profitable.
The cumulative distributions of net returns for pairs of production systems are compared for farmers in different risk preference categories. These pairwise comparisons are then used to establish a complete preference ordering for the five production systems in each risk preference category (Table 7).

**TABLE 5**
Shrimp Yield for Production Systems

<table>
<thead>
<tr>
<th>Measure</th>
<th>IMUSEH</th>
<th>7026</th>
<th>8293</th>
<th>2296</th>
<th>2723</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>10679</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>4750</td>
<td>3506</td>
<td>3438</td>
<td>719</td>
<td>1378</td>
</tr>
<tr>
<td>Maximum</td>
<td>21400</td>
<td>10833</td>
<td>13569</td>
<td>3353</td>
<td>5700</td>
</tr>
<tr>
<td>SD</td>
<td>6008</td>
<td>3267</td>
<td>2854</td>
<td>868</td>
<td>1364</td>
</tr>
</tbody>
</table>

*kg/ha.

**TABLE 6**
Net Returns for Production Systems

<table>
<thead>
<tr>
<th>Measure</th>
<th>IMUSEH</th>
<th>17754</th>
<th>27574</th>
<th>-2440</th>
<th>81.25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>37802</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>4976</td>
<td>-9657</td>
<td>-2539</td>
<td>-13968</td>
<td>-6865</td>
</tr>
<tr>
<td>Maximum</td>
<td>80051</td>
<td>40860</td>
<td>64264</td>
<td>6450</td>
<td>16439</td>
</tr>
<tr>
<td>SD</td>
<td>81.25</td>
<td>17970</td>
<td>17963</td>
<td>5904</td>
<td>7469</td>
</tr>
</tbody>
</table>

*USS/ha.

**TABLE 7**
Preference Orderings for Shrimp Production Systems within Risk Preference Categories

| Category                        | Preference orderings
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk preferring to risk neutral</td>
<td>IMUSEH, IMUH, ISIH</td>
</tr>
<tr>
<td>Moderately risk averse</td>
<td>IMUSEH, IMUH, ISIH</td>
</tr>
<tr>
<td>Strongly risk averse</td>
<td>IMUSEH, IMUH, CONL, CONH</td>
</tr>
</tbody>
</table>

*From most to least preferred within each category.
*Neither system is dominant.
*ISIH dominated by CONL only for RAC between 0.00016 and 0.000185.
For strongly risk-averse farmers, shrimp production systems having a high mean and high variation (standard deviation) in net return are less attractive than systems having a low mean and low variation in net return. For example, strongly risk-averse farmers would prefer system CONL to system ISIH even though system ISIH has a substantially higher net return because ISIH exhibits much more variation in net return than system CONL (Table 6). However, a high mean net return can more than compensate for high variation in net return. Even though it exhibits the highest variation in net return, system IMUSEH dominates all other systems for all risk preference categories because it provides a very high mean net return and does not result in a negative net return. All other systems have at least one minimum net return that is negative. For all risk preference categories, IMUSEH is the most financially attractive production system.

**Water quality**

Standards and measurements on water quality indicators for each production system are given in Table 8. In general, pond water contains high concentrations of hydrogen sulfide, ammonia and nitrite (especially nitrite), total suspended solids, phosphate and silicate. Based on these water quality indicators, system IMUSEH (independent farm with sedimentation pond and high stocking rate) and system IMUH (independent farm with multiple growout ponds and high stocking rate) are most detrimental to the coastal marine environment. System CONL (contract farm with low stocking rate) is the least detrimental. Pond water for system CONL contains the lowest concentrations of pollutants. Therefore, shrimp production systems that utilized a low stocking rate resulted in less water pollution.

Having a sedimentation pond for inflow water for contract farms does not seem to improve water quality compared to direct use of coastal water. However, compared to coastal water, the concentrations of ammonia and nitrite are significantly lower in sedimentation ponds on independent farms. In addition, concentrations of ammonia and hydrogen sulfide are lower in sedimentation ponds on independent farms than on contract farms.

Since the system with the poorest water quality (IMUSEH) includes a sedimentation pond, it is not clear whether sedimentation ponds improve the quality of water discharged from growout ponds. Apparently, other factors besides the quality of inflow water affect the quality of water discharged from a pond.

**Net returns and water quality**

None of the currently used production systems are sustainable in terms of economic and water quality criteria. System IMUSEH has the highest net
<table>
<thead>
<tr>
<th>Indicator</th>
<th>Standardb</th>
<th>Shrimp</th>
<th>Aquaculture</th>
<th>IMUSEH</th>
<th>ISIH</th>
<th>Production system</th>
<th>Sedimentation pond</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IMUH</td>
<td>CONH</td>
</tr>
<tr>
<td>Ammonia</td>
<td>&lt; 10</td>
<td>&lt; 0.40</td>
<td>0.0043a</td>
<td>0.0040b</td>
<td>0.0042c</td>
<td>0.0039d</td>
<td>0.0028e</td>
</tr>
<tr>
<td>BODa</td>
<td>&lt; 4</td>
<td>nea</td>
<td>4.21a</td>
<td>4.20a</td>
<td>4.93a</td>
<td>4.01a</td>
<td>3.91a</td>
</tr>
<tr>
<td>Chloro. µ</td>
<td>ne</td>
<td>ne</td>
<td>0.0123ab</td>
<td>0.0142ab</td>
<td>0.0232a</td>
<td>0.0143ab</td>
<td>0.0113ab</td>
</tr>
<tr>
<td>DO</td>
<td>&gt; 3-satur.</td>
<td>&gt; 4</td>
<td>6.01a</td>
<td>8.26a</td>
<td>6.78a</td>
<td>7.22a</td>
<td>5.84a</td>
</tr>
<tr>
<td>H₂S</td>
<td>&lt;0-0.33</td>
<td>0.0247a</td>
<td>0.0223b</td>
<td>0.0236c</td>
<td>0.0214d</td>
<td>0.0211c</td>
<td>0.0082f</td>
</tr>
<tr>
<td>NO₂</td>
<td>&lt;0-1.0</td>
<td>ne</td>
<td>0.2533a</td>
<td>0.1923ab</td>
<td>0.0650ab</td>
<td>0.0143ab</td>
<td>0.0066b</td>
</tr>
<tr>
<td>PO₄</td>
<td>&lt;0.1</td>
<td>ne</td>
<td>0.0475a</td>
<td>0.0658b</td>
<td>0.0286c</td>
<td>0.0223d</td>
<td>0.0097c</td>
</tr>
<tr>
<td>pH</td>
<td>7.5–8.5</td>
<td>7–8.5</td>
<td>7.66a</td>
<td>8.15a</td>
<td>8.02a</td>
<td>8.07a</td>
<td>8.17a</td>
</tr>
<tr>
<td>Salinity</td>
<td>10–15 ppt</td>
<td>f</td>
<td>33.83a</td>
<td>33.0a</td>
<td>32.85a</td>
<td>33.69a</td>
<td>34.08a</td>
</tr>
<tr>
<td>SiO₃</td>
<td>ne</td>
<td>ne</td>
<td>0.3058a</td>
<td>0.1325a</td>
<td>0.280a</td>
<td>0.1281a</td>
<td>0.1275a</td>
</tr>
<tr>
<td>Temp.</td>
<td>28–32°C</td>
<td>&lt; 33°C</td>
<td>30.1d</td>
<td>30.3ef</td>
<td>30.5hced</td>
<td>30.7hced</td>
<td>30.8hced</td>
</tr>
<tr>
<td>TSS</td>
<td>&lt; 25</td>
<td>ne</td>
<td>148a</td>
<td>129ab</td>
<td>134ab</td>
<td>109hbc</td>
<td>99Bc</td>
</tr>
</tbody>
</table>

*Values within a row having the same superscript are not significantly different (P > 0.05).


cFor system IMUSEH.

dFor contract farms.

For system IMUSEH.

fChange from natural level not more than 10%.

gBOD, biological oxygen demands.
return, but yields water quality that exceeds established standards. Economic viability of systems IMUH and ISIH is questionable even though their average net return is positive. For some farms, these systems have negative net returns. System CONH has a highly negative net return and is not economically viable. System CONL, which has the lowest stocking rate, generates the highest water quality, but has a net return that is substantially lower than the net return for systems IMUSEH, IMUH and ISIH. Some of the water quality indicators for CONL exceed the standards.

Figures 1–3 illustrate the trade-off curves between net returns and selected water quality indicators (ammonia, BOD and phosphate, respectively). Each curve is determined by plotting net return against the corresponding water quality indicator. A positively-sloped segment of the trade-off curve indicates that an increase in net return entails an increase in pollution. A negatively-sloped segment indicates that an increase in net return entails a decrease in pollution. Since the data for the trade-off curves are plotted so that net return increases moving up the curve, a positively (negatively)-sloped segment of the curve indicates there is (is not) a trade-off between net return and water quality.

Not all systems having a high stocking rate involve a trade-off between water quality and net return. While there is a trade-off between net return and total suspended solids, hydrogen sulfide, silicate and ammonia, there is no trade-off between net return and other water quality indicators. In

![Fig. 1. Trade-off curve between net return and ammonia concentration for shrimp production systems.](image-url)
addition, there is no trade-off between net return and water quality for systems CONH and CONL (lower stocking rate). System CONH generates more water pollution and lower net return. Results of the trade-off analysis provide mixed support for the hypothesis that production systems which cause less water pollution are less profitable. Changing production systems for the purpose of improving water quality does not always reduce net return.
POLICY IMPLICATIONS

From a farmer's perspective, the most preferred shrimp production system is the one which maximizes the utility of net return irrespective of water quality impacts. From this private perspective, system IMUSEH (independent farm with high stocking rate and sedimentation pond) would be most preferred by farmers having a wide range of risk preferences.

From society's viewpoint, systems IMUSEH, IMUH, ISIH and CONH, all of which have a high stocking rate, are unacceptable because of their high potential for water pollution. Water pollution not only reduces environmental quality but also has negative impacts on shrimp production in the long run. Even though system CONL produced less water pollution than other systems, it generated high concentrations of total suspended solids, biological oxygen demand and hydrogen sulfide.

Production systems which reduce water pollution at the expense of lower net return are unlikely to be adopted by farmers unless they receive economic incentives. Incentives should be considered for production systems that incorporate sedimentation ponds and lower stocking rates because of their ability to improve water quality. Historically, governmental regulation is more common in aquaculture than economic incentives. Regulations are better suited for achieving specific reductions in environmental pollution than economic incentives. While the government can regulate the stocking rate as well as the quality of pond water discharged to the environment, it would require development of a permit system for all farms and ponds and a monitoring system to enforce compliance with regulations. After three years of regulating effluent from shrimp ponds in Thailand, there has been no improvement in water quality because monitoring and enforcement have been lacking due to a limited budget (Flaherty and Karnjanakesorn, 1994). A regulatory approach does not appear to work well in Thailand.

The government could induce farmers to reduce stocking rates by imposing a tax on fry. Hatcheries could collect the tax and transfer the revenue to the government. Revenue generated from the tax could be used to finance research and extension programs to reduce water pollution from shrimp farming. Implementation cost would be less with taxes than with regulations because permitting and monitoring are not required. However, the administrative cost of collecting taxes and accounting for tax revenues can be substantial. This cost would be offset by tax revenues. Even though a tax is cost effective and the administrative cost could be paid from tax revenue, the increased cost to farmers is likely to be unpopular.

Alternatively, a subsidy in the form of grants or loans could be used to encourage shrimp farmers to invest in practices that improve water quality, such as sedimentation and treatment ponds. Loans are likely to be more
feasible than grants because government funds are very limited. Loans can be made available to individual farmers or groups of farmers who construct both sedimentation and treatment ponds. Unfortunately, subsidies provide an incentive for inefficient firms to remain in the industry, just the opposite of what is desired (Baumol and Oates, 1988).

Water treatment is another option. One version of this option, which is being considered, is a seawater irrigation system for improving the quality of water inflow to and outflow from growout ponds. A seawater irrigation system would have main canals for carrying seawater to production areas and handling discharged water. Sub-canals would deliver seawater to sedimentation ponds and remove wastewater from treatment ponds. Payment of construction costs would be shared between the government and participating farmers. Farmer participation in a water treatment program would be voluntary and participating farmers would have access to a high quality source of water and be required to discharge pond wastewater to designated canals and treatment ponds. Participating farmers would receive technical assistance in water management.

Another policy option is research and education. A major advantage of a research and education is that it is likely to result in longer lasting improvements in water quality than a subsidy or tax because changes in production practices are made on a voluntary basis rather than being mandatory.

A more efficient way for Thailand to enhance the sustainability of shrimp production is to implement a combination of policy options. The specific combination of policies selected would depend on policy goals and financial resources. Three factors should be considered in selecting a combination of policies: efficiency, equity and government cost. Efficiency is measured by net benefit (total benefit minus total cost) of the policy and equity by the distribution of the benefits and costs among affected parties. Under current fiscal conditions in Thailand, any new policy that causes government expenditures to increase would be viewed negatively. Requiring farmers to bear part of the cost of achieving the goals of the policy would be more acceptable.

REFERENCES


