Social, Economic, and Production Characteristics of Freshwater Prawn *Macrobrachium rosenbergii* Culture in Thailand

by

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Abstract

The objective of this survey was to assess the current state of production for the giant river prawn *Macrobrachium rosenbergii* in Thailand and assess the feasibility for adoption of a nutrient recycling system. A socioeconomic and technical survey of 100 prawn farmers was conducted during 1 May-31 July 2005 in Thailand. The majority of respondents were male (70%) and average age was 46 ± 1. Most farmers (77%) had completed an elementary level of schooling (4 years) and experience on the farm as owner, manager, or both averaged approximately 10 ± 1 years. Most respondents (92.9%) obtained information about prawn culture from their neighbors and only 19% received formal training. Monoculture was the dominant system (96%) while remaining farmers utilized polyculture with prawns and white shrimp *Litopenaeus vannemei*. The most common management strategy included nursing postlarvae for 30 to 60 days and harvesting with the combined method, culling only the largest market-sized individuals beginning at 5 months followed by every 30 to 45 days (66% of farmers used this system).

Culture practices at the time of this survey were intensive. Most farmers stocked at densities below 20 pieces m^{-2} and average production was 2,338 kg ha^{-1} yr^{-1}. However, some farmers utilized stocking densities and obtained production values above those described as semi-intensive. Also, commercially produced, nutritionally complete feed was most common, water exchange and aeration was utilized to maintain suitable water quality, and water quality management throughout the cycle was practiced if respondents had the resources. After the culture period, water was generally discharged directly into canals without treatment. Average net profits were 3,918 US\$ ha^{-1} yr^{-1}. Variables that significantly affected yearly gross prawn production (kg ha^{-1} $year^{-1}$) included feed inputs (kg ha^{-1} $year^{-1}$), frequent water exchange, and stocking prawns directly (R^2 = 0.299). Yearly net profits (US\$ ha^{-1} $year^{-1}$) were most influenced by gross prawn production (kg ha^{-1} $year^{-1}$), feed inputs (kg ha^{-1} $year^{-1}$), and years of experience of the respondent (R^2 = 0.795).

A recycling system that isolates production from the environment and integrates organisms which retain nutrients was simulated for 50 of the surveyed farms. Net profits were lower than average survey results. However, recycling systems do have promise; many farmers seemed to be aware of the environmental effects of current production and attributed multiple problems to water pollution. External pollution was severe for 16% of respondents, moderate for 46%, not an issue for 38%, and was perceived to be caused by multi-user effects. Major problems identified were diseased or poor quality seed supply (67%), disease outbreak within the crop (64%), and external pollution (37%).

In 2005 the freshwater prawn industry in Thailand was valued at US\$79,096,000 and ranked 3rd behind China and India (FAO 2005). To maintain this level of production, alternative systems are necessary and must balance adequate environmental benefits and economic returns similar to or better than monoculture.

Chapter One
Introduction

The giant river prawn *Macrobrachium rosenbergii* is native to Southeast Asia, South Pacific countries, northern Oceania, and western Pacific islands (New 1982; New 2002). It is the most popular prawn species used for commercial farming and has been transported to many parts of the world including South America and China (New 2002). Modern aquaculture of the species began in the late 1960s with the discovery that larval survival required brackishwater conditions (Ling 1969). Commercial development was possible due to research conducted by Takuji Fujimura which allowed for the ready availability of postlarvae (New 2000a).

Optimal production of freshwater prawn requires water temperatures ranging from 28 to 31ºC (New 2002). The larval stage of the species requires brackishwater so uncultivated individuals are often found in estuaries and postlarvae begin to move into freshwater two weeks after metamorphosis. Adults are found in most inland freshwater areas, preferring turbid conditions (New 2002). Due to aggressive behavior and competition, freshwater prawns exhibit differential growth rates and multiple morphotypes exist among sexually mature males. Small males, orange claw males, and blue claw males exist as well as intermediate stages and are easily distinguished by the size and color of their claws (New 2002).

Freshwater prawn farming was established in Thailand in 1978 when the Food and Agriculture Organization (FAO) funded the United Nations Development Program (UNDP) working with the Thai Department of Fisheries (DOF) on a project entitled “Expansion of Freshwater Prawn Farming in Thailand”. The project provided technical advice and free postlarvae for initial commercial grow-out operations (New 2000a). By 1984 Thailand produced 3,000 tons of freshwater prawns (FAO 1989). Production was expected to rise due to an increase in local demand after the 1990s financial crisis and a ban on inland marine shrimp farming (New 2000b).

Since 1995 there has been a rapid global expansion of freshwater prawn production (New 2005). A large amount of that production has taken place in China and there has been rapid expansion in India and Bangladesh (New 2005). FAO statistics reported production of 7,800 tons in Thailand in 1998 (FAO 2000) and in 2001 the country was ranked fourth in top producers, producing 12,076 metric tons (New 2005). From 1999 to 2001 *M. rosenbergii* production increased by 19 percent and Charoen Pokphand (CP), a major feed supplier, planned a large expansion in freshwater prawn production from 2000 to 2003 (New 2005). Most recent FAO statistics reported Thai production at 30,000 tons at a value of US$79,096,000, ranking 3rd in producers behind China (99,111 tons) and India (42,820 tons) (FAO 2005).

Freshwater prawn farming can be conducted by unskilled rural people on small establishments and prawns are consumed domestically by all social classes. This differs considerably from marine shrimp farming, which is controlled by a small number of individuals and is primarily for export (New et al. 2000). It is an activity that can play a role in poverty reduction and the empowerment of women. In Bangladesh it has aided in increasing job opportunities for women and increasing their contribution to household income (Ahmed 2005). Women who participated had been allowed some economic independence and a more important role in household decision making ranging from the education of children to family planning (Ahmed 2005).

Also, social conflict and environmental impacts are minimized in prawn culture compared to marine shrimp farming. Prawns are produced in inland ponds, which are easily integrated into the landscape reducing competition for coastal resources (New et al. 2000). Marine shrimp farming uses higher stocking densities and high feeding rates and discharges higher proportions of soluble and solid wastes. According to New et al. (2000), high stocking densities of prawns are less profitable due to the agonistic behavior of male prawns, this results in low stocking densities and less environmental impacts.

While environmental impacts of individual prawn farms are less than marine shrimp farms, high concentrations of farmers practicing semi-intensive to intensive culture can quickly degrade water quality within an area. Semi-intensive culture has been the most common production system for *M. rosenbergii* in Southeast Asia (Lee and Wickins 1992; D'Abramo and New 2000). Semi intensive is defined by stocking densities of 4-20 pcs m^{-2}, incorporation of fertilization and feeding, and production of 500-5,000 kg ha^{-1} $year^{-1}$ (Lee and Wickins 1992; Valenti and New 2000; New 2002).

In Thailand intensive culture is popular (Derun et. al 2004). Freshwater prawn production takes place on small farms, with 95% of farms under 2 hectares (ha) and few over 5 ha (New 2000b). Farmers are concentrated along irrigation canals and most use formulated, protein-rich diets (Derun et al. 2004). This requires frequent water exchange to maintain suitable water quality (New and Singholka 1985) and nutrient rich effluent discharged into public waterways results in eutrophication and poor water quality for multiple users (Derun et al. 2004).

Alternative systems would isolate production from the surrounding environment and/or recycle nutrients produced in prawn culture to generate other crops which have market value and will retain nutrients and reduce nutrient discharge (Derun et al. 2004). Closed systems with zero to little water exchange cause less pollution and also reduce the risk of introducing external pollutants and pathogens into culture ponds (Derun et al. 2004). While these systems can reduce environmental impacts and associated effects, farmers must first recognize a problem and adopt the system.

There is a need for socioeconomic and environmental research to understand the state of current production and ensure it is responsible and sustainable (New 2005). Ultimately, freshwater aquaculture as a whole plays an important role in Thailand. It provides quality nourishment and income opportunities to the rural poor. Employment opportunities are generated throughout the production chain and include manual labor, feed supply, and product distribution. This is compared to brackishwater culture which involves high value species that are often exported (FAO 2007). While there is potential in Thailand to increase food production for local markets as well as earnings and opportunities of local people, responsible culture practices are necessary to ensure the future viability of the industry.

In that regard the purpose of this survey was to address the following aspects of prawn culture: determine the types of production systems and management strategies utilized for freshwater prawns in Thailand and the level of production and net profits associated; describe the social framework of the industry and the availability of technical assistance and information for farmers; identify variables that have significant influences on production and net profits as these may provide insight into the economic viability of the recycling system as well as inform future research; in addition, determine if farmers perceive environmental effects of culture practices and recognize how they subsequently affect production; finally, assess the sustainability of the industry and feasibility for adoption of environmentally sound culture systems and to offer recommendations for future research.

Chapter 2
Study Area and Methods

Thailand is located in the center of Southeast Asia, covering an area of 513,115 square kilometers with a tropical climate consisting of three distinct seasons. The rainy season occurs from June to October, cool season from November to February, and the hot season from March to May. The southern region has rainfall occurring year round while March and April are the driest months. Average annual temperature is 28ºC (UNDP 2006).

The 2006 population of Thailand was approximately 64,631,595 people and the annual growth rate, 0.68 percent (CIA 2006). As of 2005 the labor force was comprised of 36.1 million with an official unemployment rate of approximately 1.8 percent (US Embassy in Thailand 2006). Roughly 60% of the labor force was employed in agriculture. Agriculture includes fish and fishery products, and rice is the most important crop (US Embassy in Thailand 2006). In 2002, approximately one-quarter of the population aged 3-21 years did not attend school and the average household income for the country was US$4,121 per year (NSO 2003). Poverty, or those without sufficient income to satisfy their basic needs, has been reduced from 27% in 1990 to 9.8% in 2002 (UNDP 2006).

A structured socioeconomic and technical survey was conducted during 1 May through 31 July 2005 in Thailand. The survey was drafted by the project staff at the Asian Institute of Technology (AIT) in Klong Luang, Pathumthani, Thailand (personal communication, Dr. Yang Yi, AIT) and I altered it to better suit responses about conditions in Thailand (Appendix I). The survey consisted of both closed and open ended questions. Open ended questions were concerned with stocking densities, feeding rates, production and corresponding costs; this information was necessary to calculate yearly production rates and net profits. All surveys were conducted in Thai; most were simultaneously translated to English while others were translated later by AIT staff.

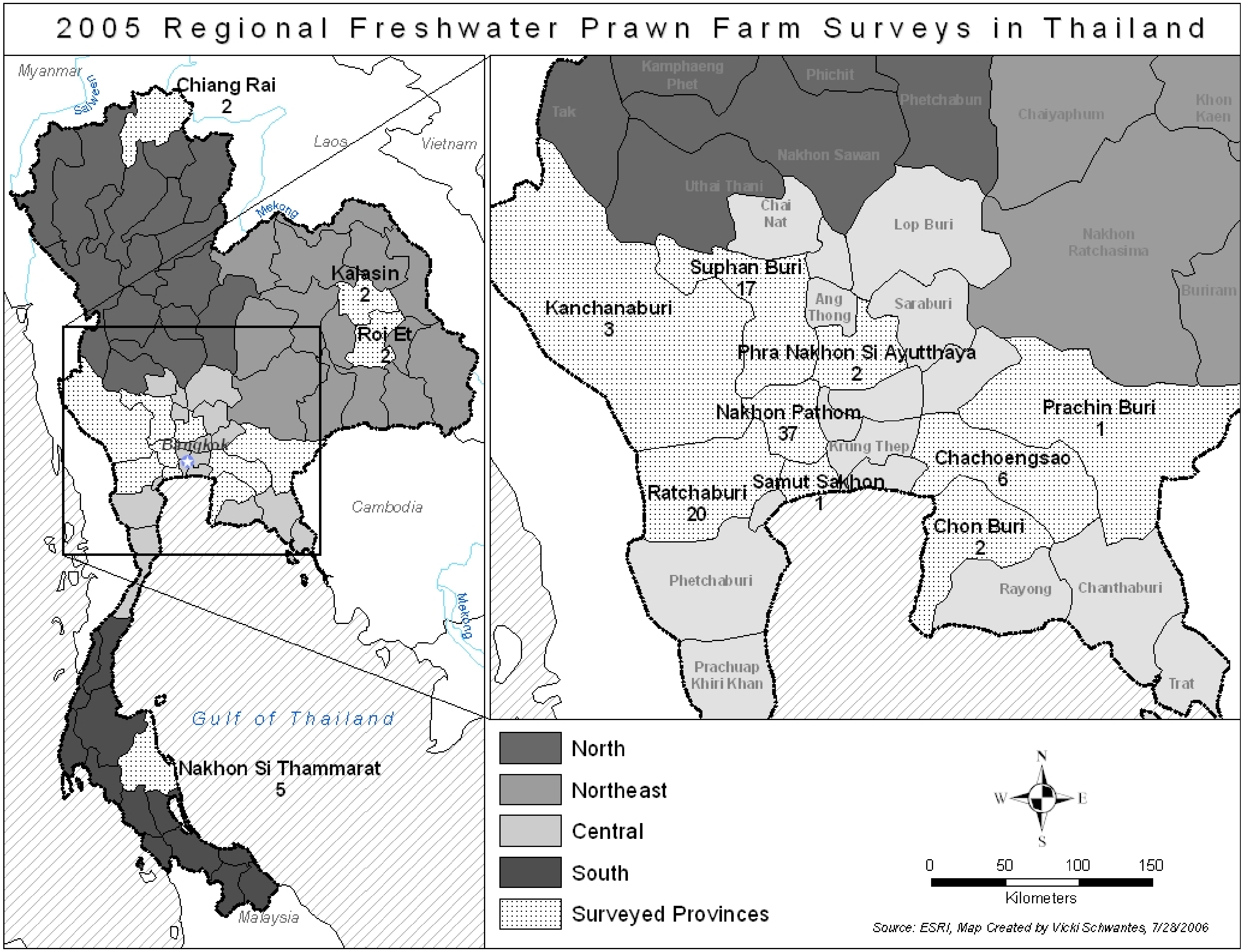
Farmers were interviewed on 100 farms that were selected in major prawn producing areas throughout the country. Focus areas were chosen based on 2003 summary data of prawn production and area in each province, collected from farmers registered with DOF (DOF 2004). The proportion of production (tons), number of grow-out farms, and area of grow-out farms (rai, 1 rai = 0.16 ha) was calculated for each province compared to the entire country. These proportions were averaged to determine the number of surveys administered per province (Appendix II).

To determine where surveys were conducted within each province, available data were collected from Provincial Fisheries Offices and the number of surveys was broken down proportionally by the number of prawn farmers within districts or sub-districts. Ultimately the number of surveys conducted was altered in some areas if farmers were difficult to find due to changing farming practices, such as the transition to white shrimp *Litopenaeus vannamei*, or tiger shrimp *Penaeus monodon* production.

Thailand is divided into four regions based on ecological, economic and social factors. The majority of the surveys (89) were conducted in the central region, predominantly in the provinces of Nakhon Pathom, Ratchaburi, and Suphanburi (Figure 1). The central region is the valley of the Chao Phraya River, which flows through Bangkok and into the Gulf of Thailand and is also known as the "rice bowl" of Asia (UNDP 2006). The eastern portion of central Thailand is differentiated by hilly countryside from Bangkok to Cambodia, higher rainfall, and poorer soils than the rest of the central region. Some rubber is grown, but it is a primary producer of fruit, maize, and cassava. An extensive coastline is utilized for both fisheries and tourism (UNDP 2006). Interviews in this area were conducted in Chachoengsao, Prachinburi, and Chonburi. Central Thailand[1] has the highest average income per household of approximately three to four people, US$4,238 $year^{-1}$, after the Bankok metropolitan region[2], US$8,472 $year^{-1}$ (NSO 2003). The central region as a whole has a population of 20,622,000 people, excluding Bangkok metropolitan area, the population is 14,840,000 (NSO 2003).

[1] Excludes Greater Bangkok
[2] Includes Nonthaburi, Pathum Thani, and Samut Prakan

Figure 1. Map of freshwater prawn surveys conducted in Thailand from 1 May-31 July, 2005 organized by region.



Four interviews were conducted in the northeastern provinces of Kalasin and Roi Et. The northeast region is comprised of the Korat Plateau which is bounded by the Mekong River to the north and east and the Dongkrek escarpment to the south. The area is arid and often subjected to floods and droughts. Due to lower and erratic rainfall and poorer soils than the rest of the country, the northeast has the lowest average household income US$2,784 year^{-1} (UNDP 2006, NSO 2003). Approximately 1/3 of the population resides here, 21,609,185 people (NSO 2003).

Two interviews were conducted in northern Thailand in the province of Chiang Rai. The north is mountainous and the majority of the people live in deep, narrow, alluvial valleys formed by four rivers that unite in the northern central plain to form the Chayo Phraya. The north was once heavily forested, but over cutting has reduced these resources (UNDP 2006). The population is 12,152,502 (NSO 2003) and average household income is US$ 2,859 year^{-1} (NSO 2003).

All interviews in the southern region were conducted in Nakohnsitthammarat. The southern region is the principal rubber growing area and contains extensive alluvial deposits of tin. Due to over harvesting of the region's forests and high rainfall, severe flooding and subsequent soil erosion has occurred (UNDP 2006). The population is 8,451,908 and average household income is US$3,746 year^{-1} (NSO 2003).

All farmers approached for this survey were willing to participate. The majority of farmers that were interviewed did not keep written records of the production cycle, but relied on memory. Incomplete recollection of major farm inputs and outputs is a source of error in analysis. All data were only as accurate as the farmer could remember, and each farmer differed in the amount of detail that could be recalled. Knowledge may also be affected by status of the respondent on the farm. For example a respondent who was active daily as farm manager was likely to have more precise information than someone who owned the farm and did not participate in management or interact with workers. Economic and production variables were analyzed with varying sample sizes due to missing or vague data.

Calculation of important variables such as stocking, production, and feeding rates was based on water area, not including dykes, water storage ponds, or fish ponds. Nursing ponds were included in water area and I assumed all farmers continued to use nursing ponds for grow-out purposes with prawns stocked at a similar density as grow-out ponds. Production values represent gross production because many farmers stocked postlarvae (PL) of negligible weight, however some stocked juveniles and in these cases I did not subtract the initial weight of prawns. Net profits were calculated for cases that included a value for both water area for prawns and the entire area of the farm including dykes and residence. All variables were calculated for a cycle period and extrapolated to yearly values; stocking density was reported on a per cycle basis. A cycle was the period of time from the beginning of pond preparation until final harvest when ponds were drained. Net profits were reported in US dollars (1 dollar = 40 Baht). Data were analyzed using SPSS (version 14.0) statistic software package (SPSS Inc., Chicago, USA). Means were reported with a ± standard error.

Multiple linear regression models were created only for monoculture prawn farms so extrinsic factors associated with different management on polyculture farms would not affect the results. Models were created in SPSS using the backward selection method to predict output for two variables of interest, production (kg ha^{-1} yr^{-1}) and net profits (US$ ha^{-1} yr^{-1}). Two models were used to predict each output. The first model for each dependent variable included key management decisions made by the farmer that should directly influence the output. This model might be useful outside of these survey results for individuals making management decisions. The second model incorporated variables into the first model that may also influence the output variable, but were not fully controlled by the farmer. These included pollution impact, access to training, or education level of the respondent. Prawn production was included in the economic models as an indirect variable, one the farmer cannot fully control. This model is only useful within this data set and will describe trends within this sample that may offer insight into prawn farming throughout Thailand.

Key management decisions chosen as predictor variables for regression included nominal and continuous variables. Nominal variables included those that were descriptive of the management strategy, such as whether the farmer stocked PL or juveniles, stocked directly or nursed, and harvested with the batch or combined method (Table 1). Dichotomous dummy variables were used for nominal data (yes or no answer) to determine the response of the dependent variable to the presence (1) or absence (0) of the independent. The reference case (0) was a well defined category that had a larger number of cases. For example, the presence of aeration was coded 0 and was more common than the absence, coded 1.

Other decisions such as stocking density, strain stocked, use of aeration, number of days before water exchange or addition, feeding, and water quality measurement were included. The most common chemicals used at pond preparation and throughout the cycle, used by at least ¼ of respondents, were also incorporated as predictor variables. Variables that incorporated all eligible cases were chosen as predictors. For example I did not use transfer survival to grow-out ponds in the models because many farmers chose to stock PL directly or stock juveniles. These cases did not involve a transfer survival value and would have been discarded from the analysis.

Table 1. Variables used in multiple linear regression models of prawn production (kg ha^{-1} $year^{-1}$) and net profits (US$ ha^{-1} $year^{-1}$) on farms in Thailand.

Management Decisions (16 variables)	Indirect Variables (4 variables)
Stocking (PL=0, juveniles=1)	Education Level (elementary=0, above=1)
Nursing (nurse=0, direct=1)	Years of Experience (years)
Harvest Method (combined=0, batch=1)	Previous Training (no=0, yes=1)
Stocking Density (pcs m^{-2} $year^{-1}$)	External Pollution Impact (present=0, absent =1)
Strain Stocked (local=0, CP/Kaset Samboon Farms=1)	Prawn Production (kg ha^{-1} $year^{-1}$)[a]
Lime and Dolomite Used for Pond Preparation (kg ha^{-1} yr^{-1})	
Lime, Dolomite, and Zeolite Applied Throughout the Cycle (kg ha^{-1} yr^{-1})	
Aeration (present=0, absent=1)	
Water Exchange (days $exchanged^{-1}$)	
Feeding Rate (kg ha^{-1} yr^{-1})	
Measure Water Quality (no=0, yes=1)	

[a] Only used for the net profit model (US$ ha^{-1} $year^{-1}$).

A theoretical recycling system was simulated for all farms, monoculture and polyculture, in the economic analysis by reducing a proportion of the original prawn stocking and feeding costs and gross profits obtained from harvest. The stocking and production of tilapia and water mimosa were then simulated on that proportion of the farm area. Different proportions were used to find the most economical variation of the recycle system. Feed costs were reduced proportionally assuming that the alternative species would not be fed and that the existing feeding rate for prawns would produce enough nutrients to support them. Aeration was considered unnecessary in all ponds and water exchange rates and all other variables remained constant. It was assumed that each farmer could complete three production cycles (120 days) for tilapia and water mimosa during the year with minimal downtime to drain and dry ponds. The cost of stocking tilapia was calculated using a stocking density of 2 fish m^{-2} and water mimosa at 0.4 kg m^{-2}, prices were 0.025US$ $fish^{-1}$ and 0.125US$ kg^{-1} respectively (Derun et al. 2004). The value used to estimate tilapia production was 12 kg ha^{-1} day^{-1} or 1,440 kg ha^{-1} $cycle^{-1}$ and water mimosa harvest was estimated with production of 88 kg ha^{-1} day^{-1} or 10,560 kg ha^{-1} $cycle^{-1}$ (Derun et al. 2004). Market prices used were 0.50US$ kg^{-1} and 0.125 US$ kg^{-1} for tilapia and water mimosa, respectively (Derun et al. 2004).

Chapter 3
Results

Farming of the giant river prawn in Thailand is a cooperative activity conducted by men and women from a wide range of demographics. Prawn farming was predominantly a private business (100%), but the majority of farmers (93%) had local management meetings and most information about prawn culture was acquired from neighbors (92.9%), while government agencies (53.5%) and feed and chemical suppliers (25.3%) were also important. Also, labor at harvest was cooperative in Samut Sakhon, Chachoengsao, and Chonburi where farmers assisted each other at harvest for no cost.

The majority of respondents in this survey were male (70%), but it did not seem as though prawn farming was dominated by one gender. While most interviews were conducted with only one person, many were directed toward one person while family members also provided input. The age of respondents (n=98) ranged from 19-72 years, average age 46 ± 1. The majority of farmers (77%) had completed an elementary level of schooling, which requires 4 years in Thailand. High school involved 12 years total and was completed by 16% of respondents; 6% had a vocational or university education while 1 person had no formal education. Experience was measured as the length of time working on the farm as owner (48%), manager (4%), or both (48%). Respondents had as little as 8 months experience and as much as 25 years with average experience approximately 10 ± 1 years.

Previous to prawn farming the majority of respondents (63%) participated in some type of agricultural activity such as rice or tiger shrimp culture. Formal training in prawn culture was received by only 19% of interviewees and usually consisted of a day long course, while one farmer had two years of training. Training was often affiliated with the Thai Department of Fisheries, but also Kasetsart University, CP, or a local prawn culture association. Five farmers surveyed in Nakhonsitthamarrat were among a group of 15 who had been trained in prawn culture by DOF 8 months prior to the survey, and had been provided with free feed and seed to stimulate their prawn business. Their previous activities in mariculture had been banned inshore after a dam had been built on the Chaingyai River in 2004 to separate salt from freshwater, especially in the dry season. This was done to improve freshwater production of rice, fish, and prawns.

There was little variety in the culture systems utilized for freshwater prawn in Thailand, but there were multiple management strategies. Monoculture was most common, practiced by 96% of respondents. Polyculture was utilized in Samut Sakhon and Chachoengsao and consisted of white shrimp cultured with freshwater prawn. These farmers indicated that if this type of polyculture proved to be successful they would continue, however if white shrimp appeared to produce better yields and offer higher economic returns alone they would consider using white shrimp in monoculture. Some farmers had fish ponds, but they were not integrated into prawn culture or the ponds were primarily used for water storage. Some respondents mentioned that they occasionally alternated crops. A farmer in Samut Sakhon said he switches to shrimp and fish culture some years and a man in Kanchanaburi produces one crop of rice every 3 years to improve soil quality. Some farmers in Kalasin also produce a rice crop every 2-3 years and intermittently use pond effluent to fertilize other crops.

Six management strategies were used by respondents (Table 2). The most common strategy included stocking with postlarvae (PL), 10-25 days old, utilizing a nursing period with high stocking densities in order to use land, water, and labor more efficiently. The nursing period ranged from 30-90 days, most commonly 60-75 days (60%). Alternatively, some farmers chose to directly stock PL or juveniles, ranging from 3-29 grams, into grow-out ponds. Two different harvest methods were used, batch and combined. In the more common combined method farmers culled only marketable sized prawns, beginning 5 months after PL were stocked and 2 months after juveniles were stocked. Prawns stunted by dominants were then allowed to grow and were harvested on a 30-45 day basis. After several months, ponds were drained, harvested entirely, and prepared for the next crop. The less common batch method allowed prawns to grow to a medium market size and then ponds were drained, harvested, and prepared for another crop.

Table 2. Six management strategies for freshwater prawn production on surveyed farms in Thailand.

Management Strategy	**% of Farmers**	**No. of Cycles/Year**	
		Avg	Range
PL-nursing-combined	66	1.3	0.83-1.9
PL-nursing-batch	19	2.1	1.5-2.5
PL-direct-batch	4	2.0	1.9-2.3
PL-direct-combined	5	1.2	1.1-1.7
Juvenile-batch	5	4.1	3-5.4
Juvenile-combined	1	1.3	1.3

Regardless of differing management strategies most farms were small and farmers used similar pond preparation techniques. A typical farm was less than 5 ha in both total and water area and used ponds with an average pond depth of 1.4 meters (Table 3). Clay substrates were predominant with loam, silt and/or sand mixed with clay also present. Water used for prawn culture was most commonly obtained directly from natural or manmade canals, while two individuals used an area reservoir. Only 19% of respondents used water storage ponds prior to draining water into culture ponds. Of those that stored water, only 4 farmers treated it, using lime and aeration, while others mentioned there were fish in the storage ponds. Prior to stocking, ponds were dried from 7 to 30 days, soil was tilled and plowed, and dykes were repaired. Ponds were filled and treated most commonly with lime or dolomite and salt was often used in nursing ponds at 0.1 to 1.2% salinity. Prawns were stocked within 1-15 days after ponds had been filled.

Table 3. Size in area and depth of ponds on surveyed farms used for freshwater prawn culture in Thailand.

		Proportion (%)	**Size**	
			Mean ± SE	Range
Total Area n=52	<5 ha	69	3.1 ± 0.2	0.5-4.8
	5-10 ha	27	6.9 ± 0.4	5.3-9.6
	>10 ha	4	32 ± 16	16-48
Water Area n=85	<5 ha	79	2.6 ± 0.2	0.3-4.8
	5-10 ha	18	6.6 ± 0.4	5.4-9.6
	>10 ha	4	23.4 ± 5.3	14.4-32.6
Pond Depth N=100	Meters	100	1.4 ± 0.03	0.8-2.5

While some farmers utilized nursing ponds with high stocking densities and others stocked directly into grow-out ponds, most farmers purchased seed to ultimately stock all ponds at low densities, below 20 pcs m^{-2} (Table 4). Approximately half (54.1%) of respondents stocked ponds with local seed as opposed to seed provided by CP or Kaset Samboon Farms, which charged almost twice the price. Transfer survival values were calculated for farms that utilized nursing pond(s) and are the number of individuals that survived from the nursing pond(s) to be transferred to grow-out ponds. Transfer survival values were significantly correlated to stocking density of the nursing pond (slope = 0.580, $p < 0.05$, $R^2 = 0.606$). The average proportion of prawns that survived to be transferred was 63% (Table 5). This was not related to stocking density in the nursing pond.

Table 4. Stocking densities (pcs m^{-2} $cycle^{-1}$) of freshwater prawn ponds in Thailand (n=84).

Rank of Stocking Density	**% of Farmers**	**Density Stocked**	
		Mean ± SE	**Range**
Low (< 20)	69	11 ± 1	1-20
Medium (20-40)	21	28 ± 1	20-38
High (> 40)	10	56 ± 4	43-74
Overall	100	19 ± 2	1-74

Table 5. Percentage of prawns transferred from nursing to grow-out ponds, size at transfer, feed conversion ratio, production, and incomes on freshwater prawn farms surveyed in Thailand.

	N	**Mean ± SE**	**Range**
Percent Transferred	68	63 ± 3	16 to 99
Size at Transfer (grams)	68	3.2 ± 0.2	0.5 to 9
Feed Conversion Ratio	79	2.1 ± 0.2	0.2 to 8.1
Prawn Production (kg ha^{-1} yr^{-1})	78	2,338 ± 144	438 to 6,381
Net Profit (US$ ha^{-1} $year^{-1}$)	48	3,918 ± 522	-935 to 14,984
Net Yearly Income (US$ $year^{-1}$)	48	24,160 ± 6,491	-5,981 to 272,908

Once prawns were stocked they were most commonly fed with commercial feed, consisting of 40% crude protein, 15% water, 5% fat, 3% fiber, 1% phosphorus (Table 6). Feeding trays were utilized by many farmers as well as broadcasting feed from the dyke or from a boat. The majority of farmers (94%) fed ad libitum, using their own judgment to modify feeding rates by checking the remaining feed in the feeding tray or on the pond bottom rather than following a feeding table provided by the feed company. Average feed conversion ratio was 2.1 and was not related to feed type.

Table 6. Feed types used in various combinations on surveyed freshwater prawn farms in Thailand.

Feed Type	Percent
Commercial Supply Feed	76
Commercial and Fresh Supply Feed	17
Homemade Feed	3
Commercial and Homemade Feed	2
Fresh Supply Feed	2

Throughout the cycle farmers either regularly managed water or used treatment only at times of poor water quality. Aeration with paddle wheels was common (78%) and one farmer used an air jet. Water was exchanged every 12 days on average to maintain water quality or topped up to compensate for losses due to evaporation. Generators fueled by diesel were the most common source of energy to power electrical aerators and pumps (97%). Fertilization was not common, only occurring on 6% of farms as many farmers believed it was unnecessary and would cause plankton blooms. Water quality in ponds was measured by 43% of respondents; all of them measured pH on a weekly to monthly basis. A few also measured alkalinity, dissolved oxygen, ammonia, and nitrogen. Periods of poor water quality were experienced by 41%; most common treatments included lime, dolomite, zeolite, or water exchange to control pH. Farmers who did not measure water quality reasoned that they lacked equipment or didn't know how, and one said it was useless. Those who did not monitor water quality relied on visual inspection to assess pond health.

Water treatment after the culture period was not common and the majority of farmers discharged water directly into the drainage canal (90%). Water treatment by the remaining farmers included discharge of water into settling ponds, a neighbor's fish ponds, or rice fields. Respondents considered fish ponds to serve as treatment ponds treated by fish to "reuse nutrients." Three farmers in two provinces, Chiang Rai and Nakhonsithammarat, stated that the local government required effluent permits, but regulations were not enforced in either area. However, the two respondents in Chiang Rai did use settling ponds.

Harvest occurred either throughout the cycle or only when ponds were drained and was most commonly done with a beach seine (98%). Yearly prawn production was on average 2,338 kg ha^{-1} yr^{-1} (Table 5) and prawns were sold most commonly to a trader at the farmgate either dead or alive (58.7%). Other options included selling prawns at Mahachai market in Samut Sakhon (43.5%) or Chatuchak and other markets in Bangkok (21.7%). Farmers interviewed in the north, northeast, and south sold prawns to local restaurants (2.2%) or hotels (1.1%). Farmgate and market prices were similar and did not differ by region. The price of prawns at market increased with size, females ranged from 1.25-3.75 US$ kg^{-1} and male prawns (which grow larger) were more profitable at 2-6.25 US$ kg^{-1}.

The majority of farms were profitable, making an average US$3,918 ha^{-1} $year^{-1}$ (Table 5). Yearly income was 24,160 US$ yr^{-1} on average (Table 5), quite high compared to the average Thai household. Only 6% of individuals had negative returns. In Ratchaburi one farmer stated that even if his profits were lower, there was no other activity that got higher returns than prawn farming. Few farmers subsidized their income, the majority (78%), concentrated only on prawn farming. Subsidiary occupations included agricultural or business ventures such as grocery, handicrafts and truck driving.

Farmers invested in multiple inputs throughout the cycle as described previously. Inputs such as feed and seed were necessary and were the highest proportion of costs, average 56% and 17% respectively (Table 7). Stocking costs were higher for respondents who stocked juveniles and those in the south who had to purchase PL from distant provinces (Suphan Buri and Songkla). In some cases inputs were not necessary or farmers chose not to expend resources on them. For example, farm land was fully owned by 48% of respondents, rented by 30%, and 22% both owned and rented some land. Some farmers rented 25 to 100% of their land at a cost of 5 to 75 dollars ha^{-1}, on average 40 dollars ha^{-1} (n=30). The highest proportion of total cost for rent was 18%. At most, labor constituted 13% of cost. However, most farmers relied on family labor which was free, but some hired casual labor for harvest and 14% hired permanent employees. Not all respondents utilized aeration or exchanged water frequently.

Table 7. Proportion of all annual costs per hectare per year on freshwater prawn monoculture and polyculture farms in Thailand (n=50).

Input	Mean ± SE (%)	Range
Feed	56 ± 2	13-89
Seed	17 ± 2	1-69
Pond Preparation	6 ± 1	0-50
Water Exchange	5 ± 1	0-20
Water Treatment	4 ± 1	0-27
Rent	4 ± 1	0-18
Aeration	4 ± 1	0-14
Labor	3 ± 0	0-13
Electricity	1 ± 0	0-12
Pond Fill	1 ± 0	0-2

Four farmers in the survey cultured freshwater prawn with white shrimp. Due to incomplete data, production and net profits could not be calculated for all four. Total stocking densities for three farmers were 11, 26, and 34 pcs m^{-2} $cycle^{-1}$ (Table 8). White shrimp were 0.04 Baht per piece and were similar in price to local prawn seed. They were stocked at transfer and not included in the prawn nursery pond. The farmer coded E-CHAC-02 had a high prawn stocking density initially, but sold prawns to neighboring farmers at transfer before stocking white shrimp and prawns together. Polyculture farmers had high total production, greater than 3,500 kg ha^{-1} yr^{-1}. White shrimp were harvested at a size of 10 grams and sold for 1.25 to 2 US$ kg^{-1}. Net profits for polyculture farms were higher than the average prawn farmers (Table 8).

Table 8. Stocking density, production, and profits for farmers polyculturing freshwater prawn and white shrimp on three surveyed farms in Samutsakhon and Chachoengsao.

	Farm Code		
	W-SA-01	**E-CHAC-02**	**E-CHAC-05**
Prawn Stocking (pcs m^{-2} $cycle^{-1}$)	5	28	14
White Shrimp Stocking (pcs m^{-2} $cycle^{-1}$)	6	6	12
Total Stocking (pcs m^{-2} $cycle^{-1}$)	11	34	26
Prawn production (kg ha^{-1} yr^{-1})	2609	5732	3860
White Shrimp production (kg ha^{-1} yr^{-1})	1174	1433	1930
Total production (kg ha^{-1} yr^{-1})	3783	7166	5789
Net Profit (US$ ha^{-1} $year^{-1}$)	5714	8714	-
Net Yearly Income (US$ $year^{-1}$)	27,425	27,886	-

Are high profits and production on monoculture prawn farms correlated and/or significantly influenced by the previously described management strategies and factors? Are extrinsic influences more important? Simple correlations describe only a small proportion of the variability in the data. Prawn production (kg ha^{-1} yr^{-1}) was positively correlated with feeding (kg ha^{-1} yr^{-1}) ($r^2 = 0.151$, $p < 0.01$), lime application throughout the year (kg ha^{-1} yr^{-1}) ($r^2 = 0.051$, $p < 0.05$) and stocking directly into grow-out ponds rather than nursing ($r^2 = 0.069$, $p < 0.05$). It was also negatively correlated with the use of non local seed ($r^2 = 0.069$, $p < 0.05$). Production (kg ha^{-1} yr^{-1}) had a strong positive correlation with net profits (US$ ha^{-1} $year^{-1}$) ($r^2 = 0.613$, $p < 0.01$), while stocking directly was less responsible ($r^2 = 0.208$, $p < 0.01$). Profits were negatively correlated with feed conversion ratio ($r^2 = 0.118$, $p < 0.05$).

A higher proportion of variability in the data was described when using multiple linear regression modeling. In the case of prawn production the models were similar using management predictors and combining them with indirect variables (Table 9, 10). In both cases only one third of the variability in the data was attributed to similar predictor variables. Feeding (kg ha^{-1} yr^{-1}) and water exchange (days $exchanged^{-1}$) had the greatest influence on production. Feed and production were positively correlated, while an increase in days before the addition of freshwater or water exchange was negatively correlated. Other important variables positively affecting production were stocking directly, measuring water quality, and use of aeration.

Table 9. Results of a multiple linear regression model for prawn production (kg ha^{-1} $year^{-1}$) using management decision predictor variables on monoculture prawn farms surveyed in Thailand (constant = 1,826.702, adjusted $R^2 = 0.299$).

Management Decision Predictors	Unstandardized Coefficient ± SE	Standardized Coefficient	P value
Feeding Rate (kg ha^{-1} yr^{-1})	0.137 ± .035	0.399	0.000
Stock Directly	796.462 ± 354.861	0.229	0.028
Measure Water Quality	410.609 ± 241.606	0.171	0.094
No Aeration	-561.229 ± 286.7	-0.199	0.054
Water Exchange (days $exchanged^{-1}$)	-27.605 ± 11.303	-0.245	0.013

Table 10. Results of a multiple linear regression model for prawn production (kg ha^{-1} $year^{-1}$) using all predictor variables on monoculture prawn farms surveyed in Thailand (constant = 1,820.452, adjusted R^2 = 0.291).

All Predictors	Unstandardized Coefficient ± SE	Standardized Coefficient	P value
Feeding Rate (kg ha^{-1} yr^{-1})	0.134 ± 0.036	0.391	0.000
Stock Directly	795.480 ± 356.650	0.230	0.029
Measure Water Quality	434.386 ± 246.424	0.180	0.083
No Aeration	-561.892 ± 288.145	-0.200	0.055
Water Exchange (days $exchanged^{-1}$)	-26.167 ± 11.640	-0.229	0.028

Only 23%, of variability in net profits was explained by management decision predictors (Table 11). Both stocking directly and increasing dolomite application throughout the year had positive influences on net profits. Net profits, similar to production, were negatively influenced by an increasing number of days between water exchange and top up events. When using all predictor variables, the R^2 was 0.795 and the most influential variables were production and feeding rate, with positive and negative influences respectively (Table 12). Production positively influenced net profits while feeding rate had a negative influence. Other positive influences included the increasing years of experience of the respondent and utilizing the batch harvest method. In this model, profits increased when aeration was absent despite the significant positive influence of aeration on production.

Table 11. Results of a multiple linear regression model for net profits (US$ ha^{-1} $year^{-1}$) using management decision predictor variables on monoculture prawn farms surveyed in Thailand (constant = 3,684.167, adjusted R^2 = 0.231).

Management Decision Predictors	Unstandardized Coefficient ± SE	Standardized Coefficient	P value
Stock Directly	3,422.909 ± 1216.264	0.378	0.007
Dolomite Use Throughout Cycle (kg ha^{-1} $year^{-1}$)	0.428 ± 0.186	0.309	0.027
Water Exchange (days $exchanged^{-1}$)	-85.85 ± 42.580	-0.272	0.050

Table 12. Results of a multiple linear regression model for net profits (US$ ha^{-1} $year^{-1}$) using all predictor variables on monoculture prawn farms surveyed in Thailand (constant = -3,323.189, adjusted R^2 = 0.795).

All Predictors	Unstandardized Coefficient ± SE	Standardized Coefficient	P value
Prawn Production (kg ha^{-1} $year^{-1}$)	2.558 ± 0.217	0.932	0.000
Years of Experience	158.147 ± 43.587	0.260	0.001
Batch Harvest	1457.122 ± 529.054	0.191	0.009
No Aeration	978.961 ± 535.847	0.128	0.075
Feeding Rate (kg ha^{-1} $year^{-1}$)	-0.328 ± 0.063	-0.406	0.000

A recycling system would reduce feed and aeration costs, but also reduce prawn production, replacing it with organisms of lower market value. Since net profits were positively correlated with prawn production and negatively correlated with feed inputs (the highest proportion of costs), it may be possible to balance the savings from reduced feed costs with profits lost from reduced prawn harvest. In that scenario the recycling system could be economically viable. However, simulation of a theoretical recycle system on 50 monoculture and polyculture prawn farms led to lower average net profits in all combinations (Table 13). If equal proportions of area were devoted to tilapia and water mimosa production for water recycling, the most profitable system utilized only 10% of the water area for these species. This is not suitable for adequate recovery of nutrients, the primary purpose of a recycling system. Another option to increase the recycling area and boost profit was to use a higher proportion of area for tilapia, the more profitable of the two crops. Under this scenario the most profitable combination was prawn, tilapia, and water mimosa at 50%, 40%, and 10% respectively. This combination better balanced profit from harvest and decreased feeding costs compared to the 60%:30%:10% combination. However, the average net profit was still 48% less than the monoculture system.

Table 13. Net profits (US$ ha^{-1} $year^{-1}$) under variations of a theoretical recycling system implemented on monoculture and polyculture freshwater prawn farms in Thailand (n=50).

% Prawns:% Tilapia:% Mimosa[a]	**Net Profit (US$ ha^{-1} $year^{-1}$)**		
	Average ± SE	**Range**	**% Reduced**
100:0:0	4,049 ± 511	-935 to 14,984	
33:33:33	1,741 ± 178	-728 to 5,636	57
90:5:5	3,803 ± 461	-823 to 13,666	6
50:40:10	2,120 ± 260	-986 to 7,767	48
60:30:10	1,005 ± 213	-1,796 to 5,320	75

[a] Value of white shrimp on polyculture farms are included in proportion of freshwater prawns.

While more research may be useful on recycling systems, farmers may be interested in adopting alternative ecologically sound systems and management strategies even if they reduce profit. Many farmers seem to be aware of the environmental affects of current systems and attributed multiple problems to external pollution. External pollution was reported to have severe impacts on 16%, moderate impact on 46% and no impact on 38% of respondent's farms. Agricultural activities were cited as the primary pollution source (75.4%) followed by aquaculture (39.3%) and industry and domestic waste (27.9% each).

The major problems most commonly identified by respondents were seed supply (67%), disease outbreak (64%), and external pollution (37%). Approximately one third (33%) of respondents cited low production which could be caused by a number of unknown factors. Seed supply problems were caused by poor quality or diseased PL or long waiting periods after ordering and some people reported not receiving what they had ordered. An increase in disease and parasites was reported by 60.6% of respondents and most common was black gill which is protozoan induced (New 2000b). Many respondents (57.4%) cited external pollution as the cause of the increase in disease prevalence, followed by seed quality (29.6%), pond water quality (22.2%), and poor soil quality (13%). In Ratchaburi one farmer stated that the increase in disease was due to pollution caused by the increasing number of farms in the area. Most farmers felt they could successfully treat disease by mixing antibiotic with feed (55.4%), but many (31.3%) saw crop failure inevitable and would harvest. Less than 1/3 (26.3%) felt that there had been no change in disease trends.

Other problems included nuisance plants, such as emergent vegetation, which often clog culture ponds, reducing suitable culture area for prawns. Only 20% of respondents reported problems with emergent vegetation, which included vegetation in ponds and water hyacinth decomposition in the water supply canal that degraded the quality of water for culture ponds. Also, high water salinity (3%), acidity (1%), or a lack of water (3%) occurred in eastern provinces Chonburi, Prachinburi, and Chachoengsao, which was the large inland shrimp production area before. A farmer in Chonburi reported that sometimes there was no water in the supply canal for 4-5 months.

Approximately half (49%) of respondents reported experiencing low production or crop collapse at some time in the past. The causes most frequently reported were disease (46.9%) followed by external pollution (20.4%), lack of water (12.2%) and poor water quality (10.2%). A small proportion of farms (3%) experienced collapse of the crop prior to the survey and this was due to lack of water on two farms in Suphanburi and poor water quality in Nakhon Pathom. Also commonly reported (45%, n=98) were large fluctuations in production from year to year. Average fluctuations reported were 37.6 ± 2.3%, ranging from 15-65%.

Despite these problems farmers seem to be interested in continuing prawn culture activities, increasing culture knowledge, and improving their operations. While many respondents consider prawn farming to involve high risk and investment, the majority of farmers (93.9%) preferred prawn farming to their previous occupation and many wanted more information about prawn culture techniques (96%) and marketing (28.3%). The majority of farmers felt this financial risk would be reduced if the government controlled market prices (63.6%) and materials cost (41.4%), and also controlled the water supply and seed quality (18.2% each). A farmer in Chachoengsao said that prawn farming is a good business especially if the market price is higher than 100 Baht kg^{-1}, or 2.5$ kg^{-1}.

Approximately 63% of farmers planned to make improvements to their farms including changes to the farm infrastructure as well as farm management. All future improvements seemed to be concerned with boosting financial returns. Examples included increasing culture area or alternating/polyculture with white shrimp. While five farmers stated they planned to reduce their stocking density, this was not likely related to the environmental effects of high stocking density, but to the better economic returns due to higher growth rates and lower disease risk.

The majority of farmers had no suggestions to offer about issues related to prawn culture (68%), while 25% did see a need for change in management techniques. It was not determined whether these management techniques were only concerned with reaping higher net economic returns or if they also included better management practices in regard to the local environment which in turn would likely lead to higher production and reduced risk. Only 2 respondents suggested that farmers should be responsible for treatment of wastewater.

Chapter 4
Discussion

Results from this survey indicated four general conclusions. First, intensive monoculture was the predominant culture system in Thailand. Second, several variables had significant influence on production and net profits providing insight into culture practices. Third, the majority of respondents discharged untreated effluent which had the potential to significantly deteriorate water quality in natural waterways and canals. Finally, perception of multi-user effects was evident and alternative production systems, such as the recycling system, might be adopted after further research and optimization.

Intensive Monoculture

Intensive monoculture was the primary culture system utilized in Thailand. While stocking and production rates were predominantly semi-intensive as defined by Valenti and New (2000), Thai production would be best described as intensive. Many farmers (31%) stocked prawns at densities greater than 20 pcs m^{-2} and a small proportion had production greater than 5,000 kg ha^{-1} yr^{-1}. Most importantly, many aspects of production were intensive as described by Derun et. al (2004) and Valenti and New (2000). In 1999 it was estimated that 50% of feed was still farm made (New 2000b), however in this survey most farmers relied solely on nutritionally complete, commercially produced diets rather than using fertilization to produce natural foods within the pond. They also relied on frequent water exchange, aeration, and water treatment with lime and dolomite to maintain water quality.

Polyculture systems with *Macrobrachium rosenbergii* have not previously been described in Thailand, but have been practiced elsewhere with fish (including tilapias, carps, mullet, pacus, and golden shiners) as well as red swamp crayfish (New 2002). Prawns have also been integrated into rice systems in Vietnam (New 2000b; Zimmerman and New 2000) and Bangladesh utilizing ditches called *ghers* (New 2000b). In this study crop rotation, integrated culture, and polyculture techniques for the purpose of nutrient recycling were rare or non existent. Polyculture with white shrimp was uncommon and experimental, and practiced for economic gain. It did yield higher production and net profits than prawn production alone. However, prawn production was still comparable to monoculture systems and was driving profits while white shrimp were supplementary. White shrimp production was less than 2,000 kg ha^{-1} yr^{-1} and received a lower price per kilogram than prawns. A higher price might have been received for white shrimp if they were allowed to grow to a size larger than 10 grams.

Significant Production Variables

Many drivers of prawn production have obvious links, such as feed and lime applications; however simple correlations and multiple linear regression models predicted only a small proportion of the variability in production. From these data one could conclude that higher levels of production could be achieved by stocking directly into grow-out ponds, monitoring water quality, using local seed, aeration, and exchanging water at least every 2 weeks.

Farmers who stocked directly may have had better survival rates due to lower stocking densities. In this survey nursing densities ranged 19-208 pcs m^{-2}, far below the 1,000 pcs m^{-2} reported by

Pillay (1990). Higher densities and overcrowding can lead to cannibalism and reduce profit (New 2002). Also, many farmers who stocked directly did so with juveniles that were already 2-3 grams and more tolerant to high pH and ammonia (New 2002). In the early stage of production nursing ponds were probably more popular in Thailand because they more efficiently used resources, and farmers could easily count juveniles and assess their health before release into production ponds (Pillay 1990).

Production also significantly increased when farmers monitored water quality parameters. Monitoring provided farmers with accurate information about factors that were significant in crop failure and low production so they could quickly and appropriately react to periods of poor water quality. All farmers who monitored water quality measured pH. Ideal pH for freshwater prawn is 7.0-8.5 and high pH results in greater solubility of waste ammonia that can be corrected by liming (New 2002). Most farmers in this survey relied on visual inspection which involved a lot of guess work and risk.

The use of non local seed was negatively correlated with production. Many farmers who purchased local and non local seed reported major problems with the seed supply stating that it was diseased, poor quality, or unavailable. According to Correia et al. (2000), poor survival is often caused by errors made during water exchange, waste siphoning, and water quality control, as well as inadequate food at the hatchery. Also, survival rates from commercial hatcheries are often only 40 to 60% and long transfer distances may stress PL which can survive in sealed plastic bags for 24 to 36 hours (Correia et al. 2000). These issues may be amplified at larger and more dispersed operations such as CP and Kaset Somboon Farms than at local hatcheries.

The absence of aeration also had a negative effect on production, and farmers who did not aerate may have had lower production due to low dissolved oxygen events in early morning. Also, New (2000b) reported that farms utilizing intensive marine farming technology that included paddlewheel aeration could attain high production (3.1 ton ha^{-1} $crop^{-1}$). In addition to aeration, water exchange was necessary to maintain water quality when utilizing protein rich diets, and in this survey production was negatively linked to the number of days between water exchanges or additions. While most individuals exchanged or added water within 1 to 15 days, some waited as many as 30 to 45 days. This, combined with high feeding rates and lack of water quality monitoring, could be detrimental to prawns. By continuously exchanging a small proportion of pond water higher water quality can be maintained (New 2002). Also, a sudden water change every two weeks causes most of the prawns to molt, resulting in more soft shelled prawns at once and less losses due to cannibalism (New 2002).

Significant Net Profit Variables

Net profits in this survey were quite high compared to the average household of Thailand. Many of the variables linked to production also significantly influenced net profits. This is likely because the most important variable positively linked to net profits was prawn production. Using this data one can conclude that higher net profits can be achieved by conservatively feeding and aerating, and utilizing the batch harvest method.

The model that described the highest proportion of variability in net profits utilized direct and indirect predictor variables. While prawn production had the greatest positive influence on profits, feed which positively influenced production had a substantial negative influence on profits. This was a result of high feed costs and may also be due to overfeeding. Moreover, net profits were negatively correlated with FCR. High feed conversion ratios equates to large quantities of food used for each kilogram of prawns produced, resulting in reduced net profit. Also, while the use of aeration led to increased production; in this case it led to decreased net profits. This also may be due to the cost associated with aeration in contrast to the added profit from prawn production. With more experience individuals were better able to limit unnecessary costs related to overfeeding, excess water treatment, and/or aeration. This was likely why the years of experience of the respondent significantly influenced net profits.

Batch harvesting was likely a positive influence on net profits because this technique reduced predator and competitor problems (New 2002). Even though it would not yield the largest and most profitable sized prawns compared to combined harvesting, more prawns could be harvested per year (New 2002). Farmers who utilized batch harvesting and stocked PL could complete up to 2.5 cycles per year, but those who directly stocked juveniles could complete up to 5 cycles $year^{-1}$. In this case the increased cost of stocking juveniles was balanced by improved survival and shorter duration to marketable size (New 2002). Multiple cycles per year combined with low pond preparation and water treatment costs as well as conservative aeration and feeding would result in greater net profits.

Environmental Impacts, Perception, and Adoption of Alternative Systems

A vast majority of respondents did not utilize any type of water treatment prior to discharging water into public canals and waterways. This combined with intensive production that utilizes protein rich diets has the potential to significantly degrade water quality in the natural waterways and canals relied upon by multiple users. While recycling systems could mitigate current and future environmental problems, it is necessary that these systems optimally balance adequate environmental and economic benefits. Also, individuals must perceive that there is a problem in order to change practices. This is vital because an intervention to correct a problem not perceived on a local level, but externally identified will often fail (Rogers 1995, Blanchet 2001). A perception of environmental problems that will ultimately affect production and subsequent profits is evident in Thailand on an individual, community, and national level.

In this study a simulated recycling system that reduced feed and aeration costs resulted in lower net profits than monoculture. However, the simulation only considered economic variables and utilized production values for tilapia and water mimosa that may not be realistic for each case as they were obtained under different conditions, such as research conducted by Derun et al. (2004). For example, on some farms included in the simulation, water was exchanged every 30 days, which was linked to decreasing prawn production and may be unsuitable for optimum tilapia or water mimosa production using a recycling system. Unfortunately, in the most economical variation of the recycle system, where average net profits were only 6% lower than the survey average, only 10% of the land was utilized for tilapia and water mimosa. It is likely that the excess nutrients in this scenario would have detrimental effects on the health and survival of these alternative crops and this ratio would be unsuitable for nutrient recovery.

While the recycling system requires further research for optimization, the adoption of such a system is promising. It is evident that farmers perceive current multi-user effects on water quality in natural waterways and canals. Within this study many farmers considered impacts of external pollution to be either moderate or severe. Agriculture and aquaculture were most often cited as an external pollution source, evidence that farmers believed the problem was upstream and caused by multiple users. External pollution was recognized as a major problem by 37% and could be responsible for other major issues such as disease outbreak and low production. It was also considered a cause of low production and crop collapse, and responsible for an increase in disease. Except for black gill, which was commonly reported in this study, most disease had previously gone unnoticed on prawn farms (New 2000b).

Within the aquaculture community in Thailand there have been examples of action being taken on part of sustainability and environmental welfare. For example in Chachoengsao, Bang Pakong province shrimp farmers used microorganisms, or probiotics, not only because of lower cost especially when mixed with molasses, but because it was "sustainable" (Kanwanich 2001). Also in Chachoengsao, 60 farmers owning 600 rai had formed a group, "Bang Samak Freshwater Tiger Prawn Farmers for the Environment." Within the group the farmers used man-made shrimp feeds and probiotics (Kanwanich 2001). In addition, shrimp farmers in the area had developed a closed farming system using lower stocking densities, less chemicals, and reserve and treatment ponds (Kanwanich 2001). In my survey, two respondents in Ayuttayah stated that they use probiotic because "now a days DOF suggests the use of microorganisms instead of chemicals".

On a larger scale, certification programs are ideal to promote environmentally and socially sound production systems as consumers are becoming more conscious of their purchases. Currently there are two certification programs developed by the DOF in Thailand for marine shrimp aquaculture. None exist specifically for prawn farming or freshwater aquaculture, however the Good Aquaculture Practice (GAP) certificate is most commonly applied to prawn operations nationwide and is issued at the farm level. The Code of Conduct (COC) certificate encompasses the whole production line from the hatchery to the processing plant to achieve international quality standards and is only applicable to marine shrimp. Farmers can request an audit from DOF and if they comply with standards receive a one year certification. Both programs predominantly stress good sanitary practices and a safe consumer product absent of chemical or antibiotic residues (Marine Shrimp Culture Research Institute 2003).

Biases and Assumptions

Due to long distances traveled for this study farmers were first located based on information provided by Provincial Fisheries Offices and then by other respondents in the survey. Such methods may have introduced bias into the survey sample and it may not have been entirely random. However, this is likely insignificant because I assume the freshwater prawn industry is well connected via word of mouth and outreach. A high percentage of respondents relied on information provided by neighbors and participated in local management meetings. Moreover, district and provincial level fisheries offices were pervasive and easily accessible.

An additional bias is represented by net profits which in this survey were substantially higher than the average household income in Thailand. Costs associated with depreciation, maintenance, interest, and miscellaneous costs used by Shang (1982) to compare returns of prawn farms in Hawaii and Thailand were not included in the calculations. In the Shang (1982) study these represented 30-40% of annual operating costs. Compounding this, farmers may have overestimated harvest and profits or underestimated costs. Many respondents could not give a complete answer about fuel costs related to aeration and water exchange and I may have underestimated these costs. These factors represent important sources of error and estimation of net profits might be 40% higher than reality. However, Pillay (1990) states that there is little doubt of profitability because it is often the primary source of income and had shown significant increases over time. Results of this survey agree with that conclusion, as few farmers subsidized their income with other activities and most respondents considered prawn farming to be a good business.

Implications

From a social and economic standpoint prawn farming will remain an important part of the rural Thai economy. Unlike shrimp production the majority of prawns are sold for local consumption and prawns are integral to Thai cuisine (Lin and Boonyaratpalin 1988). It is predominantly a cooperative and lucrative venture and does not necessitate higher education and specialized training. Farmers work together holding local management meetings, sharing information with neighbors, and in some areas working communally at harvest.

In Chachoengsao and the southern province of Nakhonsithammarat, farmers turned to prawn culture when local bans prohibited salt water shrimp production. Despite the risk involved, prawn farming yields higher net profits than most other occupations and farmers rarely subsidize their income with other activities. The majority of farmers surveyed preferred prawn farming to previous activities, planned to improve their operations, and would like more information about prawn farming. Also, support for the industry exists on the community, provincial, and national level.

From an environmental standpoint impacts of intensive monoculture will only become exacerbated if the discharge of untreated effluent continues. This could have severe consequences for the industry in the future. Alternative systems, such as nutrient recycling systems, or alternative water treatment strategies are necessary to mitigate negative impacts in the future.

Suggestions for future research of the recycling system that have already been identified include determining the appropriate ratio of area and density of organisms to optimize a recycling system both for nutrient recycling and profits. Additionally, the next phase of research would be most applicable if conducted in ponds and might include significant variables from this study that had previously not been considered. These variables include utilizing optimal aeration practices, comparing nursing PL to stocking juveniles directly, and comparing combined harvest with batch harvest conducted in sync with the harvest of alternative organisms. Results from in pond trials should more realistically reflect energy costs, nutrient cycling, production, feed conversion ratios, profits, and ease of transition to a new system, and be more comparable to current farming practices.

Once the recycling system is optimized, on farm trials could be conducted in collaboration with DOF within high production provinces such as Nakhon Pathom, Suphanburi, or Ratchaburi. Environmental factors, such as rainfall and temperature, and management differences between farms can have significant affects on experimental results when conducted outside of the research facility. For example Uddin et al. (2006) found that experiments conducted in farmer's ponds resulted in lower survival of prawns and tilapia than in other experiments.

There are additional methods to introduce more sustainable culture practices to the aquaculture community in Thailand. These include augmenting existing certification programs and community level planning and training. Effluent permits that force farmers to monitor water quality could have significant results, but few respondents measured water quality due to lack of equipment. Government funding to provide equipment or regular testing by district fisheries officers to enforce effluent permits could be costly.

New et al. (2000) states that recognition of responsible aquaculture should include attention to the discharge of polluted effluents into natural waterways and canals as well as written records containing stocking data, feeding rate, water quality and other parameters as an assessment of management techniques. The GAP certification does mention that effluent must be treated to reduce environmental impact to the surrounding area while COC stresses no impacts to the ecological system. Both programs require record keeping of relevant activities to serve as a useful guide for future improvement. Maximum nutrient loads and treatment options for effluent are not specified (Marine Shrimp Culture Research Institute 2003).

Certification programs should provide suggested management techniques to reduce nutrient loads to be effective. Many farmers interviewed, specifically in Chachoengsao province, held GAP certificates, but none kept written records and 3 of the 6 interviewed said they discharged some water into a fish pond. Since very few treated water post cycle, it is unlikely many of those who held GAP certificates did. It is also important that programs include regular follow up visits to ensure the farm continues to meet standards specified in the certification as well as offer technical support which may help farmers with minimal resources. Many farmers requested more information on prawn farming techniques and this is an opportunity to inform them of more sustainable production methods, such as the recycling system. Incentives for certification may prompt farmers to seek out these types of programs.

Community level planning and training sessions also have potential. The canals and natural waterways used for prawn production serve as a common-pool resource system within which flow resource units, the volumes of water which absorb biological wastes produced by multiple users; maintenance of the system will benefit all individuals (Ostrum 1990). Communal practices in Samutsakhon, Chachoengsao, and, Chonburi is evidence of cooperation for the common good. This tight knit community is advantageous for the dissemination of information about environmental and production issues related to current practices. Only a quarter of farmers suggested that alternative culture methods are necessary, but again the majority of individuals were interested in learning new techniques and outreach efforts will likely be welcomed. Provincial Fisheries Offices could organize community training sessions and provide a venue for local farmers to discuss environmental issues and plan water supply management within their area. Community mandated settling and/or treatment ponds could be noticeably beneficial, and the initial steps to implementing recycling systems.

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Appendix I – Questionnaire

SOCIO-ECONOMIC AND TECHNICAL SURVEY OF FRESHWATER PRAWN CULTURE IN THAILAND

Farmer Code: ____________________ Province: ____________________
Interviewer name: _______________________ Date of interview _____________
Location of farm:
Distance of farm from Muang District (center of province): _______________ Km

A: Farmer Background

1.1 Farmer Name : _______________________________Sex __________Age _________
Address: ____

Status: ☐ Owner ☐ Manager ☐ Owner/manager

Would you like us to put your name in acknowledge of this research?
☐ No ☐ Yes

1.2 Level of your education (grade):__________________________

☐ Elementary ☐ High School ☐ Vocational/University

1.3 When did you begin as prawn culture manager:______________

1.4 Did you get any training on prawn/fish farming before starting prawn culture?

☐ No ☐ Yes

If yes, please specifiy: Training organization:_______________________________
Supported by:___________________________; Year:________________________
Course period:_____________________

1.5 Your main occupation before prawn culture management?

☐ Agriculture activity ☐ Fish Culture ☐ Fish seed producer
☐ Government employee ☐ Business ☐ Other______________

1.6 Number of present subsidiary occupations: (#) ________________________

1.7 Ownership

☐ Sole ☐ Lease ☐ Company ☐ Other_____________

1.8 Land Ownership

☐ Owner ☐ Rent if rent, how much ________________baht per year
☐ Owner/rent if rent, _________rai, how much ________________baht/rai/year

1.9 Type of management:

☐ Private ☐ Cooperative ☐ Public company
☐ Other____________

1.10 From your experiences, what were the major problems faced by prawn framers?

☐ Seed supply:__________ ☐ Low production ☐ Disease out break:__________

☐ Poor pond bottom condition ☐ External pollution ☐ Social affect (thieves, conflicts)

☐ Low economic return ☐ Market

1.11 Have you ever experienced significant low prawn production or crop collapses?

☐ No ☐ Yes, why____

1.12 Do you wish/plan to make any improvements to your farm in the future?

☐ No ☐ Yes

1.13 What are your plans?____

1.14 Source of energy for farm operation? ☐ No ☐ Yes if yes

☐ Electricity ☐ Own generator
Energy Cost ____________baht/month

1.14a Source of energy for farm operation at the start? ☐ No ☐ Yes

1.15 Machinery or equipment used on farm

☐ Generators__________(Number) ☐ Pump__________(Number)

☐ Compressor__________(Number) ☐ Aerators__________(Number)

☐ Vehicles__________(Number) ☐ Computers__________(Number)

☐ Printers__________(Number) ☐ Telephone__________(Number)

1.15a Machinery or equipment used on farm at the start

☐ Generators__________(Number) ☐ Pump__________(Number)

☐ Compressor__________(Number) ☐ Aerators__________(Number)

☐ Vehicles__________(Number) ☐ Computers__________(Number)

☐ Printers__________(Number) ☐ Telephone__________(Number)

1.16 Total area of your farm ________________rai, used for;

☐ Water storage ____________ponds _____________rai/pond
☐ Effluent treatment ____________ponds _____________rai/pond
☐ Prawn pond ____________ponds _____________rai pond
☐ Fish pond ____________ponds _____________rai/pond
☐ Nursery pond ____________ponds _____________rai/pond
☐ Others ____

1.16a At the start what was the total area of your farm ________________rai, used for;

☐ Water storage ____________ponds _____________rai/pond
☐ Effluent treatment ____________ponds _____________rai/pond
☐ Prawn pond ____________ponds _____________rai pond
☐ Fish pond ____________ponds _____________rai/pond
☐ Nursery pond ____________ponds _____________rai/pond
☐ Others ____

1.17 How many laborers are in your farm (Pl. specify gender) including farmer?

☐ Labor in family _________persons ___________baht/person/month

☐ Permanent labors _________persons ___________baht/person/month

☐ Casual labors _________persons ____________baht/person/day

1.17a At the start how many laborers are in your farm (Pl. specify gender) including farmer?

☐ Labor in family _________persons ___________baht/person/month

☐ Permanent labors _________persons ___________baht/person/month

☐ Casual labors _________persons ____________baht/person/day

1.18 Type of culture:

☐ Monoculture **Go to B Type 1** ☐ Polyculture **Go to B Type 2**

1.18a At the start type of culture:

☐ Monoculture **Go to B Type 1** ☐ Polyculture **Go to B Type 2**

B: Type 1 Prawn monoculture

1.1 Present production system:

☐ Nursing ☐ Brood stock ☐ Grow out ☐ Nursing and grow out

1.1a Production system at the start:

☐ Nursing ☐ Brood stock ☐ Grow out ☐ Nursing and grow out

I Nursing Period

1.2 How many prawns do you stock in the nursing pond__________________/rai/cycle

1.2a In the past how many prawns did you stock in the nursing pond______________________/rai/cycle

1.3 What species /or strains are used and what are the stocking sizes and seed prices of prawn?

☐ Prawn ______________________________size PL _____price ________baht/______prawn

1.3a At the start what species /or strains were used and what are the stocking sizes and seed prices of prawn?

☐ Prawn ______________________________size PL _____price ________baht/______prawn

1.4 Which methods are used for prawn stocking?

☐ Stock directly in to the pond How long do you nurse? ______________ days

☐ Nurse in hapa/cage before stocking

1.4a At the start which methods are used for prawn stocking?

☐ Stock directly in to the pond How long do you nurse? ______________ days

☐ Nurse in hapa/cage before stocking

1.5 How many kgs of prawns do you transfer to the growout pond? ________________kgs

1.5a At the start how many kgs of prawns did you transfer to the growout pond? ________________kgs

1.6 What is the weight of prawns when transfer from nursing to growout pond?

_______________pcs/kg

1.6a At the start what was the weight of prawns when transfer from nursing to growout ponds?

_______________pcs/kg

II Growout Period

1.7 When do you first harvest ________________months

1.7a At the start when did you first harvest ___________________months

1.8 How do you harvest the prawns?

- ☐ Beach Seine ☐ Cast nets

1.9 How long do you culture prawn per cycle?

__________months/cycle

1.9a At the start how long did you culture prawn per cycle

__________months/cycle

1.10 What is the production of prawns (kg/rai or pond)?

1st harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg_______B/kg

2nd harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg_______B/kg

3rd harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg_______B/kg

4th harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg_______B/kg

5th harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg_______B/kg

6th harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg_______B/kg

7th harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg_______B/kg

8th harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg_______B/kg

9th harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg_______B/kg

10th harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg______B/kg

11th harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg______B/kg

12th harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg______B/kg

1.10a At the start what was the production of prawns (kg/rai or pond)?

1st harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg_______B/kg

2nd harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg_______B/kg

3rd harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg_______B/kg

4th harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg_______B/kg

5th harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg_______B/kg

6th harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg_______B/kg

7th harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg_______B/kg

8th harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg_______B/kg

9th harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg_______B/kg

10th harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg______B/kg

11th harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg______B/kg

12th harvest_______total_______males_______pcs/kg_______B/kg_______females_______pcs/kg______B/kg

1.11 Where do you sell prawn and fish productions?

☐ ____

1.11a At the start where did you sell prawn and fish productions?

☐ ____

1.12 Do you have large fluctuations in production between years?

☐ No ☐ Yes

1.12a How much in kg/rai:____________________________________

C: Pond and Water Management

2.1 What are the sources of water supply for your farm?

☐ River ☐ Lake ☐ Reservoir ☐ Dam

☐ Ground water:- ☐ Shallow well ☐ Deep Well

☐ Other ____

2.2 What impact does external pollution have on the quality of your source water?

☐ No impact ☐ Moderate ☐ Severe impact

2.3 What pollution source(s) most affect your operation (check all that applies)?

☐ Agriculture ☐ Industry ☐ Domestic waste

☐ Aquaculture ☐ No affect

2.4 What nuisance plants affect your operation (check all that applies)?

☐ Filamentous algae ☐ Emergent vegetation ☐ Toxic blue-green algae

☐ Toxic dinoflagellates ☐ Algae that causes off-flavor ☐ No affect

2.5 Do you have a water storage pond?

☐ No, go to 2.7 ☐ Yes, go to 2.6

2.6 Do you treat water in your water storage pond?

☐ No ☐ Yes,

If yes, how do you treat water in your water storage pond?

a. Chemicals Chlorine ___________kg/pond/cycle , how long? ______ days

Formalin ___________L/pond/cycle , how long? ______ days

Lime ___________kg/pond/cycle , how long? ______ days

BKC ___________L/pond , how long? ______ days

(BKC is Benzakonium chloride)

Others ___________kg/pond/cycle , how long? ______ days

b. Aeration (motor power) __________no/pond/at the peak time

c. Other____

2.6.1 If water in the storage pond is treated why? Rank each reason from 1 (concern), 2 (little concern), 3 (no concern).

Reduce the disease	1	2	3
Improve water quality	1	2	3
Reduce environmental impact	1	2	3
Improve pond productivity	1	2	3
Improve economic return	1	2	3

Other ____

2.7 On what types of soil are your ponds located?

☐ Clay ☐ Silt/sand clay ☐ Loam ☐ Others________________

2.8 What is the average depth of your ponds? ________m

2.9 How do you prepare the pond to begin culture?

a. Dry pond __________days/crop

b. Mechanical removed mud ________once per ______crop/s expenditure _______baht/time

c. Flushing removed mud ________once per ______crop/s expenditure _______baht/time

d. Tilling or plow the soil _________once per ______crop/s expenditure _______baht/time

e. Repair dikes ___________once per ______crop/s expenditure _______baht/time

2.10 How do you apply chemical in pond water for preparation per cycle?

a. Lime ___________kg/pond or rai price __________ baht/kg

b. Teaseed cake ___________kg/pond or rai price __________ baht/kg

c. Dolomite ___________kg/pond or rai price __________ baht/kg

d. Rice Bran ___________kg/pond or rai price __________ baht/kg

e. Fish meal ___________kg/pond or rai price __________ baht/kg

f. Salt ___________kg/pond or rai price __________ baht/kg

g. Other ___________kg/pond or rai price __________ baht/kg

2.11 What types of fertilizer do you apply for water preparation before stock prawn and during culture?

☐ Organic ____________________________ ________kg/pond price _____ baht/kg

☐ Inorganic ___________________________ ________ kg/pond price _____baht/kg

☐ Other ______________________________ ________kg/pond price ______baht/kg

☐ Do not use fertilizers (Why?) ____

2.11a Did you do this differently at the start?

☐ Organic ____________________________ ________kg/pond price _____ baht/kg

☐ Inorganic ___________________________ ________ kg/pond price _____baht/kg

☐ Other ______________________________ ________kg/pond price ______baht/kg

Do not use fertilizers (Why?) ____

2.12 How soon do you stock prawn into the pond after filling the water? _______________days.

2.12a At the start how soon did you stock prawn into the pond after filling the water? _______________days.

2.13 Do you use aerator to increase oxygen in prawn monoculture or fish-prawn polyculture pond?

☐ No, go to 2.15 ☐ Yes, go to 2.14

2.14 What type of aerators do you use to increase the oxygen in your farm?

☐ Paddle wheels at surface ☐ Paddle wheels under water

☐ Air jet ☐ Super charge pipe

☐ Super charge plate ☐ Other ___________________________

2.14a At the start what type of aerators did you use to increase the oxygen in your farm ?

☐ Paddle wheels at surface ☐ Paddle wheels under water

☐ Air jet ☐ Super charge pipe

☐ Super charge plate ☐ Other/None ___________________________

2.15 What types of chemical do you apply into the prawn ponds during the poor of water quality; pH drop/ and disease outbreak?

☐ Lime ___________________________ kg/pond/time_____time/cycle___________baht/kg

☐ Dolomite _________________________kg/pond/time_____time/cycle___________baht/kg

☐ Zeoloite __________________________kg/pond/time _____time/cycle___________baht/kg

☐ Other ____________________________kg /pond/time_____time/cycle___________baht/kg

2.15a At the start what types of chemical did you apply into the prawn ponds during the poor of water quality; pH drop/ and disease outbreak?

☐ Lime ___________________________ kg/pond/time_____time/cycle___________baht/kg

☐ Dolomite _________________________kg/pond/time_____time/cycle__________baht/kg

☐ Zeolite ___________________________kg/pond/time______time/cycle__________baht/kg

☐ Other ___________________________kg /pond/time_____time/cycle__________baht/kg

2.16 How often do you add/change water into the pond? and how many centimeters ?

☐ one time / ________ ______cm / pond

2.16a At the start how often did you add/change water into the pond? and how many centimeters ?

☐ one time / ________ ______cm / pond

2.17 Where do you discharge the water?

☐ Fish pond ☐ Treatment pond ☐ Drainage canal

☐ No-discharged, (reused water on farm) ☐ Other _________________________

2.18 If discharged in treatment pond, how do you treat the effluent water?

☐ Lime _________kg/pond ☐ Chlorine __________ kg/pond

☐ Formalin ________ kg/pond ☐ Biocontrol; Mollusk ____/pond , fish _____fish/pond

☐ Aeration ________ no/pond ☐ Other _____________________________________

2.18.1 If effluent water is treated or reused why? Rank each reason from 1 (important), 2 (little concern), 3 (no concern).

Reduce the disease	1	2	3
Improve water quality	1	2	3
Reduce environmental impact	1	2	3
Improve pond productivity	1	2	3
Improve economic return	1	2	3

Other ____

2.19 Do you measure the water quality in prawn pond?

☐ No ☐ Yes

2.19a Did you always measure the water quality in prawn pond?

☐ No ☐ Yes

2.19b If no, how long ago did you start? ________________________

If yes, what parameters do you measure?

☐ Alkalinity ☐ pH ☐ Temperature ☐ Dissolved oxygen

☐ Secchi disk transparency ☐ Ammonia ☐ Nitrite ☐ Nitrate

☐ Chlorophyll

☐ Other ____

If no, why ____

2.19.1 If water quality is measured why? Rank each reason from 1 (concern), 2 (little concern), to 3 (no concern).

Reduce the disease	1	2	3
Improve water quality	1	2	3
Reduce environmental impact	1	2	3
Improve pond productivity	1	2	3
Improve economic return	1	2	3

Other ____

2.20 How often do you measure the water quality?

☐ Daily ☐ Weekly ☐ Bi-weekly ☐ Monthly ☐ Other ________________

2.21 What is the typical pH in your ponds?

☐ 6.0 - 7.0 ☐ 7.1 - 8.0 ☐ 8.1 - 9.0 ☐ >9.0

2.22 What treatment(s) do you use for high pH?

☐ Apply acid ☐ Add organic material

☐ Apply lime ☐ Other ________________

D: Feeds and Feedings Management

I. Feeding regimes during nursing period

3.1 What kinds of feed are fed to prawn during the early age?

☐ Fresh supply feed ☐ Commercial pelleted feed

☐ Both (fresh, pellets) ☐ Home made feed:_____________________(ingredients)

☐ None

3.1a At the start what kinds of feed were fed to prawn during the early age?

☐ Fresh supply feed ☐ Commercial pelleted feed

☐ Both (fresh, pellets) ☐ Home made feed:_____________________(ingredients)

☐ None

3.2 Commercial pelleted feed is fed the early age of prawn, could you please fill up the table.

Prawn age	prawn PL _____________(at stocking)		
	Feeding rate (kg/100,000/day)	Feeding frequency (times/day)	Remarks
First month (how do you feed?)			

3.3 Fresh feed, what are the types of fresh feed and feeding rate? How often do you feed early prawn? Please fill up the table.

Fresh feed	Feeding rate (kg/100,000/day)	Feeding frequency (times/day)	How often? (weeks)
1. Trash fish			
2. Mollusk			
3.			
4.			

3.4 Do you use the feeding tray to check amount of feed during the early age of prawn?

☐ No, go to 3.6 ☐ Yes , if yes, how often do you check? Once per ______ week (s)

3.5 How many feeding trays do you have per pond? ___________________ trays / rai

3.5a At the start how many feeding trays did you have per pond? ___________________ trays / rai

3.6 If do not use feeding tray, what is your feeding method?

☐ Manual broadcasting from boat ☐ Manual broadcasting from levee

☐ Mechanical broadcasting from boat ☐ Mechanical broadcasting from levee

☐ Other____

II. Feeding regimes during growout period

3.7 What are the indicators being used for feeding methods?

☐ Remained feed in the feeding tray ☐ Pond Bottom ☐ Other ________________________

3.7a At the start did you use different indicators?

☐ Remained feed in the feeding tray ☐ Pond Bottom ☐ Other ________________________

If remained feed in the feeding tray or the pond bottom, how do you adjust the feed?

% of remained feed	How to adjust
1. If > 50 %	
2. If > 30 %	
3. If ≈ 10 %	
4. Finished all feed in the tray (during checking tray)	
5. Finished all feed in the tray (before checking tray)	

Other indicators:

☐ Food in intestines ☐ Faeces in the tray ☐ Molting

☐ Age ☐ Weight ☐ Survival Density

How do you feed the prawn?

____

3.8 What other indicators do you use for adjusting the feeding rate?

☐ Water color (Plankton bloom) ☐ Low DO ☐ High temperature ☐ Disease

☐ Moult cycle ☐ Other ____________

3.9 What are the sources of feeding table being used for feeding rate?

☐ Feed company ☐ Fishery government ☐ Farmer's modification

☐ Other ______________________

3.10 How many times do you feed between day and night and how many kgs per feeding?

Month	Day	Night
2		
3		
4		
5		

3.11 How do you check the growth and survival of prawn during culture period?

☐ Sampling growth and amount of prawns from feeding tray

☐ Sampling growth and amount of prawns from cast net

☐ Other ____

3.12 How many kg of feed do you use per cycle?

☐ Commercial pelleted feeds _____________kg per cycle/rai

☐ Fresh feed _____________kg per cycle/rai

3.12a At the start how many kg of feed did you use per cycle?

☐ Commercial pelleted feeds _____________kg per cycle/rai

☐ Fresh feed _____________kg per cycle/rai

3.13 Feed cost ?

☐ Pelleted feed _______ baht /kg

☐ Fresh feed ________baht/kg

3.13a At the start what was feed cost ?

☐ Pelleted feed _________ baht /kg

☐ Fresh feed __________baht/kg

E: Parasite and Disease Problems

4.1 From your experience, what is the trend of parasite problem when compare to the start?

☐ Increase ☐ Decrease ☐ No change

Please give the reasons (why, from your answer)__________________________________

____

4.2 What types of disease/parasites do you find in your farm, during culture period?

☐ Viral treatment_______________________________ kg or L/pond

☐ Protozoa treatment_______________________________ kg or L/pond

☐ Fungus treatment_______________________________ kg or L/pond

☐ Bacteria treatment_______________________________ kg or L/pond

☐ Parasites treatment________________________________ kg or L/pond

☐ Others treatment________________________________ kg or L/pond

4.3 From No. 5.6, which treatments gave you success to treat the disease?

☐ ____

F: Other

5.1 Do you like this occupation better than your previous occupation?

☐ No ☐ Yes

If no, why not

____

5.2 Do you have local management meetings with nearby farmers?

☐ No ☐ Yes

5.3 Where did you get the information of prawn culture or fish-prawn polyculture?

☐ Government (DOF) ☐ Magazine ☐ Neighbors ☐ Television ☐ Other _________

5.4 What kind of information do you want for your prawn farming business?

☐ Techniques on prawn culture ☐ Marketing ☐ Other__________________

5.5 Does your government require you to have effluent permit?

☐ Yes ☐ No

5.5.1 If yes, what qualitative standards are specified for effluents in the permit? (get from DOF)

☐ No odor ☐ No foam ☐ No floating debris ☐ No visible plume

☐ Other ________________ ☐ Does not contain qualitative criteria

5.5.2 What quantitative standards are specified for effluents in the permit?

☐ pH:__________ ☐ Total suspended solids: ____________mg/l

☐ Total nitrogen: __________mg/l ☐ Total phosphorus: __________mg/l

☐ BOD:_______________mg/l ☐ DO: __________mg/l

☐ Ammonia:___________mg/l ☐ Chlorophyll: __________mg/l

☐ Other:_____________; ______________;_____________mg/l

☐ Does not contain quantitative criteria

5.6 What are the constraints/problems you encounter? Rank 1 (concern), 2 (little concern), 3 (no concern).

☐ Natural resource (natural seed supply)	1	2	3
☐ Financial resource	1	2	3
☐ Infrastructure	1	2	3
☐ Communication	1	2	3
☐ Seed supply	1	2	3
☐ Feed supply	1	2	3
☐ Material and equipment supply	1	2	3
☐ Technology and the application of known technology	1	2	3
☐ Collaboration	1	2	3
☐ Market	1	2	3
☐ Environmental constraints (area pollution)	1	2	3
☐ Inadequate nursery pond	1	2	3
☐ Low survival	1	2	3
☐ Poor water quality	1	2	3
☐ Flood	1	2	3

- Inadequate access to knowledge update 1 2 3
- Others 1 2 3

5.7 What type of support do you want from the government?

- ____

5.8 Do you have any suggestions?

- ____

Appendix II – Preliminary Data Analysis

In the preliminary data analysis the country was divided into six regions (Table 14). The majority of the surveys that occurred took place in the western region followed by the east. In the east a survey was conducted in Prachinburi instead of Chantaburi after contacting the provincial fisheries office and having difficulty locating prawn farmers due to changing practices in the region. The number of surveys in northeastern provinces, Kalasin and Roi-et, were altered to make driving between the two worthwhile and an additional survey was conducted in Chaingrai. All surveys in the south were conducted in Nakhonsithammarat, despite incomplete data, after consultation with project staff at AIT.

Table 14. Proportion of surveys per region and province based on the average of the percentage of production (tons), number of grow-out farms, and area of grow-out farms (rai) in each area (DOF 2004).

Region/Province	% Production (tons)	% Number of grow-out farms	% Area of Grow-out farms	Number of Surveys
Central Region	**2.15**	**2.57**	**2.58**	**2**
Ayutthaya	1.50	1.87	1.52	2
Western Region	**91.07**	**63.09**	**79.64**	**78**
Kanchanaburi	4.91	2.60	2.87	3
Nakhonpathom	36.76	28.68	44.72	37
Ratchaburi	41.10	9.38	12.73	21
Samutsakhon	0.36	0.83	0.43	1
Suphanburi	7.57	20.55	18.57	16
Eastern Region	**3.98**	**15.63**	**7.75**	**9**
Chantaburi	0.01	1.29	1.46	1
Chonburi	0.18	3.61	1.43	2
Chachoengsao	2.91	8.64	3.95	5
Prachinburi	0.73	0.61	0.32	1
Northeastern Region	**1.13**	**11.55**	**4.70**	**5**
Kalasin	0.38	7.24	3.07	4
Roi-et	0.39	2.31	0.62	1
Northern Region	**1.38**	**0.98**	**1.16**	**1**
Chiangrai	1.05	0.77	0.74	1
Southern Region	**0.28**	**5.01**	**4.17**	**7**
Nakhonsithammarat[a]	-	2.15	3.23	-
Pathalung	0.08	0.64	0.10	0
Narathiwat	0.02	0.27	0.05	0
Songkhla	0.18	0.31	0.10	0

[a] missing values

Appendix III – Fuel Use Estimates

On small-scale farms in Asia, aerators are often used at the farmers' convenience and the availability of machines instead of accurately based on stocking density or culture area. Operation time is often dependent on the farmers' judgment of water quality (personal communication, Dr. Yuan Derun, AIT). All farmers used diesel to power generators for aeration and water exchange and cost at the time of this study was 3,700 Baht for a 200 Liter barrel (18.5 B $Liter^{-1}$).

To estimate fuel cost for aeration I assumed that each farmer used one generator for two ponds, putting the generator on the dyke and having paddle wheels extending into ponds on both sides. If the farmer did not own one generator for every two ponds it was assumed that all generators owned were used for aeration every day and moved between ponds daily. If the farmer owned more than one generator for 2 ponds it was assumed only the necessary number of generators were used per day. The number of hours aerated per day during nursing and grow-out and the diesel used per hour per generator (5 liters 8 $hours^{-1}$ $generator^{-1}$) was estimated by Supat Ponza and derived from previous experience working with aquaculture farmers in Thailand. During nursing, aeration commonly occured between the hours of 8 or 10 pm until 6 am, approximately 9 hours day^{-1}. During grow-out farmers aerate from first to last harvest between the hours of 12 or 2 am until 5 or 6 am, approximately 5 hours day^{-1} (personal communication, Dr. Supat Ponza, AIT).

To calculate the cost of water exchange I again assumed the same rate of fuel use for generators. I also assumed that each farmer could pump water at 227.12 m^3 $hour^{-1}$. This value was received from Dr. Claude Boyd (Auburn University) who estimated that an average 5 horsepower pump commonly used on aquaculture farms in Thailand would pump 1,000 gallons $minute^{-1}$ or 60,000 gallons $hour^{-1}$, equal to 227.12 m^3 $hour^{-1}$. I then used the water surface area and the depth at which farmers stated they exchanged or topped up water to calculate the total volume of water exchanged at a time. Many farmers did not state the depth at which they top up or exchange water and may not have because they did not measure, could not remember, or it was different every time. For these missing values I used the average depth of all other farmers, which was 0.329 m to calculate a value for total volume of water exchanged. If farmers did not state the number of days between each exchange an average of all other values was also used, which was one exchange every 11.59 days. The grow-out period in this case was considered the number of days after nursing until final harvest. Nursing ponds were considered grow-out ponds after transfer. The cost to fill ponds was used with similar assumptions about pump rates and fuel efficiency. The Volume of water was calculated with the stated water area and pond depth. Calculations are below.

Fuel Use per Cycle
Aeration + Water Exchange + Pond Fill

Aeration

Aeration (B Rai^{-1}) = Nursing aeration (B Rai^{-1}) + Grow-out aeration (B Rai^{-1})

Nursing aeration

(# of days nursing * # of generators used for nursing * 9 hours day^{-1} * 0.625 liters hour^{-1} generator^{-1} * 18.5 Baht liter^{-1}) / total Rai = Baht Rai^{-1}

Grow-out aeration

(# of days grow-out * # of generators used for grow-out * 5 hours day^{-1} * 0.625 liters hour^{-1} generator^{-1} * 18.5 Baht liter^{-1}) / total Rai = Baht Rai^{-1}

Water Exchange

Water Exchange (B Rai^{-1}) = Nursing water exchange (B Rai^{-1}) + Grow-out water exchange (B Rai^{-1})

Nursing water exchange

Area of nursing ponds (Rai) * 1 hectare 6.25 Rai^{-1} * 10,000m^2 hectare^{-1} = Area of nursing pond (m^2)
Area of nursing pond (m^2) * Depth of water (m) exchange^{-1} = Volume of water (m^3) exchange^{-1}
Volume of water (m^3) exchange / 227.12 m^3 hour^{-1} = hours exchange^{-1}

(# Hours exchange^{-1} * 0.625 liters hour^{-1} * 18.5 Baht liter^{-1} * number of exchanges during nursing) / total Rai = Baht Rai^{-1}

Grow-out water exchange

Area of all ponds (Rai) * 1 hectare 6.25 Rai^{-1} * 10,000m^2 hectare^{-1} = Area of all ponds (m^2)
Area of all ponds (m^2) * Depth of water (m) exchange^{-1} = Volume of water (m^3) exchange^{-1}
Volume of water (m^3) exchange^{-1} / 227.12 m^3 hour^{-1} = hours exchange^{-1}

(# Hours exchange^{-1} * 0.625 liters hour^{-1} * 18.5 Baht liter^{-1} * number of exchanges during grow-out) / total Rai = Baht Rai^{-1}

Pond Fill

Area of all ponds (Rai) * 1 hectare 6.25 Rai^{-1} * 10,000m^2 $hectare^{-1}$ = Area of all ponds (m^2)
Area of all ponds (m^2) * Depth (m) = Volume of water (m^3)
Volume of water (m^3) / 227.12 m^3 $hour^{-1}$ = hours $fill^{-1}$

(# Hours $fill^{-1}$ * 0.625 liters $hour^{-1}$ * 18.5 Baht $liter^{-1}$) / total Rai = Baht Rai^{-1}