Ecological and Socioeconomic Characteristics of Integrated Aquaculture Practices in Yingbin Bay, Hainan Province, China

by

Lauren Theodore

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science

School of Natural Resources and Environment
University of Michigan

December 2007

Thesis Committee:

Professor James Diana, Chair

Professor Paul Webb

Acknowledgements

This study was conducted from March through June 2006, and is a component of the Aquaculture Collaborative Research Support Program (ACRSP) supported by the U.S. Agency for International Development, Grant No. DAN-4023-6-00-0031-00, and by contributions from the University of Michigan and the Asian Institute of Technology.

Special thanks to Professor James Diana at the University of Michigan, Professor Paul Webb at the University of Michigan, Dr. Yang Yi at the Asian Institute of Technology, Professor Lai Qiuming at Hainan University, and to the Hainan University students who helped with the field work and lab analysis: Qiu Yunhao, Sun Jie, Jane, Wang Jianguo, Ricky, You Zhengrong, Wang Huangxing, and Chen Xuebei.

Thanks also to the following farmers who participated in our interviews (those farmers who asked to remain anonymous are not listed here, but are thanked just the same): Cai Du Xiu, Cai Du Jieng, Kuang Yao, Cai Ducheng, Cai Weiming, Chen Shunji, Wu Boming, Wu Zhongyin, Chen Shunji, Cai Duyu, Chen Huasheng, Cai Duyu, Chen Sheng, Lin Daoli, Cai Duyong, Cai Huaxin, Wu Ganghua, Fong Ergi, Chen Dongcheng.

Thanks to Cao Lin, Mr. Yuan and his family, and Dr. Yang Yi and his family for showing me such a great time. Special thanks to Ricky, and Jane, without whom I wouldn't have lasted one day. Sunny, thank you for being such good company – as well as a wonderful guide. And thanks to Professor Fan and his family for making me feel like a part of the family.

Abstract

This study focuses on two types of integrated aquaculture systems used in Yingbin Bay, Hainan Province, China: a shrimp (intensive) and abalone system, and a shrimp (semi-intensive), seaweed and duck system. The specific goals of the study were to 1) evaluate water and sediment quality in ponds for these two integrated farming systems; 2) determine common farming methods in the region through interviews with farmers; and 3) evaluate effects of integrated culture on water quality in Yingbin Bay. In order to accomplish these goals, a combination of on-site water and soil quality analysis, as well as interviews with twenty-two farmers, were conducted from March to June 2006.

The two integrated systems varied greatly in their design and management. The shrimp and abalone system was comprised of three intensive shrimp ponds that were fed by abalone effluent and groundwater. The shrimp, seaweed and duck system was comprised of one semi-intensive shrimp pond and one seaweed and duck pond. The farmer used the seaweed and duck pond for biofiltration of his shrimp effluent, such that water was recirculated between the two ponds. Both integrated systems were able to maintain water quality adequate for shrimp growth. However, both systems failed to meet Global Aquaculture Alliance's standards for total phosphorus and total suspended solids.

The seaweed and duck pond was hypothesized to have lower nutrient concentrations relative to all of the shrimp ponds in the study due to seaweed's ability to uptake nutrients, but nitrate and total phosphorus concentrations were much higher in the seaweed and duck pond than in the shrimp ponds. Other nutrient parameters in the duck and seaweed pond were found in concentrations similar to those in the intensive shrimp ponds.

Total ammonia and phosphate concentrations decreased downstream through the Yingbin Bay culture area, implying that water quality improved on an upstream to downstream gradient. This may be the result of aquaculture activities utilizing nutrients flowing downstream. However, total phosphorus, and COD concentrations did not decrease (and in some cases increased). In particular, high total phosphorus concentrations were observed throughout the study ponds and bay in April (as high as 1.70 mg/L); phosphate concentrations did not increase as dramatically, indicating that the phosphorus source was not inorganic fertilizer.

According to the results of farmer interviews, farmer perceptions of water quality in the bay varied. Shrimp farmers believed that the bay had significant water quality problems, especially in terms of nutrients and disease. Seaweed farmers perceived no nutrient problems, but felt that physical water quality parameters, such as temperature and salinity, were not adequate for seaweed growth. Almost all farmers interviewed were interested in receiving help from universities and the government in order to develop better production systems.

Given that farmers interviewed perceived problems with environmental quality in the bay and were interested in learning new and better management techniques, there are opportunities for researchers to work with Yingbin Bay farmers to adjust pond management techniques in order to increase productivity and improve water quality.

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Chapter 1 Introduction

China is by far the largest producer of aquaculture products in the world: it was responsible for 69.9% (41.3 million tons) of world aquaculture production in 2004 (FAO 2006). Integrated aquaculture practices date back over 2,000 years in China (Li 2003). However, it is only in the past decade that Chinese researchers have begun to publish frequently in the international environmental science and technology literature (Zhu et al. 2007). The growing body of literature out of China focused on integrated farming suggests that China has developed relatively successful commercial integrated farming systems (Chen Jia 1989, Li 2003, Yang 2003, Xie et al. 2004, Xiugeng 2004, Yu Feng et al. 2004, Hongsheng et al. 2005, Yang 2006, Yi et al. 2006).

This study was conducted jointly by U.S. and Chinese researchers in order to improve understanding of integrated aquaculture and promote dissemination of information regarding Chinese integrated systems throughout the international aquaculture community. Given the enormity of the aquaculture industry in China, an improved understanding of Chinese integrated aquaculture practices will contribute greatly to the development of more effective integrated aquaculture techniques throughout the developed and developing world.

This study focuses on two types of integrated aquaculture systems used in Yingbin Bay, in the Hainan Province of China: one with shrimp and abalone, and one with shrimp, seaweed and ducks. Farmers in Yingbin Bay have developed these integrated systems in order to cope with surface water that is too nutrient rich to allow for shrimp culture.

The specific goals of the study were to 1) evaluate water and sediment quality in ponds for the two integrated farming systems over a three month grow-out cycle; 2) determine common farming methods in the region through interviews with farmers; and 3) evaluate effects of integrated culture on water quality in Yingbin Bay. Data were collected from March to June 2006. An indirect goal of the study was to establish a stronger relationship between local farmers and the Hainan University Food Technology Department.

Each of the study goals is addressed in a separate chapter; and each chapter contains its own introduction, methodology, results, and short discussion. Chapter one provides background and an overview of the study site; chapter two compares water and sediment quality in the two integrated farming systems; chapter three addresses pond management and socioeconomic data collected through interviews with farmers; and chapter four provides an assessment of how aquaculture activities affect water quality in Yingbin Bay itself. The final chapter is a concluding discussion that draws the results of the previous three chapters together.

Farmers volunteered use of their ponds for the on-farm portion of the study. Farmers were asked to manage ponds as they usually would and to keep track of all feed and fertilizer inputs, as well as water exchange rates. Researchers visited each study farm once per month in order to conduct sampling. In addition to sampling in and around ponds, researchers also sampled at sites established in open water areas surrounding the ponds.

Participation in the socioeconomic survey was also voluntary; and the survey was non-random. Twenty-two farmers were interviewed, including those farmers whose ponds were used for the water quality study. The intent of the interviews was to gain a more detailed understanding of specific farming practices in the bay as well as the economic return for species grown.

While each farmer participating in this study practiced integrated aquaculture on a small scale, Yingbin Bay as a whole can be examined as one large integrated aquaculture system. Hundreds of farmers grew a multitude of organisms, including ducks, shrimp, abalone, algae, rice and many other aquatic plants. Understanding the effects of integrated aquaculture on the ecological and economic health of Yingbin Bay will assist researchers, government agencies and farmers in promoting the use and expansion of successful integrated techniques.

Background

As the world population grows, demand for aquaculture products will continue to increase. World aquaculture production has increased an average of 8.8% per year since 1950 (FAO 2006). Aquaculture is increasingly filling the void left as yield from capture fisheries plateaus and world population continues to increase (FAO 2004). Even if capture fisheries continue to grow at the current rate, the FAO estimates that they are unlikely to meet the market demand in the year 2030 (FAO 2004).

Thus, even though many commercial aquaculture practices are accused of being unsustainable and harmful to native ecosystems (Conner 1988, Tobey et al. 1998, Naylor et al. 2000, Paez-Osuna 2001, Costa-Pierce 2002, Frankic and Hershner 2003, Neori et al. 2004, Yu Feng et al. 2004), the demand for aquaculture products – particularly high trophic level species such as shrimp – is incontrovertible (FAO 2003, FAO 2004). Throughout the literature there are calls for dramatic changes in the shrimp farming industry in hopes of making shrimp culture more sustainable. Academic and professional aquaculture communities increasingly are focused on improving aquaculture systems to reduce environmental impacts (Conner 1988, Funge-Smith and Briggs 1998, Tobey et al. 1998, Naylor et al. 2000, Stonich and Bailey 2000, Paéz-Osuna 2001, Costa-Pierce 2002, Neori et al. 2004, Xie et al. 2004).

The shrimp farming industry is frequently charged with the destruction of coastal ecosystems for pond construction; eutrophication of otherwise oligotrophic waters; introduction of exotic invasive species; spread of diseases to native populations; and negative net protein gain (Conner 1988, Li and Lee 1997, Tobey et al. 1998, Naylor et al. 2000, Paéz-Osuna 2001, Xie et al. 2004, Primavera 2006). Additionally, some assert that the shrimp farming industry has damaged social and economic structures by concentrating wealth (Bailey 1988), and privatizing what were once publicly accessible lands and waters (Primavera 2006).

In general, there are three primary types of shrimp production: extensive (low density), semi-intensive (higher density), and intensive (high density) (Boyd and Egna 1997). There is also a new category of shrimp farming called super-intensive (Tobey et al. 1998), in which shrimp are produced in extremely high densities in controlled, recirculating water systems (Boyd and Clay 2002). A variety of environmental impacts is associated with each farming method.

The two shrimp farming methods studied in Yingbin Bay were semi-intensive and intensive. Semi-intensive and intensive production systems usually rely upon a combination of feed and inorganic fertilizer, as well as frequent water exchange. The feed applied is usually high in nitrogen (sometimes up to 30%), and studies of nutrient retention have generally shown that less than half of the nitrogen applied to aquaculture ponds (as protein feed) is retained by the target organism (Boyd and Egna 1997). The remaining nitrogen is lost to the pond sediments, air, and discharge water. As this waste nitrogen – particularly ammonia – accumulates in ponds, it becomes toxic to aquatic animals. The most common method of avoiding lethal toxicity from ammonia is to flush the pond with new water and discharge nutrient-rich water into natural waterways. Pond water is also flushed in this manner during pond harvest. Frequent flushing can cause significant water quality problems in waters near and downstream of ponds.

Currently, there are approximately 14,000 shrimp farms in China. Of these, 85% are semi-intensive, 10% are extensive, and 5% are intensive (Biao and Kaijin 2007). In most cases, farmers do not aerate their ponds, and problems with disease, poor water quality, lack of farmer training, and inappropriate use of drugs and antibiotics are considered common (Biao and Kaijin 2007).

This study was most concerned with the issues of poor water quality and the influx of high nutrient loads during pond discharge that can lead to cultural eutrophication. Negative impacts associated with cultural eutrophication include algal blooms, increased water turbidity, altered water chemistry, and altered food chain dynamics. In order to avoid these impacts, there is growing interest in incorporating a variety of low trophic organisms, such as seaweed and bivalves, into culture of shrimp and other high trophic-level species. These low trophic organisms function both as filters of nutrient-rich effluent and as additional marketable products. Multi-species systems, in which water is cycled from areas with high trophic organisms (salmon, shrimp) to areas with low trophic organisms (seaweed, bivalves, mangroves) are referred to as *integrated aquaculture systems*.

Integrated aquaculture has been used for centuries to culture organisms in relatively low densities (Li 2003), but has only been considered for large-scale commercial aquaculture production (in China and elsewhere) in the past few decades (Troell et al. 2003). Increasingly, articles are appearing in the literature on the design and effectiveness of integrated aquaculture systems of all types and sizes. Some studies are laboratory experiments to determine optimum species densities, feed and water exchange rates, and farm design (Shpigel et al. 1993, Neori et al. 2000, Jones et al. 2001, Schuenhoff et al. 2003, Metaxa et al. 2006). Other studies examine on-farm use of integrated aquaculture in order to assess ecological effects of commercial integrated culture systems (Gautier et al. 2001, Jones et al. 2002, Marinho-Soriano et al. 2002, Wu et al. 2003, Fei 2004, Ryder et al. 2004, Yang et al. 2005). Yet another set of studies focus on promoting the philosophy of integrated aquaculture, referring to it as potentially "sustainable" aquaculture, and emphasizing the need for fundamental changes in the aquaculture industry (Bailey 1988, Chopin et al. 2001, Paez-Osuna 2001, Costa-Pierce 2002, Frankic and Hershner 2003, Fei 2004).

I found no studies in the literature that addressed in detail both the socioeconomic dimensions of integrated aquaculture and the ecological effects of these systems in one geographical location. Studies of integrated aquaculture in the literature tend not to be interdisciplinary, in spite of the fact that farmer motivations for integrating culture of different species seem to be influenced by ecological, cultural and economic factors. For example, in Yingbin Bay, farmers state that they use integrated aquaculture in order to cope with poor water in the bay as well as to ensure an income if one species becomes diseased. Studies of integrated aquaculture need to do a better job of integrating economic, cultural, and ecological elements that influence use and development of integrated aquaculture practices in developing countries.

If conducted using appropriate species in appropriate quantities, integrated aquaculture can be successful in improving water quality (Neori 1996, Brzeski and Newkirk 1997, Chopin et al. 2001, Jones et al. 2002, Lüning and Shaojun 2003, Fei 2004, Neori et al. 2004, Hernández et al. 2005). There is also evidence that economic markets for low trophic organisms – seaweed in particular – may continue to grow (FAO 2004). However, substantial research efforts are needed to determine ways in which current monoculture models for large-scale commercial aquaculture could be adapted successfully into integrated aquaculture systems (Troell et al. 2003).

Integrated systems tend to be complex, at the very least requiring appropriate ratios, densities and placements of organisms within the system. Small-scale and commercial farmers alike must understand the ecology and life histories of multiple cultured organisms, as well as multiple grow-out and harvest techniques. Farmers also need access to different markets for different species. Moreover, some commonly farmed species, such as shrimp, are highly susceptible to a variety of diseases, requiring careful management in integrated systems in which water circulates (Funge-Smith and Briggs 1998).

If integrated aquaculture is to live up to its potential, a concerted, continued effort needs to be made to work with small-scale and commercial farmers in order both to design farming systems that will meet a plethora of social and economic needs, and to develop effective outreach and training programs. One way to design such systems is to look at already accepted and practiced integrated farming techniques, such as those described here, and focus research on improving these techniques and applying them on a commercial scale.

Study Site

Hainan Province, an island located in the South China Sea, is both the southernmost and smallest province in China. Hainan is separated from the Chinese mainland by Qiongzhou Strait. The Chinese government has designated the province a Special Development Zone. Therefore, substantial efforts are being made to develop the island's economy while also maintaining its scenic beauty for tourism.

Hainan's capital city, Haikou, is home to approximately 500,000 people. Economically, tourism, agriculture and aquaculture are the primary industries in Hainan Province. Coconuts, coffee, rice, and a variety of fruits are also grown in Hainan. Additionally, shrimp, pearls, seaweed, and several finfish are grown.

Hainan Province has a tropical climate with two seasons: a cool season from November to March and a hot season from April to October. This study was conducted from March until June, during the transition between seasons, which is reflected in the temperature and rainfall data. The nearest weather station was in Haikou City and all weather data were provided by the Chinese government. Given that Haikou City is only 22 km to the East of the study site, I assumed that weather conditions at the two locations were similar. However, the heat island effect may cause some differences between urban and rural (study site) locations.

Weather conditions changed greatly during the study period. Average daily temperatures increased steadily throughout the study period, starting at 22°C in March and ending at 30°C in June. Rainfall was quite variable during the study, with little rain in March and April (50.1 mm and 44.3 mm, respectively) and significant rainfall in June (547.5 mm). Average daily evaporation was lowest in March (2.2 mm) and highest in May (4.9 mm), though there was considerable variability in these numbers throughout each month.

I found only one study of integrated aquaculture in Hainan Province in the literature (Wu et al. 2003). The study documented use of integrated seaweed and pearl oyster cultivation in bays along Hainan's east and west coasts. The authors found that integrating seaweed and pearl oyster culture by growing seaweed and oysters together on suspended, open-water cages produced pearls of higher economic value (they had a thicker nacre, or outer coating) than cages with only oysters. There was also substantial but undocumented use of integrated farming techniques in Yingbin Bay, located just west of Haikou. Informal conversations with researchers at Hainan University suggested that integrated farming is practiced mainly in areas located close to Haikou (such as Yingbin Bay), as water quality is poor in this area due to urban and suburban development. However, observations indicate that many farmers around the island utilize integrated fish and rice culture.

Yingbin Bay is a long, narrow bay located just west of Haikou City (Figure 1). The bay has been altered hydrologically by a dam constructed approximately four to six kilometers upstream from the confluence of the bay with Qiongzhou Strait. According to researchers, the Chinese government manages releases from the dam and does not allow any intrusion of seawater upstream via the dam. The dam has created an 8500 km^2 brackish water lagoon in which a variety of aquaculture activities takes place. The bay is fed from the northwest by runoff from rice farms through a straightened channel. This main channel (6 – 12 meters wide) may at one point have been a stream or might have been created in order to drain and control flow through wetlands that were converted to rice farms.

The main channel is surrounded on either side by a multitude of ponds, until it dissipates into a large open water area just upstream from the dam. Seaweed *Gracilaria verrucosa* is grown throughout this area, with individual farmer jurisdiction over rented, farmed plots delineated by wire fencing. While the original characteristics of the bay are unknown, it is likely that Yingbin Bay was formerly fringed with mangrove forests. There are many surface and groundwater water sources to the bay, and innumerable nutrient sources, including human sewage, buffalo and duck feces, run-off from rice farms, as well as feed and fertilizer used in aquaculture practices. Flow throughout the study area was quite low, presumably due to minimal dam releases. I did not have access to a flow meter and was not present during rain events; however, flow was minimal on all sample collection days in the main channel and in the open seaweed culture area.

During the study, salinity at the upstream end of the main channel ranged anywhere from zero to six ppm, while salinity at the dam was consistently 12 – 13 ppm. Thus, it is likely that seawater intruded into the study area. At least the one abalone farm studied here discharged seawater effluent (30 ppm) into a channel that ran past the Area A farmer and toward the main channel. Additionally, observed low flows in the study area could also have led to increased evaporation and a consequential increase in salinity. The hydrology of the study area, in particular the extent of tidal influences, was difficult to assess. No confluences between freshwater channels and Qiongzhou Strait or lower Yingbin Bay were observed. A long berm or seawall is apparent on the aerial photograph of the area (Figure 1); however, there may be breaches in this berm that allow for confluence between sea and fresh water. Conversely, it also could be that inland flows have been re-directed away from the sea and into the aquaculture area in order to maximize farmer access to freshwater.

Initially, a primary goal of the study was to make statistical comparisons of water and sediment quality in *three* different integrated systems. Nine ponds representing three integrated systems were originally selected for the study. However, five of the nine ponds became infected with White Spot Syndrome Virus (WSSV) one month into the study. These ponds were dropped from the study. Additionally, an inability to find replicates for all of the disease-free ponds complicated statistical analysis.

Thus, due to conditions on the ground, the goals of the study shifted to a more qualitative comparison of water and sediment quality in *two* different integrated shrimp systems (the shrimp and abalone, and the shrimp, seaweed and duck system), as well as in the bay itself.

The shrimp and abalone integrated system (Area A) was approximately 1212 m northwest of the shrimp, and seaweed and duck ponds (Area B). Three intensive shrimp ponds (A1, A2 and A3) were located in Area A approximately 3724 m from the dam that separates the farming area from the open bay (Figure 1). The seaweed and duck pond, as well as the shrimp pond in Area B pond were located approximately 3688 m upstream from the dam (Figure 1). The length of the overall study area (from C1, the sampling site furthest upstream of the dam, downstream to the dam) was approximately five kilometers.

Figure 1. Aerial photograph of Yingbin Bay study area showing sampling site locations and study ponds A1, A2, A3, B1 and B3. The open water sites are represented by sampling sites C1, C2, C3, W1, W2, and the Area B small channel. Sites C1 and C2 were located at bridges over the main channel. Sites W1, W2, and C3 were along the periphery of the open water seaweed culture area. Site C3 was located along the dam.

Chapter 2 Water and Sediment Quality

Introduction

Water and sediment quality monitoring is frequently conducted in aquaculture ponds and their effluents in order to assess effects of aquaculture on surrounding ecosystems (Boyd and Egna 1997, Funge-Smith and Briggs 1998, Jackson et al. 2004, Schneider et al. 2005). Such water and sediment monitoring studies are usually conducted either on-station in tanks or ponds managed by researchers, or on-farm in real-world aquaculture production ponds actively managed by farmers. The primary goal of on-station research is to perform controlled, scientific experiments in order to understand more precisely the effects of specific pond management actions, while the primary goal of on-farm research is to understand what farmers are doing in the field to manage their own ponds.

The objective of this chapter is to provide analysis of pond water and sediment quality data collected on-farm for the two integrated farming systems (a shrimp and abalone system, and a shrimp, seaweed and duck system) over a typical three-month growout cycle (mid-March to mid-June 2006). These data were collected in study ponds, pond inflows and pond effluents. Then the data were evaluated in order to compare and contrast 1) shrimp ponds in the two integrated systems; 2) shrimp ponds relative to the duck and seaweed pond; 3) inflows to shrimp ponds; 4) effluents from both integrated systems; and 5) effluents relative to internationally accepted standards. While on-farm studies such as this one cannot control for the multitude of environmental variables that affect ponds, they are crucial in developing culture techniques that are both acceptable to farmers and accurate in portraying the real-world conditions that farmers face.

I anticipated that water quality in the duck and seaweed pond would be better than water quality in all four of the shrimp ponds due to settling and nutrient extraction in that pond. Water quality in all shrimp ponds was expected to be similar. This hypothesis was based upon the supposition that the integrated shrimp and abalone system probably received higher quality inflow (abalone effluent mixed with groundwater) but grew shrimp in higher densities with more feed, while the integrated shrimp, seaweed and duck system presumably had lower quality inflow (main channel water filtered by the duck and seaweed pond with no added groundwater), but grew fewer shrimp. Thus, the high density and higher quality inflow system (Area A) would be balanced out by the lower density and poorer quality inflow system (Area B).

Finally, I hypothesized that shrimp, seaweed and duck system effluent would be better in quality than the shrimp and abalone system effluent because the shrimp, seaweed and duck system both grew shrimp in lower density and had the benefit of the duck and seaweed pond for settling out solids and filtering nitrogen and phosphorus.

Methods

Study Ponds

The Area A farmer managed three out of the five total study ponds (ponds A1, A2 and A3) for intensive production of Pacific white shrimp *Litopenaeus vannamei*. These three ponds were considered replicates, though the farmer varied slightly the stocking, water exchange, and feed application rates (Table 1). The ponds were 0.22 ha (A1), 0.23 ha (A2), and 0.25 ha

(A3). All three ponds were lined and had at least two paddlewheel aerators. Effluent from a nearby abalone farm flowed through a cement-lined canal to all three Area A ponds. This water was high in salinity (30 ppm), so the farmer mixed it with groundwater to produce brackish water for the shrimp.

Seven sampling sites were established in and around the Area A ponds. Sampling sites were established in each of the three ponds themselves (A1, A2, and A3), as well as in the three pond outflows (A1OUT, A2OUT, and A3OUT). A sampling site was also established in the abalone farm effluent channel (A4).

This system was considered minimally integrated in that effluent from the abalone farm was used for shrimp production, but shrimp pond effluent was then discharged directly into the surrounding environment and was not reused on-site to grow any other organism. In the past, the farmer emptied his shrimp pond effluent into a single evaporation pond (i.e., the effluent sat in the pond until it evaporated and never flowed offsite). However, he recently decided to increase production, and his evaporation pond would not hold the increased effluent. At the start of the study he was building a canal to connect his evaporation pond to the main channel that fed Yingbin Bay.

The Area A ponds were treated with a variety of chemical treatments (teaseed cake, lime and zeolite) to maintain water quality and fertilizers (inorganic fertilizer and chicken manure) to promote primary production. The farmer monitored pH, temperature, ammonia, and nitrite in the ponds. He fed the shrimp a commercial pellet feed purchased from a local feed company.

The Area B farmer managed the two other study ponds (B1 and B3) for integrated shrimp, seaweed, and duck culture; these ponds were not replicates. One pond, B1, was cement-lined, and used for semi-intensive production of *L. vannamei*. The other pond, B3, was used for seaweed *Gracilaria verrucosa* and white domestic duck culture (species unknown, but possibly *Anas platyrhynchos*). He fed both ducks and shrimp a commercial pellet feed. The shrimp feed was applied directly to the water and the duck feed was left on the bank. The Area B farmer did not aerate either pond.

The shrimp pond was approximately 0.077 ha (770 m^2) and the duck and seaweed pond was approximately 1 ha (10,000 m^2). A small channel, which flowed directly into the main channel feeding Yingbin Bay, separated the two ponds. Three sampling sites were established in Area B (Figure 1): one in the semi-intensive shrimp pond (B1), one in the duck and seaweed pond (B3), and a third in the small channel located between the two (B2).

Nutrient-rich water from the shrimp pond was discharged into the small channel and allowed to settle before being pumped into the duck and seaweed pond. Seaweed production and additional settling time was intended to remove nutrients from the water column. Water from the seaweed and duck pond was then pumped back into the shrimp pond via the small channel. This recycling water system was not closed because the small channel was connected to the main channel in the bay. Visual assessment of flow in this channel indicated that it was quite low; and downstream of the sampling site the channel was highly vegetated, so I do not know the extent of mixing that occurred between water in the main channel and smaller B2 channel.

Sample Analysis

Water and sediment quality samples from each location were analyzed over a three-month period on March 18, April 15, May 13, and June 18. Due to difficulties with equipment and on-site conditions, it was not always possible to measure all variables or collect a water sample at every site on every sampling date. Moreover, due to the number of sampling sites, it was not possible to sample water quality simultaneously at every site. For most sites, sediment samples were collected on the first and last sampling days. The Area A intensive shrimp ponds were lined; thus there was no sediment to sample at the start of the study. So sediment samples in Area A were collected only after harvest.

Water temperature, dissolved oxygen, salinity, pH, and Secchi disk depths were measured *in situ* at each sampling location. In all study ponds, dissolved oxygen, salinity, pH and temperature were measured at three different depths in the center of the pond. At other locations, these parameters were measured at the middle depth. A dissolved oxygen meter (WTW Oxi330i/SET), a pH meter (pHB-5) and a salinity meter (WYY-II) were used for collection of *in situ* measurements.

Water samples were collected from each sampling location using a water column sampler. In study ponds, three water column samples, taken from the sides and center of each pond, were combined to create a composite two-liter sample. At all other sampling sites, two-liter water samples were taken from one location. Ten mL of chloroform were added to each sample at the time of collection to hault chemical reactions caused by bacteria. Water samples were stored and transported on ice to Hainan University for analysis of total ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, Kjeldahl nitrogen, phosphate, total phosphorus, total suspended solids and chemical oxygen demand.

Two Chinese reference manuals were used as sources for standard analytical methods (Jiarong 1996 and Lin 2002). Chemical oxygen demand was determined in the lab using the potassium permanganate acidic method. Total ammonia nitrogen was determined using the colorimetric method with a potassium tartrate sodium reagent. Nitrite nitrogen and nitrate nitrogen were also measured using the colorimetric method. Active phosphate was measured using the colorimetric method with ammonium molybdate and sulfuric acid reagents. Total phosphorus was determined using the molybdenum blue method. Total Kjeldahl Nitrogen (TKN) was determined using the standard colorimetric method, which involves the digestion of the sample in the presence of sulfuric acid, K_2SO_4 and $HgSO_4$. Total suspended solids were measured by filtering samples through a pre-weighed glass fiber filter (GN-CA filter membrane, aperture 0.45um), then drying and weighing the filter.

Sediment samples were collected with a shovel that was washed thoroughly between samples. The ponds were not harvested until June; so final pond sediment samples were not collected until June and July. Sediment samples were transported to Hainan University and analyzed for bulk density, total nitrogen, total phosphorus and organic matter using standard Chinese methods (Rukun 2000).

Results

Pond Management Techniques

The Area A shrimp ponds were 3 to 3.5 times as large as the Area B shrimp pond. Both farmers applied approximately the same amount of inorganic fertilizer per square meter of pond. Additionally, the Area A farmer stocked an average of 110 post-larvae/m^2, while the Area B farmer stocked 81 post-larvae/m^2 (Table 1). The Area A farmer also applied more feed per square meter of pond. In both Areas A and B, inorganic fertilizer was applied only once, at the start of the growout cycle, and both farmers applied about 0.008 kg fertilizer/m^2 pond. The Area A shrimp farmer exchanged an average of 11,000 m^3 of water in the shrimp ponds. The Area B shrimp farmer exchanged 3335 m^3 in shrimp pond B1.

The Area B farmer only maintained management records for his shrimp pond, so data regarding management of pond B3 is unavailable. According to the questionnaire he completed, he stocked the seaweed and duck pond with approximately 7496 kg seaweed/ha and approximately 285 – 380 ducks/ha. He stated that he harvested about 5997 – 7496 kg seaweed/ha from the pond approximately once every 25 days. He had two to three duck crops each year.

Table 1. Description of shrimp pond management techniques, as recorded by farmers.

Pond Name	Pond Area (m^2)	Production Type	Growout (Days)	Stocking Density (PL/m^2)	Feed application rate (kg/m^2)	Fertilizer application rate (kg/m^2)	Total water exchanged (m^3)	Shrimp Production ($kg\ m^{-2}\ d^{-1}$)	Avg. Body Weight (g) at harvest	Feed Conversion Ratio
A1	2249	Intensive	98	133	1.5	0.008	10,120	0.013	11.5	1.22
A2	2724	Intensive	99	110	1.3	0.007	13,075	0.012	13.0	1.12
A3	2605	Intensive	99	115	1.6	0.007	12,244	0.014	12.7	1.18
B1	776	Semi-intensive	99	81	1.0	0.008	3335	0.008	10.4	1.26

Water Quality in Shrimp Ponds

Concentrations of some nutrients, such as nitrate and COD, were similar in the Area A and B shrimp ponds (Figures 2 and 3). Other parameters, such as total phosphorus and total ammonia, were much lower in the Area B shrimp ponds than in the Area A ponds (Figures 4 and 5). In fact, maximum concentrations for total phosphorus and total ammonia in Area B were less than half those in Area A (see Appendices A and B, Tables 9 and 12).

The two integrated systems experienced significant differences in dissolved oxygen (DO) levels as summer temperatures increased. The Area A intensive shrimp ponds stratified and DO dropped as low as 0.90 mg/L in bottom waters of pond A1 (Figure 6) and 4.13 mg/L in bottom waters of pond A3. Because dissolved oxygen measurements were only conducted once per month, it is not possible to know the frequency or duration of these low DO events. On the other hand, DO levels never dropped below 6.45 mg/L in pond B1, and never dropped below 9.80 mg/L in pond B3. Shrimp pond B1 did not stratify in spite of the significant temperature increases in April and May, perhaps due to its small size.

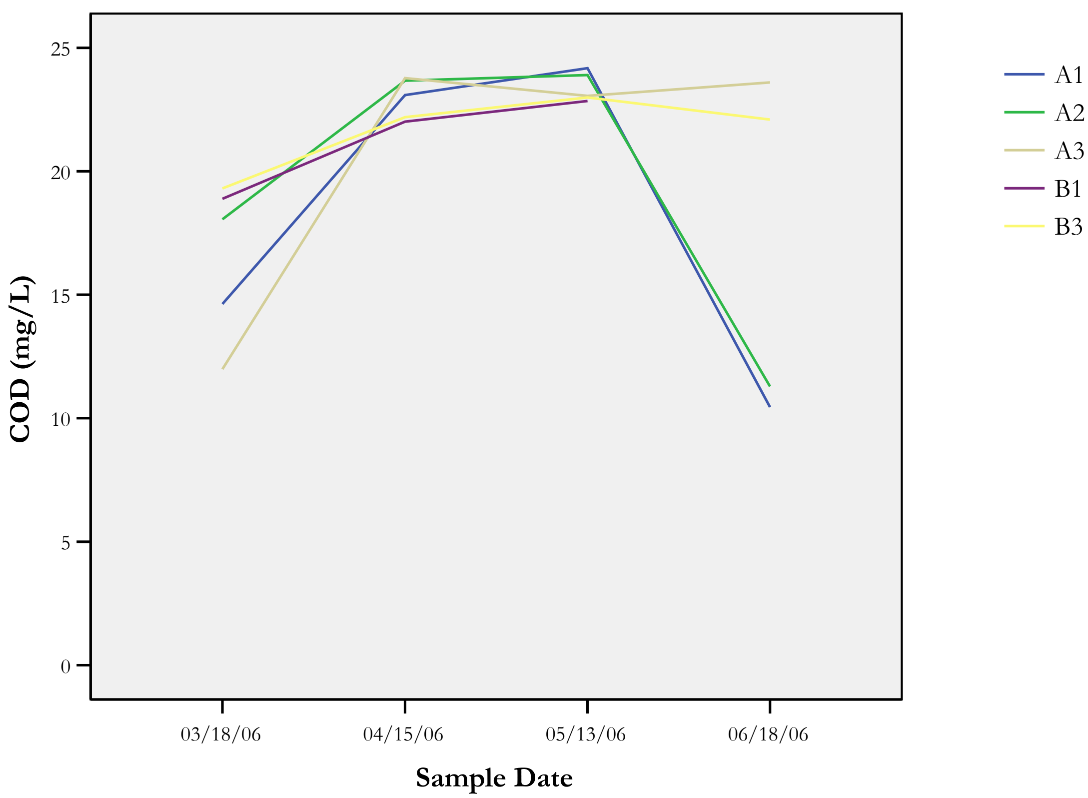

Figure 2. Chemical oxygen demand levels in Area A and B ponds for each sampling date.

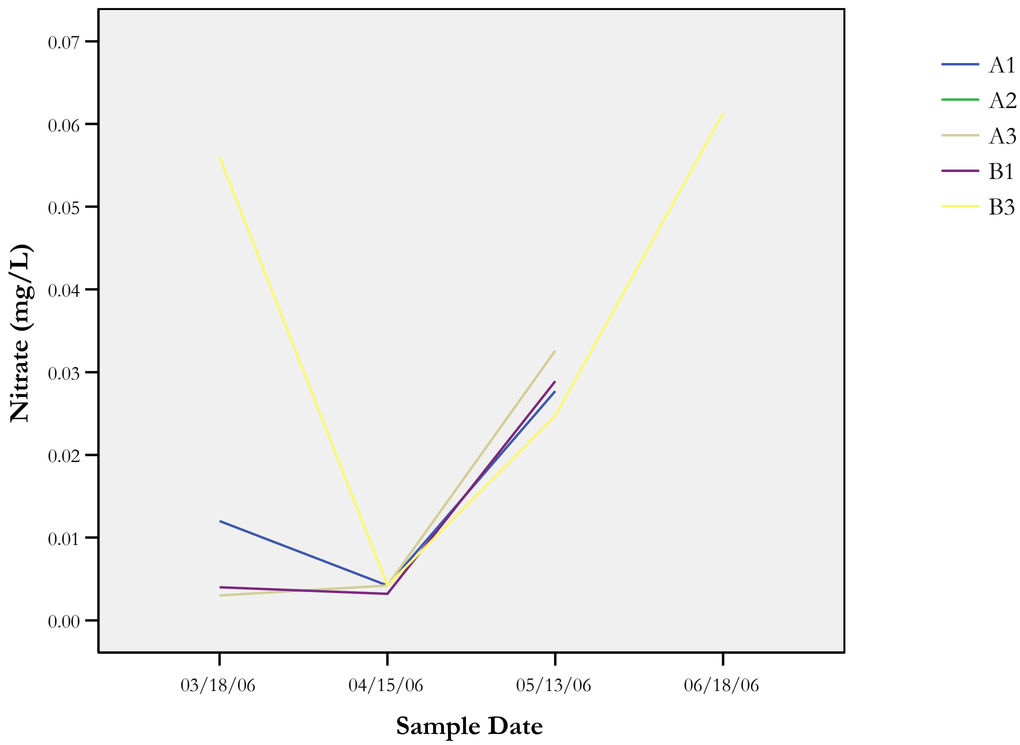

Figure 3. Nitrate concentrations in Area A and B ponds for each sampling date.

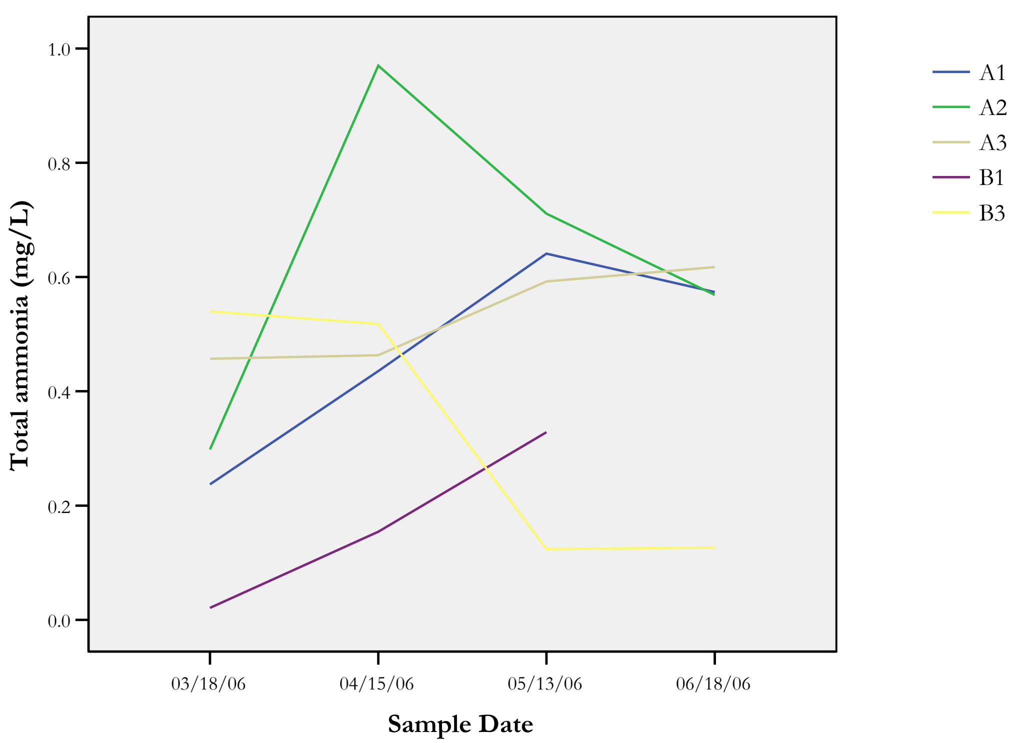

Figure 4. Total ammonia nitrogen in Area A and B ponds for each sampling date.

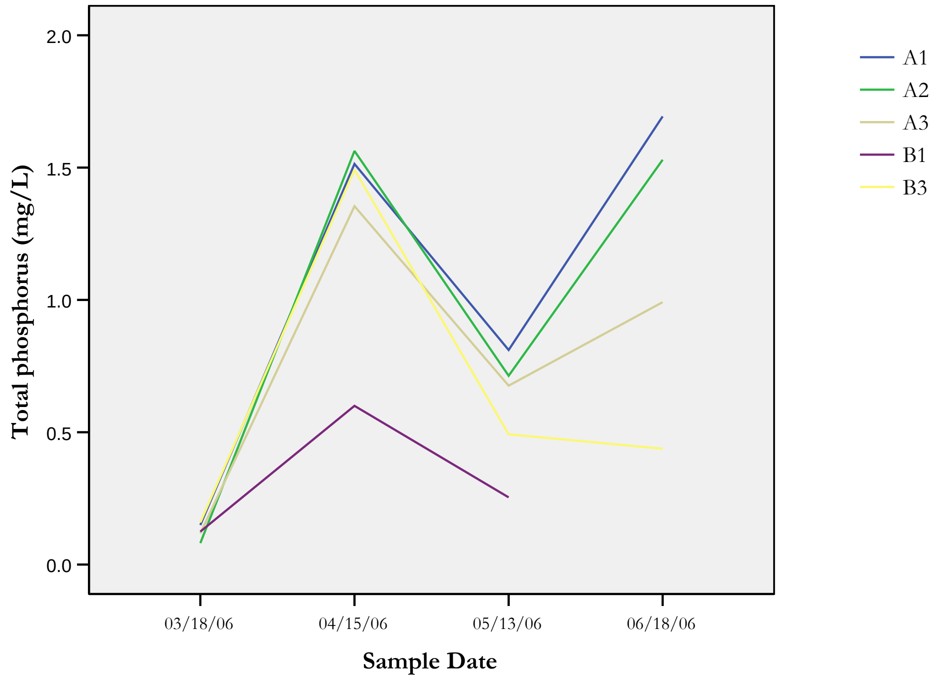

Figure 5. Total phosphorus in Area A and B ponds for each sampling date.

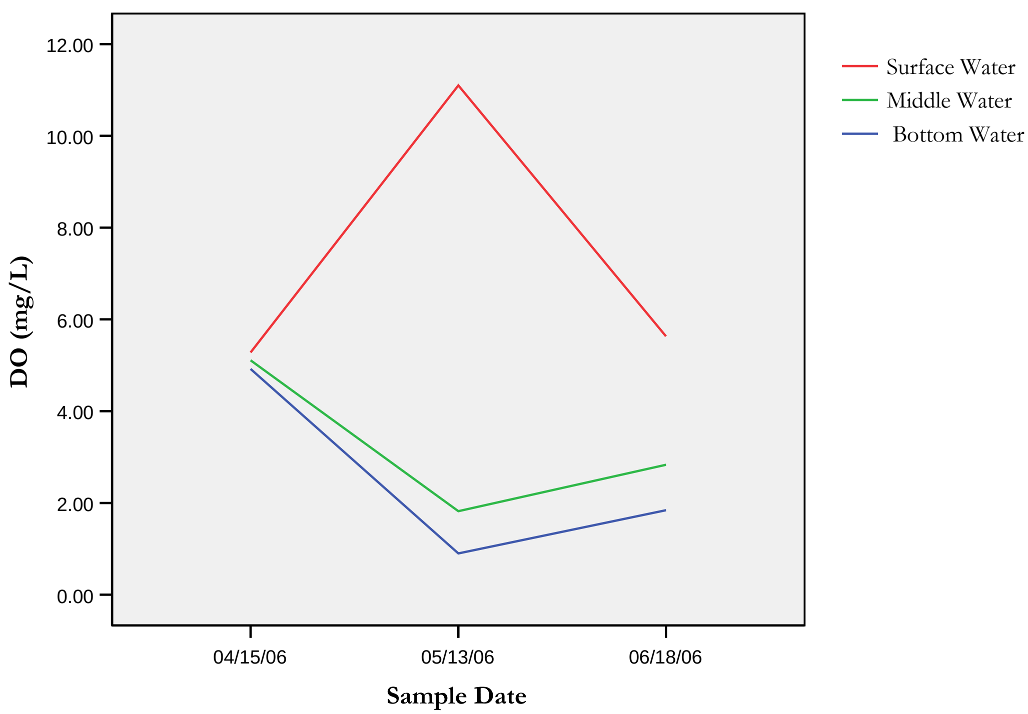

Figure 6. Dissolved oxygen concentrations at different depths in pond A1 for each sampling date.

A substantial increase in phosphorus occurred in both culture systems and their inflow water in April (Figure 5). In fact, this sharp increase in phosphorus was observed at all sampling sites throughout the bay. Total phosphorus increased by over 1 mg/L from March to April in the intensive shrimp ponds in Area A, and by approximately 0.5 mg/L in the semi-intensive shrimp pond in Area B. However, both farmers applied the same amount (0.007 to 0.008 kg/m^2) of inorganic fertilizer per unit area only once during the first few days of the growout cycle. Total phosphorus concentrations also increased dramatically in both the abalone farm effluent (from 0.04 mg/L to 1.58 mg/L) upstream of the Area A system, and at other open water sampling sites throughout the bay (see Chapter 4). The high total phosphorus concentrations in April were followed by similar, though less dramatic increases in phosphate in May.

Water Quality in Shrimp Ponds and the Duck and Seaweed Pond

I expected water quality in the seaweed and duck pond (B3) to be better than in any of the shrimp ponds, but this was not the case. Total phosphorus concentrations (Figure 5) in the seaweed and duck pond were similar to those in the Area A ponds and were considerably higher than those in pond B1 (with which it shared water). Nitrate concentrations (Figure 3) were much higher at the beginning and end of the study in the duck and seaweed pond (0.03 to 0.05 mg/L higher) than in any of the shrimp ponds. For the rest of the nutrient parameters, the seaweed and duck pond maintained concentrations within the same range as the shrimp ponds (see Appendices A and B, Tables 9 and 12).

The water exchange pattern in the Area B system was analyzed to determine if the seaweed and duck pond had received nutrient-rich water from the shrimp pond right before water quality sampling dates. If water was pumped into the seaweed and duck pond close to sampling dates, that might explain the higher nutrient concentrations measured. However, water was exchanged three, four, and thirteen days before water quality sampling dates, and there was no clear connection between the water exchange dates and nutrient concentrations on any particular sampling day. There was a significant rain event (57.7 mm) two days before the June sampling date but nitrate was the only nutrient that had a substantially higher concentration in the seaweed and duck pond than in the other sampling sites on that sampling day.

Shrimp Pond Inflow Water Quality

Due to the fact that the abalone farm effluent was mixed with groundwater in the Area A shrimp ponds, the abalone farm effluent itself was not representative of inflow to the Area A system. On the March sampling date, however, the Area A ponds were filled, but not stocked, so the water quality on this day was considered representative of inflow to the system. I assume that the Area A farmer used the same ratio of abalone effluent to groundwater whenever he added water to his ponds.

Researchers were not present when the Area B farmer exchanged water between his two ponds. According to his records, he did not exchange water in March and exchanged water three days before the April and May sampling dates. Thus, water in the seaweed and duck pond on the April and May sampling dates represented our best estimate of inflow water quality to pond B1. Nutrient concentrations on these two sampling dates were averaged, and this average represented inflow quality to pond B1 (see Table 2).

With the exception of total suspended solids (TSS) and ammonia, all nutrient parameters were lower in Area A inflow than in Area B inflow. This was likely due to the dilution of the abalone farm effluent with groundwater. Interestingly, both inflows had the same ammonia concentrations, indicating that the seaweed and duck pond was as effective in lowering ammonia concentrations for Area B as dilution was for Area A.

Table 2. Nutrient concentrations of inflow water to Area A (intensive) shrimp ponds and Area B (semi-intensive) shrimp pond. Nutrient concentrations for the three Area A ponds in March were averaged. Nutrient concentrations in April and May in the seaweed and duck pond were averaged. All values in are in mg/L.

Source of Inflow Water	Ammonia	Nitrate	Phosphate	Total Phosphorus	TSS	COD
Average of Area A Shrimp Ponds in March	0.33	0.002	0.007	0.12	199	14.89
Seaweed and Duck Pond (Inflow to Area B Pond)	0.33	0.04	0.20	0.65	63	21.65

Pond Effluent Water Quality

The effluents from the two systems were compared to water quality in the two main channel sampling sites located upstream of both culture systems. Since the shrimp, seaweed and duck system cycled water via a small, open channel (B2), and sampling was not conducted when this cycling occurred, it was difficult to characterize effluent from this system. For the purposes of comparison, the water in the small channel (B2) was considered to be characteristic of the effluent from Area B, even though channel B2 was connected to – and thus influenced to some degree by – the main channel. Effluent for Area A was sampled by lifting the standpipes that controlled pond outflow.

Average total phosphorus, TSS, and nitrite concentrations were highest in the shrimp and abalone system effluent (Table 3). Average total phosphorus and TSS concentrations in effluents were lowest in the shrimp, seaweed and duck system. Nitrate concentrations were by far highest in the shrimp, seaweed and duck system. Total ammonia concentrations were highest in the main channel (C1) site, which was furthest upstream. Total ammonia concentrations were similar in Area A effluent, Area B effluent and main channel C2 site. Average COD values were similar in effluent and main channel sites.

Table 3. Average nutrient concentrations (mg/L) in pond effluent and main channel sampling sites.

Sampling Site	Total Ammonia	Nitrate	Nitrite	Total Phosphorus	Phosphate	TSS	COD
Area A Effluent	0.90	0.03	0.16	1.97	0.32	118	21.48
Area B Effluent	0.72	0.40	0.05	0.56	0.17	49	19.92
Main Channel C1	1.59	0.08	0.06	0.64	0.15	65	20.86
Main Channel C2	0.87	0.03	0.03	0.74	0.33	65	20.15

Pond Effluents Relative to International Effluent Standards

An underlying goal of this research was to find shrimp culture techniques that caused fewer and less severe impacts to water quality. One way to assess the general efficacy of these two integrated systems is to compare effluent water quality to current accepted water quality standards for aquaculture effluents (Table 5). One well-known set of standards is published by the Global Aquaculture Alliance (GAA). GAA has begun certifying aquaculture farms based upon these standards (Boyd 2003).

Both the Area A and B inflows and effluents met the total ammonia standard 100% of the time. But both Area A and B effluents violated the total phosphorus standard 75 – 100% of the time. The Area B inflow water also violated the total phosphorus standard 75% of the time, thus the water feeding the Area B system was already high in phosphorus. The Area A inflow never violated the total phosphorus standard.

Area A inflow and effluents exceeded standards for TSS (mean was 118 mg/L) 100% of the time. The Area B system exceeded the TSS standard only 25% of the time; its inflow exceeded the TSS standard 50% of the time. The Area B system effluent failed to meet the DO standard 50% of the time. I was unable to sample the Area A effluent for DO, as it was too dangerous to get down near the standpipes when they were released.

Pond Sediment Quality

Changes in total phosphorus, total nitrogen and organic matter of sediments were tracked (Table 4). Because the Area A (shrimp and abalone system) ponds were lined, they started with no sediment, and thus could only show positive or no gains in phosphorus, nitrogen and organic matter. Pond B1 was lined with cement, but a considerable amount of sediment was present on the pond bottom at the start of the study so it was able either to gain or lose nitrogen, phosphorus and organic matter (Table 4). Pond B3 was not lined and also was able to gain or lose nutrients (Table 4).

The intensive ponds in Area A accumulated more nitrogen in their sediments than did the Area B shrimp pond. The Area B ponds saw a small decrease in sediment total phosphorus throughout the growout period, and the Area A intensive shrimp ponds showed a slight increase in total phosphorus. While the small sample size prohibited statistical analysis, it is likely that the small changes in total phosphorus were insignificant.

Table 4. Soil quality changes in the two integrated systems. All values expressed in g/kg.

Sampling Site	Δ in TN	Δ in TP	Δ in Organic Matter
Pond A1	6.0675	0.1395	16.3200
Pond A2	4.4108	0.0400	3.6580
Pond A3	7.0840	0.2820	19.1860
Pond B1	2.4272	-0.0628	21.6939
Channel B2	5.8199	-0.0572	3.0050
Pond B3	6.2920	-0.1953	3.0929

Table 5. A comparison of pond inflow and effluent water quality to standards recommended by the Global Aquaculture Alliance. Values are presented as the ratio of samples that violated GAA's target standard to the total number of samples collected. Dissolved oxygen and pH were not measured in the Area A pond effluent.

Variable	GAA Target	Ratio of Samples Violating Target in Pond A1 Effluent	Ratio of Samples Violating Target in Pond A2 Effluent	Ratio of Samples Violating Target in Pond A3 Effluent	Ratio of Samples Violating Target in Area B Effluent	Ratio of Samples Violating Target in Area A Inflow	Ratio of Samples Violating Target in Area B Inflow
pH	6 - 9	n/a	n/a	n/a	0/4	0/3	0/4
TSS	≤50 mg/L	3/3	3/3	3/3	1/4	3/3	2/4
TP	≤0.3 mg/L	3/3	3/3	3/3	3/4	0/3	3/4
NH_3	≤ 3 mg/L	0/3	0/3	0/3	0/4	0/3	0/4
DO	≥ 5 mg/L	n/a	n/a	n/a	2/4	n/a	1/4

Out of all the ponds, B1 had the greatest increase in organic matter. Interestingly, pond A2 experienced little gain in organic matter relative to the other shrimp ponds - in spite of the fact that all Area A ponds were managed similarly. At the end of the study, sediments in pond A2 had the lowest total phosphorus concentrations (0.04 g/kg), while pond B1 had the lowest total nitrogen concentrations (2.85 g/kg). In all three Area B sites, total nitrogen increased in sediments from the beginning to end of the study while total phosphorus levels decreased.

Discussion

In terms of overall shrimp pond water quality, inflow to Area A ponds had lower nutrient concentrations than did inflow to Area B, with the exception of TSS and ammonia. Ammonia concentrations were equal in both inflows. TSS concentrations were quite high in the Area A inflow and it is possible that this was the result of a sampling or laboratory error. In general, it appears that Area A had the benefit of "cleaner" inflow water during growout.

I hypothesized that water quality would be equivalent in Area A and B shrimp ponds during the growout cycle. This was true only for some parameters, such as nitrate and COD. Other parameters, such as total phosphorus and total ammonia, were much lower in the Area B shrimp pond than in the Area A ponds. Thus, while the Area A ponds began the growout cycle with cleaner water, the Area B system appears to have been more effective at maintaining water quality.

When compared to a traditional (not integrated) intensive shrimp farm in Australia (Jackson et al. 2004), effluents from my shrimp study ponds had lower average total nitrogen concentrations (1.09 mg/L in Area A, 1.17 mg/L in Area B, and 2.47 mg/L at the Australian farm), but higher average total phosphorus concentrations (1.97 mg/L in Area A, 0.56 mg/L in Area B, and 0.25 mg/L at the Australian farm). Average TSS concentrations were lower in Area B effluent than in the Australia study, but were higher in Area A's effluent than in the Australia study (118 mg/L in Area A, 49 mg/L in Area B, and 79 mg/L at the Australian farm). Given the differences in stocking, water exchange, feed, fertilizer application rates, and water circulation patterns between Yingbin Bay and the Australia site, it seems that the Yingbin Bay shrimp ponds were relatively typical in terms of nitrogen discharge. However, the high total phosphorus concentrations give rise to concern, especially given the sharp increase in phosphorus observed throughout the bay in April.

As expected, evaluation of effluent quality data suggested that the Area B shrimp, seaweed and duck effluent had lower nutrient (and TSS) concentrations than the shrimp and abalone system effluent, with the exception of nitrate. The average nitrate concentration in the Area B effluent was higher (0.4 mg/L) than in either the Area A effluent or the main channel water. The reasons for this are unclear.

Interestingly, while the Area B effluent was for the most part better in quality than the shrimp and abalone effluent, it tended to have about the same nutrient concentrations as were found in the main channel water. Thus, it appears that the shrimp, seaweed and duck system was not discharging water that was substantially more degraded than water already feeding the bay through the main channel. However, the system was also not discharging water that was much improved. The similarities in Area B's effluent and the main channel water could have resulted from the hydrologic connection between the B2 channel and the main channel, but I cannot determine this based upon the data collected. In order to characterize Area B's effluent more accurately, researchers would need to be present during water exchange events and collect samples directly from the pond pumps.

Relative to the GAA effluent standards (Boyd 2003), both systems met the ammonia target, but were less successful in meeting the standards for total phosphorus (TP) and TSS. In the Area B system, even the inflow water to the shrimp pond violated the GAA TP standard 75% of the time and the TSS standard 50% of the time. In the Area A system, inflow water violated the TSS standard 100% of the time, but did not violate the total phosphorus standard. If the inflow water to these systems violated the GAA standards, then poor effluent water quality was not solely attributable to pond culture activities. In the case of Area B, the ponds were being supplied with water already poor in quality.

Again, when compared to the shrimp farm in Australia, these results give rise to concerns regarding phosphorus in both study systems. Either there is consistent over-fertilization occurring in the ponds (as well as the abalone farm), there is an additional source of phosphorus to the bay, or circulation in the bay promotes the accumulation of phosphorus over time. The data point to a phosphorus source other than inorganic fertilizer because there was no corresponding spike in phosphate concentrations during April, and one would expect phosphate concentrations to be higher if large amounts of inorganic fertilizer were applied.

The fact that the shrimp, seaweed and duck system met GAA's TSS standard 75% of the time, while the shrimp and abalone system effluent never met the TSS standard may be due to the fact that the shrimp, seaweed and duck effluent was sampled in the B2 channel, where some settling occurred, whereas the shrimp and abalone effluent was sampled directly from the ponds' outflow pipes, allowing no time for settling. Moreover, release of effluent from the standpipes may have caused re-suspension of previously settled solids. It also may be that the seaweed and duck pond in Area B served not only as a biofilter for the shrimp effluent but also as a settling pond.

Nutrient concentrations in the seaweed and duck pond were expected to be lower than in the four shrimp ponds. The fact that nutrient concentrations were not as low as expected suggests either that our sampling regime did not sufficiently capture pond nutrient fluctuations, or that there are better ways to manage the pond in order to reduce nutrient concentrations.

It is almost certain that the once per month sampling regime used in this study prohibited detailed characterization of nutrient fluctuations in the seaweed and duck pond (as well as in all of the sampling sites). Additionally, language barriers existing between researchers and farmers, as well as between American and Chinese researchers, likely led to miscommunication about farm management practices. For example, I assumed that the Area B farmer put only water from his shrimp pond into his seaweed and duck pond. However, it could be that he pumped additional main channel water into the seaweed and duck pond at certain times to compensate for evaporation and did not report it. If so, this might explain the higher nutrient concentrations in the pond. One way to resolve this issue would be to ask the farmer's permission to sample the seaweed and duck pond weekly and whenever he pumps water into either pond. Closer and more frequent communication between the farmer and researchers would be necessary to accomplish this.

In general, integration of high trophic level culture (e.g., shrimp culture) with culture of phototrophic organisms (e.g., seaweed) has been found to increase retention of nitrogen from feed by 15 – 50% and retention of phosphorus from feed by up to 53% (Schneider et al. 2005). Highly refined integrated shrimp aquaculture systems have demonstrated nitrogen reductions of 66% and total phosphorus reductions of 56% (Jones et al. 2002). *Ulva sp.* have been shown to uptake ammonia-nitrogen from shrimp effluent even in the absence of light (Sato et al. 2006).

Integrated aquaculture systems (not specifically with shrimp) that utilize *Gracilaria sp.* have been shown to remove upwards of 81% ammonium, 72% total nitrogen, 83% phosphate and 61% total phosphorus (Chopin et al. 2001). Laboratory experiments in China growing *Gracilaria lemaneiformis* in fish effluent showed up to 85% reductions in ammonia nitrogen and 65% reductions in phosphate (Yu Feng et al. 2004). On-farm studies of *Gracilaria chilensis* grown around salmon cages resulted in a 27% reduction in dissolved phosphorus and a 5% reduction in dissolved inorganic nitrogen (Yu Feng et al. 2004).

However, at least one study found that *Gracilaria sp.* did not grow well in integrated systems (Neori et al. 2000), and multiple farmers in Yingbin Bay stated in their surveys that *G. verrucosa* did not grow well (see Chapter 3). Thus, it is possible that the seaweed itself, rather than pond management and water recirculation patterns, was the cause of lower than expected nutrient filtration. If seaweed was not absorbing nutrients effectively, then the seaweed and duck pond may have served more as a settling pond than as a biofiltration unit.

Overall, the shrimp and abalone system functioned as a typical intensive shrimp production system, taking in relatively clean water by GAA standards (except for TSS) and discharging nutrient rich water (often in excess of GAA standards). The abalone farm effluent was utilized in both production systems, but it not was not treated to remove nutrients before being discharged by the shrimp farm into the surrounding environment. The shrimp, seaweed and duck system, while it did not produce as much shrimp, managed to maintain adequate water quality for shrimp growth in spite of the fact that its inflow did not meet all of GAA's effluent standards. Moreover, it discharged effluent that was no worse in quality than the main channel water upstream. It is possible that this system could be improved to reduce nutrient concentrations further. Both systems had to cope with high total phosphorus concentrations. Understanding phosphorus cycling in the bay is crucial to helping farmers better manage their ponds.

Chapter 3 Socioeconomic Dimensions

Introduction

Interviewing farmers is a common way of gathering detailed information regarding pond management techniques, land use, socioeconomic aspects of farming, and local perceptions about the effects of aquaculture on the environment (Cooley 1999, Clough et al. 2002, Clark 2003, Martinez-Cordero and Leung 2004, Giap 2005). There are idiosyncrasies in the way that every farmer manages ponds, and it can be difficult to assess the causes of these idiosyncrasies, whether they are ecological, social or economic. Talking with a multitude of farmers provides researchers the opportunity to distinguish cultural and regional patterns in pond management techniques from these idiosyncrasies. Such patterns then can be used to design extension and outreach programs that meet the needs of local communities and cultures, while also helping farmers to increase production, improve economic returns, and protect water and land resources (Cooley 1999, Turongruang and Demaine 2002, Tain and Diana 2007).

The goal of this portion of the study was to determine and better understand common farming methods in the Yingbin Bay region through interviews with farmers. In particular, I was interested to see whether farmers who grew only shrimp profited more than farmers who grew shrimp in conjunction with seaweed, ducks, or both in an integrated system. In other words, my aim was to see if integrated farming methods paid off economically for farmers in the bay.

Methods

I and researchers from Hainan University met with Yingbin Bay farmers on several occasions and worked to get as many farmers as possible – no matter what their farming system – to complete a survey. We relied heavily upon the farmers we knew to spread word about the survey to other farmers in the community. Twenty-two farmers agreed to be interviewed for this study, including the two farmers whose ponds were monitored during the study. The other 20 farmers interviewed managed shrimp-only, shrimp and seaweed, seaweed and duck, or seaweed-only systems.

Distinct questionnaires were designed for each farming system with a few exceptions. Only one farmer used a shrimp, seaweed, and duck system, so he completed a shrimp and seaweed survey and provided some supplemental information. The farmer involved with the integrated shrimp and abalone system filled out a 'shrimp-only' questionnaire because, while he received effluent from the abalone farm, he was not personally involved with abalone production. Surveys were written by researchers at the University of Michigan and Hainan University, based upon similar surveys used by the University of Michigan and the Asian Institute of Technology to interview prawn farmers in Thailand (Clark 2003, Schwantes 2007).

Farmers were asked about their educational background, pond management techniques (including use of fertilizers, feed, chemicals, and mechanized equipment), production numbers and the economic value of their crops (Appendix D). Interviews were conducted on-site in Yingbin Village by Hainan University students and Professor Lai Qiu-Ming.

Given that we had no access to existing information about the names, numbers and locations of farmers working in this area, we could not randomize the survey. Additionally, the local language in Yingbin Bay villages, Hainanese, is spoken by very few people. Only one Hainan University student helping with the study spoke Hainanese. Thus, researchers were reliant upon the farmers interviewed to know at least some Mandarin. Some farmers in the bay who knew both Mandarin and Hainanese administered the survey to other farmers who spoke only Hainanese. Researchers at Hainan University first translated the interview questions from English to Mandarin. Once the interviews were complete, the survey results were translated back into English. It is likely that information was lost during the translation process, especially given the language barrier between Mandarin and Hainanese speakers. Many survey questions were left blank and some had answers that did not appear to correspond to the intended question. Because of these issues, data collected from the surveys were not analyzed statistically. Rather, the surveys were used to develop a preliminary understanding both of farmer perceptions of water quality in the bay and the socioeconomic factors that influence this small subset of farmers in the bay

Results

Shrimp and Seaweed Farmers

Seven shrimp and seaweed farmers were interviewed; all seven grew shrimp and seaweed in separate ponds (Tables 6 and 7), and all seven cultured *Litopenaeus vannamei* (Pacific white shrimp) and *Gracilaria verrucosa* (red weed). Four of the seven farmers owned their ponds and three rented their ponds for 300 – 350 renminbi (RMB) per year (1 RMB ~ $0.125 US). One renter was part of a cooperative. These seven farmers had between five and eleven years experience; six of the seven had a high school education; and one had a college education.

Depending upon the number of shrimp and seaweed ponds managed, these farmers hired anywhere from no outside labor to four additional laborers. All farmers had at least one pump, and all but one had at least one aerator. Farmers used either chicken manure or inorganic fertilizer to fertilize ponds; and all used commercial pellet feed. Farmers stated that the main obstacles to shrimp production were viruses and disease, as well as water quality degradation.

On average, farmers produced two shrimp crops per year and seven to eight seaweed crops. Shrimp ponds were stocked at densities of 374,813 – 899,550 post-larvae/ha (38 – 90 PL/m^2), at a cost of 0.005 – 0.01 RMB/post-larvae. Seaweed ponds were seeded with approximately 5997 – 7496 kg seed/ha (equals 0.6 – 0.75 kg/m^2) at a cost of 0.4 – 0.6 RMB/kg seed. Thus, it cost them upwards of 1124 RMB ($140) to stock a 0.25 ha seaweed pond, and upwards of 2250 RMB ($280) to stock a 0.25 ha shrimp pond.

Shrimp and seaweed farmers produced anywhere from 9,000 – 22,500 kg shrimp ha^{-1} $year^{-1}$ (70 -90 shrimp per kg), and were paid between 25 – 40 RMB/kg. As an example, a farmer who stocked his 0.25 ha pond three times per year with 374,813 PL ha^{-1} $crop^{-1}$ at a price of 0.01 RMB/PL, it would need 2,811 RMB/year to stock the ponds. If he produced at least 10,000 kg shrimp ha^{-1} $year^{-1}$ (2,500 kg in his 0.25 ha pond) and sold them for 30 RMB/kg, he could yield as much as 72,000 RMB/year ($9,000/year).

Farmers stated that seaweed production was usually between 42,000 – 81,000 kg ha^{-1} $year^{-1}$, and seaweed market prices ranged between 0.3 and 0.7 RMB/kg. Thus, during a year of good production (81,000 kg ha^{-1} $year^{-1}$) when the price of seaweed is 0.7 RMB/kg, a 1 ha seaweed pond could yield as much as 56,700 RMB/year ($7,088/year). These profits do not take into account the operational costs associated shrimp farming, which are considerably more than those associated with seaweed farming.

Farmers stated that seaweed did not grow well in the summer, but also consistently stated that integrating seaweed and shrimp culture resulted in improved shrimp survival and seaweed production. All farmers mentioned problems with viral diseases in their shrimp crops. Six of the seven farmers met on a regular basis with other farmers to discuss aquaculture issues. Several farmers expressed a wish for the government to help improve market prices for shrimp and seaweed.

Shrimp Farmers

Three shrimp-only farmers were interviewed (Tables 6 and 7). All three had a high school education, three to seven years experience farming shrimp, and managed between one and seven ponds. All three cultured *Litopenaeus vannamei,* had between one and five pumps, and between one and forty aerators. Additionally, all three farmers hired at least one additional permanent laborer, and one of the farmers hired between 10 and 20 casual laborers. One of the three farmers owned his ponds and the other two rented their ponds for 3,000 – 4,500 RMB ha^{-1} $year^{-1}$; one of the two renters was part of a cooperative. All three farmers stated that they had problems with viral diseases in their ponds.

All three shrimp farmers used commercial pellet feed and applied some form of fertilizer, which included fish meal, soybean cake, chicken manure or inorganic fertilizer. These farmers did not provide stocking rates, though the questionnaire inquired about them. However, it was known that the Area A farmer stocked his ponds with approximately 1,098,900 post-larvae/ha (approximately 110 PL/m^2), which may be representative of the other two farmers. None of the three farmers provided the cost of post-larvae, but the shrimp and seaweed farmers estimated this cost to be 0.005 – 0.01 RMB/post-larvae.

These farmers stocked their ponds at higher densities and annually produced more shrimp (kg) per ha than did the shrimp and seaweed farmers. For each crop, the shrimp-only farmers generally produced 10,500 kg of shrimp/ha, which equates to about 31,500 kg ha^{-1} $year^{-1}$ if there are three successful crops each year. They sold their shrimp for 30 – 50 RMB/kg of shrimp, with approximately 70 – 80 pieces of shrimp/kg. Thus, if a shrimp-only farmer had one 0.25 ha pond, and produced three crops with 10,500 kg shrimp/ha, he would gross between 236,250 RMB and 393,750 RMB per year ($29,531 and $49,218 year), depending upon the price of shrimp.

Seaweed Farmers

The majority of farmers in the Yingbin Bay area who agreed to be interviewed farmed seaweed only (*Gracilaria verrucosa*). Nine seaweed-only farmers were interviewed; they managed between one and five ponds, and had between 5 and 23 years of experience farming seaweed (Tables 6 and 7). Six of those interviewed owned their ponds and three rented. Eight of the nine farmers had a high school education and one farmer had an elementary school education.

Two of these seaweed farmers worked in open water, in the open seaweed culture area located just upstream of the dam in Yingbin Bay; the others cultured seaweed in ponds. Those who farmed in ponds applied either chicken feces, duck feces or inorganic fertilizer to the ponds; the two open water farmers did not apply fertilizer as it was too difficult to apply in open water. All nine farmers hired casual laborers (between three and twelve people) to assist with harvesting. Farmers harvested seaweed from their ponds about 8 – 10 times per year, with a total yearly production of between 30,000 and 90,000 kg/ha. They sold this seaweed for 0.3 – 0.7 RMB/kg. Thus, gross income from sale of the seaweed from a 1 ha pond or farming area when seaweed prices were 0.7 RMB/kg ranged from 21,000 RMB to 63,000 RMB per year ($2,625 USD to $11,250 per year), depending on seaweed production.

The seaweed farmers interviewed perceived no major water quality or disease problems affecting seaweed culture, though all said that filamentous algae was a nuisance. Additionally, many farmers stated that, during the hot summer months, salinity dropped too low and temperatures got too high to allow for good seaweed production. One farmer hoped that the government would build a seawater channel so that seawater could be pumped into the area to increase salinity. Farmers also wanted help from the government in improving market prices for seaweed.

Seaweed and Duck Farmers

Three seaweed and duck farmers were interviewed (Tables 6 and 7). The three farmers had from five to eight years experience specifically with integrated duck and seaweed farming. Two of the farmers had a high school education and the third had an elementary school education. All three farmers rented their ponds for between 300-500 RMB per year; one of the three farmers was part of a cooperative. Each farmer had between one and four duck and seaweed ponds; and in each case the duck and seaweed were cultured together in the same pond with duck feces serving as fertilizer for the seaweed. All farmers interviewed cultured *Gracilaria verrucosa* and white duck. Ducks were fed with pellet feed; due to an apparent translation error, farmers provided a food conversion ratio (1.8 – 2) rather than the cost of the feed itself.

Seaweed and duck ponds were stocked with 6,000 – 7,500 kg seed/ha. Seaweed production was 52,470 – 72,000 kg ha^{-1} $year^{-1}$, and farmers sold the seaweed for 0.4 – 0.6 RMB/kg. A farmer with a 1 ha pond that produced 72,000 kg seaweed/year would earn between 28,800 and 43,200 RMB ha^{-1} $year^{-1}$ ($3600 – $5400), depending upon the price of seaweed.

Ponds were stocked with 450 – 600 ducks/ha. Farmers purchased the ducks for around 2 RMB and sold them for 5 – 8 RMB per duck. Thus, a 1 ha pond stocked with 450 ducks (with a 95% survival rate) would net between 1237 and 2340 RMB per crop. One farmer cultured 2 – 3 duck crops per year, while the other two farmers cultured 6 – 10 duck crops per year. Ten crops of duck per year, in 1 ha ponds stocked with 450 ducks, could gross between 21,380 and 34,200 RMB/year ($2672 and $4275 per year). A farmer who produced 8 duck crops per year at 2340 RMB per crop, as well as 72,000 kg seaweed per year (at 0.6 RMB/kg), could earn upwards of 61,920 RMB ($7,740) per year.

Farmers interviewed universally cited water quality improvement as motivation for culturing seaweed and ducks in the same ponds. They stated that they were able to produce more seaweed by growing it in duck ponds. Likewise, they said that seaweed filtered nutrients out of the water and led to a reduction of disease in ducks.

Table 6. Summary of farmer background and culture system data collected from surveys.

Culture System	Farmers Interviewed	Years experience	Education Level	Ponds	Farmers with Pumps	Farmers with Aerators	Laborers per farm (including farmer)
Shrimp and Seaweed (*Litopenaeus vannamei* and *Gracilaria verrucosa*)	7	5 - 11	High school (6) College (1)	2 - 6	7	6	1 - 4
Shrimp (*Litopenaeus vannamei*)	3	3 - 7	High school (3)	1 - 7	3	3	10 - 20
Seaweed (*Gracilaria verrucosa*)	9	5 - 23	High school (8) Elementary school (1)	1 - 5 (2 farmers worked in open water)	7	0	3 - 12
Seaweed and Duck (*Gracilaria verrucosa* and white duck)	3	5 - 8	High School (2) Elementary School (1)	1 - 4	3	0	1 - 10

Table 7. Summary of pond management and production data collected from surveys. 'PL' stands for post-larvae shrimp, which are used to stock ponds.

Culture System	Farmers Interviewed	Farms Using Feed and Fertilizer	Stocking Rate	Stocking Cost	Crops/year	Production (kg ha^{-1} $year^{-1}$)	Sale Price (RMB/kg)
Shrimp and Seaweed	7	7	Shrimp: 38 - 90 PL/m^2 Seaweed: 5997 – 7496 kg/ha	Shrimp: 0.005 - 0.01 RMB/PL Seaweed: 0.4 – 0.6 RMB/kg	Shrimp: 2 Seaweed: 7-8	Shrimp: 9,000 - 22,500 Seaweed: 42,000-81,000	Shrimp: 25-40 Seaweed: 0.3-0.7
Shrimp	3	3	110 PL/ m^2	0.005 – 0.01 RMB/PL	3 to 4	31,500	30 - 50
Seaweed	9	7	n/a	0.4 – 0.8 RMB/kg	8 to 10	30,000 to 90,000	0.3 - 0.7
Seaweed and Duck	3	3	Seaweed: 6,000 – 7,500 kg/ha Duck: 450 – 600/ha	Seaweed: 0.6 – 0.8 RMB/kg Duck: 2 RMB/duck	Duck: 1-3 Seaweed: 6-8	Seaweed: 52,470 - 72,000 Duck: 10,000 - 15,000	Seaweed: 0.4-0.6 Duck: 5-8 RMB

Discussion

Data collected from the 22 interviews provided an interesting perspective on aquaculture in Yingbin Bay. Shrimp-only farmers grossed more – by far – than did any of the other farmers. While shrimp and seaweed farmers estimated that they produced 9,000 – 22,500 kg shrimp ha^{-1} $year^{-1}$, shrimp-only farmers estimated that they produced 10,500 kg ha^{-1} $crop^{-1}$. Thus, shrimp-only farmers produced as much shrimp in one crop as some shrimp and seaweed farmers produced in one year. Moreover, shrimp-only farmers produced more shrimp crops per year than the shrimp and seaweed farmers and sold their shrimp at a higher price. The additional profit that shrimp and seaweed farmers made off of seaweed production was not enough to equal that of shrimp-only farmers. Thus, even given water quality concerns in Yingbin Bay, at least some farmers are able to maintain water quality sufficient for intensive monoculture shrimp systems. However, the number of disease outbreaks per year that these farmers experienced is unknown. Shrimp disease is cited in the literature as having been a major problem in Hainan Province in the past (Kautsky et al. 2000). Shrimp-only farmers were asked if they ever had problems with shrimp parasites and all cited shrimp viruses as a concern. But farmers were not asked specifically how many crops they lost each year to disease.

The farmer whose ponds I initially intended to use in the study, but which became infected with WSSV, stated in casual conversation that he loses about one shrimp crop per year, usually when seasons are changing. If it is common for shrimp farmers in the bay to lose an entire crop each year, then they perhaps are likely to 1) perceive shrimp farming as a highly risky venture and 2) believe that they will make more money growing seaweed, which guarantees them a crop almost every month. In fact, a couple of farmers remarked in casual conversation that the abalone farm in Yingbin Bay had recently increased its purchasing of seaweed, and that they already were earning more money selling seaweed than shrimp.

According to information provided in our surveys, seaweed farmers were not making more money than shrimp-only farmers – even when shrimp-only farmers were losing one out of three crops per year. Based upon survey data, a shrimp-only farmer with a 0.25 ha pond who produced 10,500 kg shrimp/ha, sold them for 40 RMB per kg (farmers cited a range of 30 – 50 RMB/ kg of shrimp), but who lost one of three crops each year to WSSV would make 210,000 RMB or $26,250 (207,000 RMB, factoring in stocking costs). Comparatively, a shrimp and seaweed farmer with a 0.25 ha pond who was unaffected by WSSV and produced three crops of shrimp each year would earn in the range of $10,000 to $16,000, depending upon how much seaweed was produced. Seaweed farmers and seaweed and duck farmers, depending upon the number of ponds, might expect to make between $2,000 and $12,000 annually. However, farmer perceptions may be that seaweed farming is more profitable, or it may be that only a few farmers have access to water clean enough for monoculture shrimp production.

As would be expected, farmers involved with shrimp culture universally perceived water quality problems to exist in the bay, whereas those farmers involved solely with seaweed and duck farming did not perceive any substantial water quality problems other than reduced seaweed production during the summer due to climate conditions. Shrimp farmers also monitored water chemistry parameters, such as pH, alkalinity, and ammonia, while other farmers did not. Thus, shrimp farmers' knowledge of water quality was likely more detailed. As a result of these differences in pond management requirements, the species they grow may likely influence farmers' perceptions of environmental quality in the bay.

Many of the seaweed farmers remarked on the poor growth of *Gracilaria verrucosa* during the summer. Previous studies have investigated the use of *Gracilaria sp.* as a biofilter for aquaculture effluent (Neori et al. 2000, Jones et al. 2002, Marinho-Soriano et al. 2002), with variable success. An on-farm study in Brazil (Marinho-Soriano et al. 2002) showed success using *Gracilaria sp*. On the other hand, Neori et al. (2000) was unable to get *Gracilaria sp.* to grow in a recirculating tank experiment with fish and abalone.

Yang et al. (2005), in a study of *Gracilaria lemaneiformis* used as a biofilter for shellfish farming in Sanggou Bay, northern China, found that *G. lemaneiformis* fluctuated in its photosynthetic activity. It was most productive in July (average temperature 21.2° C) and least productive in April (average temperature 7.7° C). Temperatures in the open seaweed area in Yingbin Bay fluctuated between 19.9° C and 31.9° C. Thus, it may be that farmers are correct and hot summer temperatures put the seaweed outside of its optimum temperature, thus impeding growth. Perhaps a different seaweed species would work better in Yingbin Bay. Researchers may consider setting up some test culture plots in the bay with several other species in order to compare growth rates.

Another common theme that ran throughout the interview data was the frequency and importance of regular meetings with neighbors to discuss aquaculture issues. Twenty one out of twenty-two farmers interviewed stated that they get information about farming most frequently from their neighbors. In terms of specific pond management advice, ten out of twenty-two farmers stated that they rely on universities for sound pond management advice; and nineteen out of twenty-two farmers stated that they most rely upon neighbors. Thus, if an underlying goal of this research is to work with farmers in order to develop more effective integrated farming systems, and if farmers currently rely mainly on neighbors for pond management advice, then researchers and government agencies need to build stronger relationships with farmers.

One way to build such relationships is through extension agents, the traditional conduits between scientists and farmers (Tain and Diana 2007). Communication and interaction between farmers and extension agents have been important to farmers' abilities to increase production in northeastern Thailand (Tain and Diana 2007). In particular, one and two day technical workshops have been effective in helping farmers to increase their yields (Tain and Diana 2007). Carr and Wilkinson (2005) have suggested forming "boundary organizations" (as alternatives to the traditional extension agent model) in order to help farmers with resource management and production issues. These proposed boundary organizations are organizations in which scientists, extension agents, and farmers work directly together (each on the "boundary" of their own field) in order to pool their knowledge, improve natural resource management, and increase production (Carr and Wilkinson 2005). Others have suggested reforming fisheries and aquaculture education programs at the university level in developing countries in order to make programs more interdisciplinary and increase contact between students and farmers (Allison and McBride 2003). In this way students (who may one day work for government or universities) are hypothesized to graduate with a better understanding of the cultural and economic realities influencing farmers and therefore be able to design more effective research and outreach programs.

As with all interviews, it is likely that data provided by the farmers was biased to some degree. Farmers may have altered their statements about their income or pond management techniques based upon their own concerns about sharing this information. Additionally, I learned retrospectively that at least one survey question that asked whether farmers owned or rented their ponds, may have been confusing to those interviewed. Property rights in China are defined and treated differently than are those in the U.S. (Liu 2007). Property is officially "owned" either by the State or collective peasant groups. Individuals and families are granted varying types of rights to use the land and natural resources (Liu 2007). Thus, it is likely that farmers in China discuss ownership using much different terminology than was used in the survey. Those farmers that stated they were part of cooperatives were likely part of the large peasant cooperatives; farmers not part of these cooperatives may have been confused by the terms 'rent' and 'own' when discussing their land.

Moreover, information was certainly lost across the Hainanese-Mandarin-English language barriers. Because the study was non-random and the sample size small, it is difficult to extrapolate significant trends or patterns from these data. However, given that this was the first time that farmers in Yingbin Bay had worked with researchers from a university, there was relatively high interest on the part of farmers in participating. If researchers were to return to the bay to conduct additional surveys, it is recommended that they first meet with local government officials in order to request help in designing a randomized survey of farmers. Additional research into local Hainanese culture (quite different from typical urban Chinese culture) would also be helpful understanding farmer perceptions of aquaculture and the environment (Cooley 1999).

The scope of our survey was broad, but it provided insight into the potential for and success of integrated aquaculture practices involving shrimp in the bay. Yingbin Bay farmers using integrated farming techniques did not make as much money as shrimp-only farmers. However, the extent to which disease impacted shrimp farmers was not completely clear. Additionally, it was unclear how many intensive shrimp farmers were active in the bay. It is possible that there were only enough resources (clean, disease-free water) in the bay to support a limited number of shrimp-only farmers. The prevalence of disease in the bay may, in the long run, favor farmers who grow and can sell multiple organisms.

Chapter 4 Understanding Yingbin Bay as a Large Integrated System

Introduction

Perhaps the most fascinating aspect of this study is that it presents an opportunity to explore integrated aquaculture on a scale larger than that of a single farm. The goal of this portion of the study was to see whether water that exited the bay at the dam was better in quality than water that entered the study area from rice farms upstream. Given observed minimal flows through the study area, I expected that the residence time of water in the seaweed farming area was at least 1 – 2 days, which would allow for some settling (Gautier 2002) and nutrient uptake by seaweed. Thus, I hypothesized that the large seaweed farming area just upstream from the dam would have the effect of removing at least some nutrients from the combined effluent flowing downstream. If water quality had improved by the time it reached the dam, then the cumulative effect of aquaculture (and human activities in general) on water quality in the bay could be considered positive. Indeed, if this was the case, Yingbin Bay would serve as an example of ways in which small-scale integrated farming systems could be used in concert to improve water quality in coastal areas.

As stated in the introduction, there are many studies in the literature that examine the effects of individual integrated farming systems on water quality (Neori et al. 2000, Jones et al. 2001, Gautier et al. 2001, Jones et al. 2002, Wu et al. 2003, Hernández et al. 2005), as well as studies that investigate effects of commercial monoculture of seaweeds on water quality in near shore ecosystems (Chen Jia 1989, Lüning and Pang 2003, Fei 2004, Yang et al. 2005, Yang 2006). This study moved beyond the scope of these others in order to investigate the compounded effects of multiple integrated systems, as well as seaweed monoculture, on water quality. It may be that maintaining a diversity of farming activities, each of which utilize and discharge nutrients differently, is critical to achieving maximum nutrient uptake and minimal impacts to water quality in coastal areas. So often, one or two types of aquaculture are dominant in a bay or coastal region, whether it be shellfish, salmon or seaweed farming. But utilizing several different types of integrated aquaculture may result in a more effective and efficient use of nutrients in feed and excrement.

Methods

Six open water sampling sites were established throughout the study area. Two of the sites (C1 and C2, see Figure 1) were located at bridges along the main channel upstream of the Area A and B ponds. Site B2 in Area B was used as a third open water site. Two open water sites (W1 and W2, Figure 1) were located on the fringe of the shallow, open seaweed farming area, which was downstream of Areas A and B (Figure 1). These sites were within approximately 750 m of the dam. The final open water site (C3) was located along the earthen dike for the dam that controls outflow to the bay.

Collection and analysis of water and sediment samples at the six open water sites were conducted according to the protocols described in Chapter 2. All sampling equipment was cleaned thoroughly with water from each site before sampling. Water temperature, dissolved oxygen, salinity, pH and Secchi disk depths were measured *in situ* at each sampling location. Water was often too shallow to collect a secchi disk reading (the disk was always visible, even though the water was turbid). Two-liter water samples were collected at each site using a water column sampler, and transported on ice to Hainan University for analysis of total ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, phosphate, total phosphorus, total suspended solids and chemical oxygen demand

I had no access to a boat so sediment samples were collected from banks. The site located at the dam (C3) contained too many large boulders to allow for a sediment sample. Sediment samples were transported to Hainan University and analyzed for bulk density, total nitrogen, total phosphorus and organic matter according to the standard methods described in Chapter 2.

Results

Data from these open water sites indicated that there may have been some improvement in water quality as water flowed through the aquaculture production area toward the dam. Phosphate (Figure 9), and total ammonia (Figure 10) concentrations were consistently lower at downstream sites than they were at upstream sites. Nitrite concentrations were also lower at downstream sites; however, the reductions were not as striking. There were no similar reductions observed in COD, TSS and total phosphorus concentrations. In fact, these parameters were sometimes higher at downstream sites than the upstream sites.

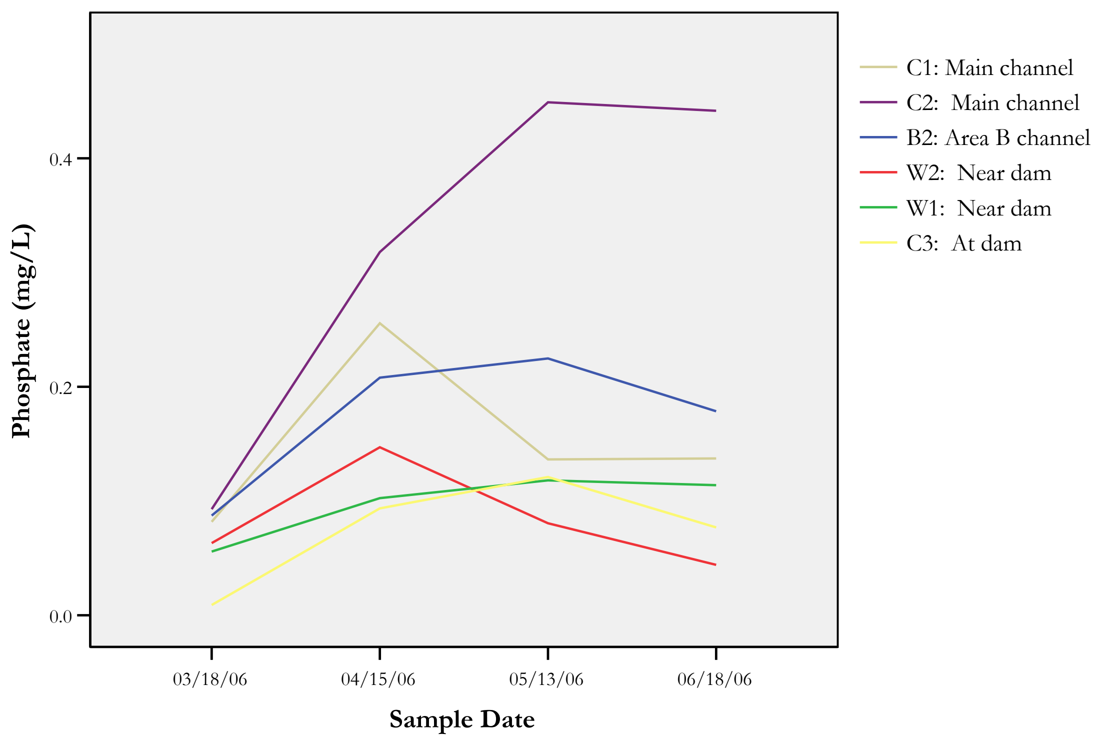

Figure 7. Phosphate concentrations in open water sampling sites for each sampling date. Sites are listed in upstream to downstream order.

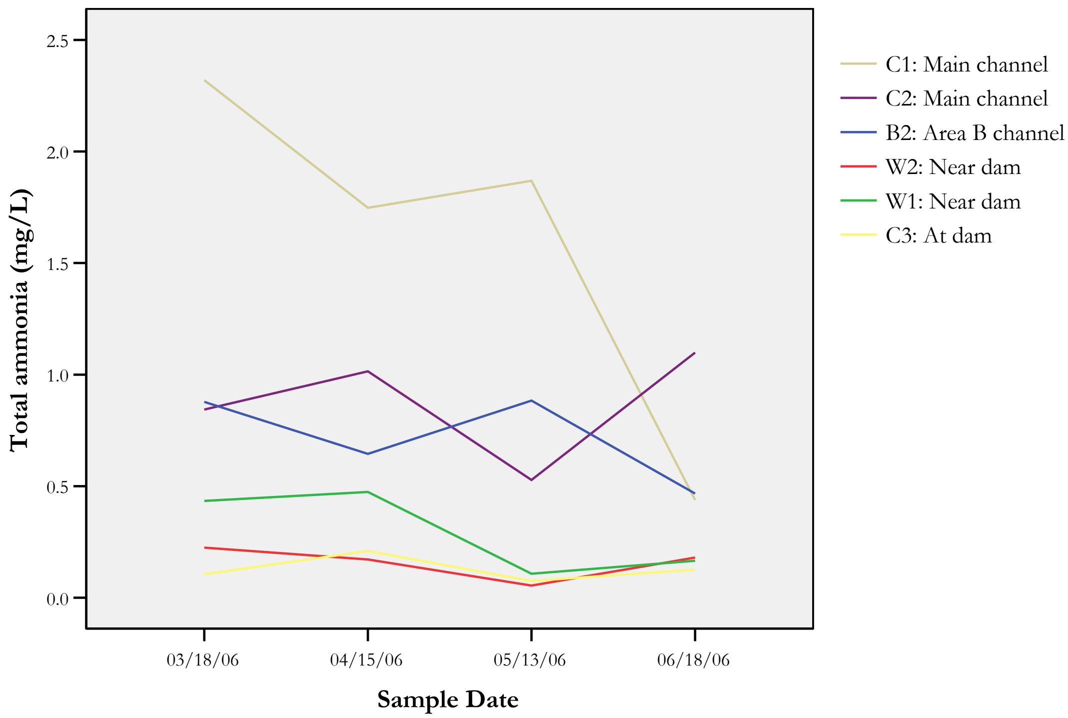

Figure 8. Total ammonia concentrations in open water sampling sites for each sampling date. Sites are listed in upstream to downstream order.

One intriguing result was that a 'slug' of total phosphorus was observed in April, similar to that seen in the Area A and B ponds in April (Figure 9). The sampling sites with the highest concentrations of total phosphorus were site C3 at the dam (1.70 mg/L), the abalone farm effluent (1.58 mg/L), and site W1 just upstream of the dam (1.55 mg/L). The abalone farm effluent was included in the graph because its total phosphorus concentration was so high. Interestingly, the abalone farm inflow was miles upstream of the dam (Figure 1). Site C1, located furthest upstream in the main channel, maintained the lowest concentration of total phosphorus in April (0.16 mg/L). Phosphate concentrations at these sites did not increase enough to account for this more dramatic increase in total phosphorus.

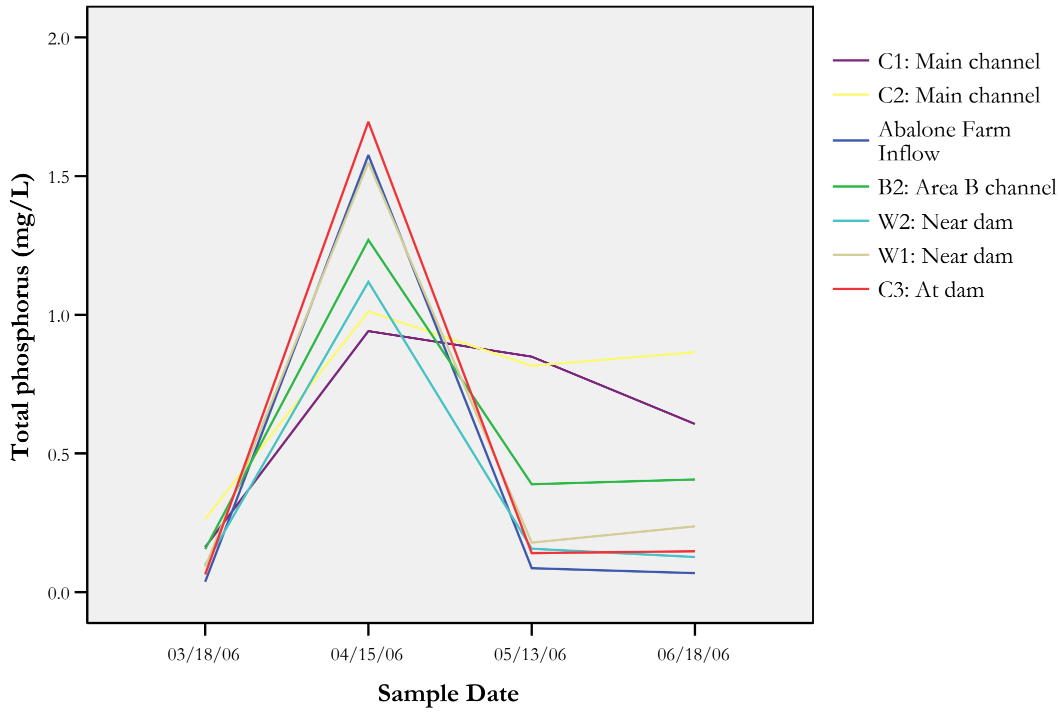

Figure 9. Total phosphorus concentrations in open water and abalone farm inflow sampling sites. Sites are listed in upstream to downstream order.

Sediment total nitrogen concentrations increased by between 5 and 10 g/kg in all open water sites between March and June; and sediment total phosphorus concentrations at these sites decreased by between 0.01 and 0.07 g/kg during that time (Figure 10 and 11). Total nitrogen concentrations were consistently higher in upstream locations; this was not always the case for phosphorus. If nitrogen was limiting in this system, which it is in many coastal ecosystems, then nitrogen accumulating in the sediment as a result of pond discharges may have allowed phosphorus in the sediment to be utilized for algal and plant growth.

Site C1, located furthest upstream in the main channel, maintained the highest concentrations of sediment total nitrogen and phosphorus throughout the three months (2.95 g/kg in March and 11.04 g/kg in June). Organic matter increased at some sites, such as the main channel site near the Area B ponds (C2), but decreased at other open water sites, such as C1 (furthest upstream). This may be an effect of sediment transport throughout the channel.

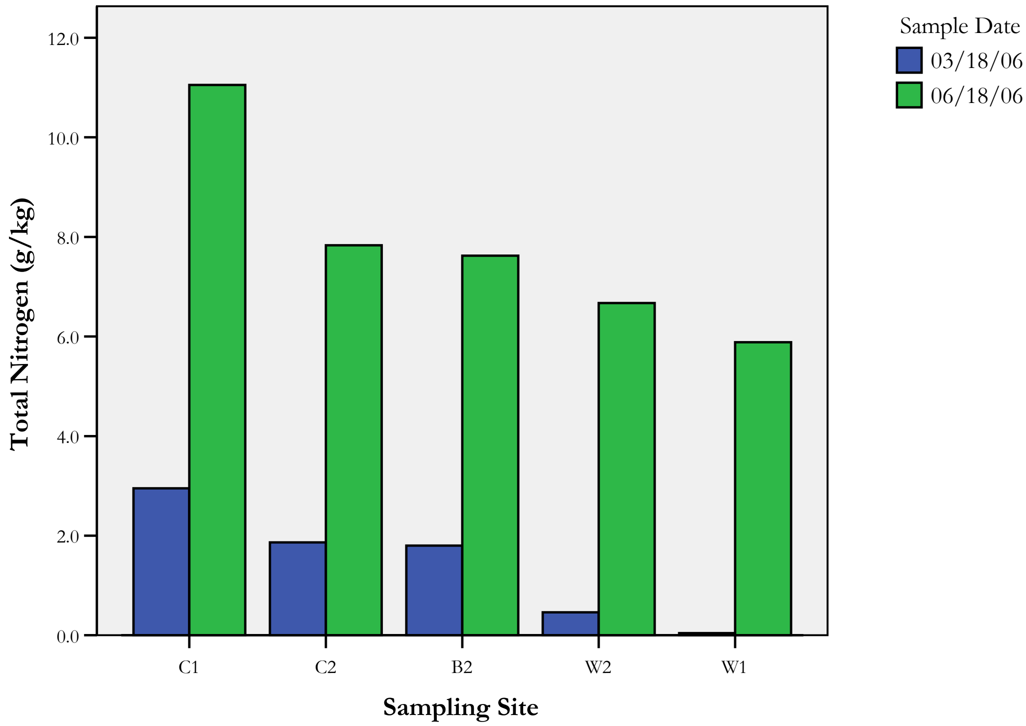

Figure 10. Sediment total nitrogen concentrations in open water sites at the beginning and end of the study. Sampling sites are listed in upstream to downstream order, left to right.

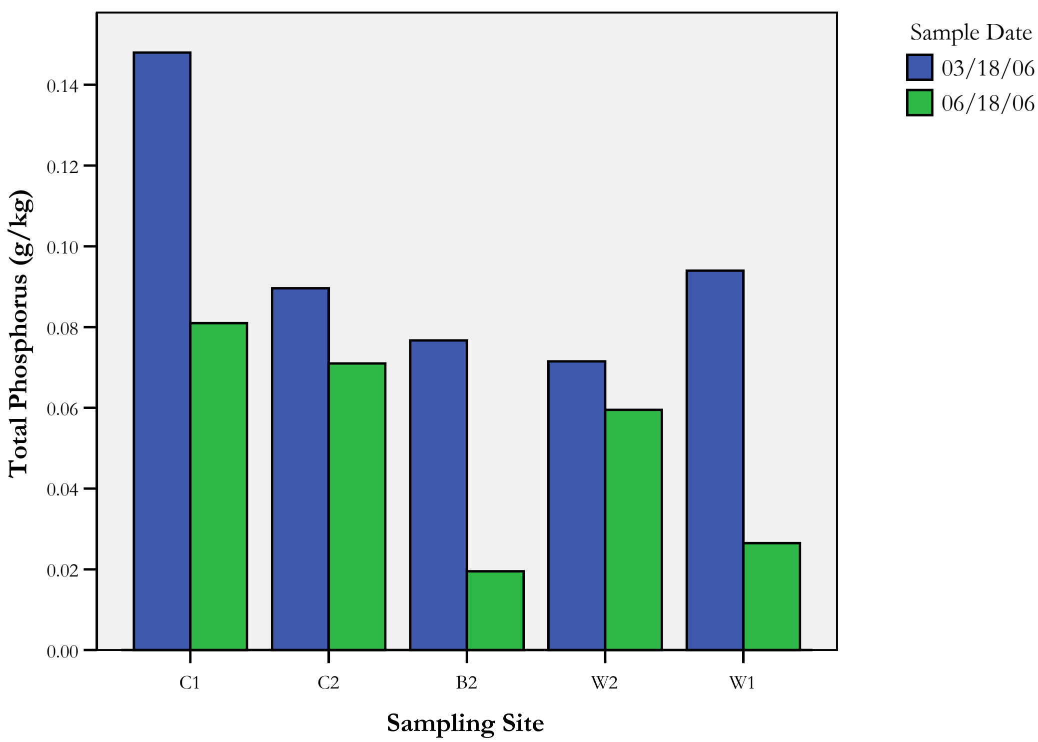

Figure 11. Sediment total phosphorus concentrations in open water sites at the beginning and end of the study. Sampling sites listed in upstream to downstream order, left to right.

Discussion

In terms of some nutrient parameters, especially total ammonia, data suggested that water exiting through the dam had lower nutrient concentrations than water entering the culture area upstream. This was consistent with my hypothesis and with previously cited studies suggesting that large-scale seaweed production can serve as a filter for aquaculture effluent (Marinho-Soriano et al. 2002, Yang 2006). However, some parameters were elevated at the dam, including chemical oxygen demand, TSS, and total phosphorus. This gave rise to concerns that water entering the open bay through the dam was still poor in quality, even if it was in some ways improved relative to upstream sites.

The sharp increase in total phosphorus found in April at all open water sites, as well as in the abalone farm water, the Area A ponds, and the Area B ponds, is of particular concern. The fact that sampling sites at the dam and the abalone farm effluent miles upstream had the two highest total phosphorus concentrations in April is bewildering and implies that either phosphorus sources, water circulation patterns, or both, are not well understood. It may be that the abalone farm simply had several discharge channels that flowed in different directions toward the open seaweed area. The abalone farm and other discharges need to be more accurately mapped in order to make a further determination.

The short water sampling period and small sample sizes also limit our understanding of phosphorus fluctuations in the bay. It could be that the phosphorus increase was the result of a seasonal fluctuation in phosphorus. Seawater used to fill the abalone culture area also could have been the source or one of the sources of phosphorus. Additionally, an increase in organic matter in the water (such as seaweed) might have caused the observed increase in total phosphorus. Total phosphorus analysis relies upon acid digestion of organic tissue; thus the high total phosphorus values may have reflected the presence of phosphorus in an algal bloom, but not necessarily reflected increases in dissolved phosphorus concentrations. Because I did not monitor chlorophyll, I was unable to correlate the high total phosphorus concentrations with increased plant growth. Another possible explanation for the high phosphorus concentrations is that a significant portion of the phosphorus present was unavailable to the seaweed. Phosphate concentrations were lower at the dam than at the upstream sites, and phosphate is bioavailable; perhaps the other forms of phosphorus present were not.

The sediment quality data showed a universal increase in total nitrogen and decrease in total phosphorus in all of the open water sites during the study period, which may be due to the increased rainfall and runoff from adjacent land. The fluctuation in sediment nitrogen and phosphorus may also have resulted from farmers in the bay initiating their growout cycles simultaneously, in which case they would all be discharging nutrient-rich water during the same months.

In order to assess the effectiveness of the open seaweed culture area as a biofilter, water quality in Yingbin Bay's main channel and open seaweed culture area was compared to water quality found in a coastal creek that received shrimp farm effluent in China's more northerly Jiangsu Province (Biao et al. 2004). Average COD levels were higher in Yingbin Bay than in the Jiangsu Province coastal creek (20.3 mg/L in Yingbin Bay's main channel, 18.64 mg/L in the open seaweed culture area, and 5.77 mg/L in the Jiangsu Province coastal creek). Mean total phosphorus concentrations were also higher in Yingbin Bay (0.64 mg/L in Yingbin Bay's main channel, 0.47 mg/L in the open seaweed culture area, compared to 0.024 mg/L in the Jiangsu Province coastal creek). Average total ammonia nitrogen concentrations were lower in the Yingbin Bay open seaweed culture area (0.23 mg/L) than in either the Yingbin Bay main channel (1.24 mg/L) or the Jiangsu Province coastal creek (1.5 mg/L).

Certainly, the coastal creek in the Biao et al. study had drastically different hydrology than Yingbin Bay. The Jiangsu Province creek may have flushed the shrimp farm nutrient load out to sea quickly while restricted flow through the Yingbin Bay dam may have held back nutrients. Again, the relatively low total ammonia concentration in the open seaweed area (0.23 mg/L), and the relatively high average phosphorus concentration (0.47 mg/L) suggest that the open seaweed culture area is not completely functional as a biofilter.

Relative to a 2002 study in Brazil that investigated effectiveness of *Gracilaria sp.* grown in shrimp effluent (Marinho-Soriano et al. 2002), the open seaweed culture area in Yingbin Bay maintained similar phosphate concentrations, and lower total ammonia and nitrate concentrations (Table 8). Nutrient concentrations in Yingbin Bay's open seaweed area were similar to those found in the Area B seaweed and duck pond (Table 8). The Marinho-Soriano et al. study looked at *Gracilaria* grown in ponds that receive intensive shrimp farm effluent. The lowest total ammonia level observed in that study was 4 mg/L, whereas the highest concentration of total ammonia observed in Yingbin Bay's open seaweed culture area was only 0.474 mg/L. The lowest nitrate concentration found at the Brazil site was 2.97 mg/L; whereas highest nitrate concentration found in the Yingbin Bay open seaweed area was only 0.059 mg/L. Phosphate concentrations were similar at all three sites.

Table 8. Comparison of nutrient concentration ranges in *Gracilaria sp.* culture areas receiving aquaculture effluent. All values in mg/L.

Study	Study Type	Ammonia	Phosphate	Nitrate
Duck and Seaweed Pond (Yingbin Bay)	On-farm	0.124 to 0.540	0.080 to 0.298	0.004 to 0.061
Open Seaweed Culture Area (Yingbin Bay)	On-farm	0.054 to 0.474	0.009 to 0.147	0.006 to 0.059
Marinho-Soriano et al. 2002 (Brazil)	On-farm	4 to 20	0.1 to 0.8	2.97 to 8

A multitude of environmental variables could have caused total ammonia and nitrate concentrations to be lower in Yingbin Bay than in the Brazilian study. Seaweed in the Brazilian study was grown in ponds, while the seaweed culture area in Yingbin Bay was open, possibly allowing for more effluent dilution. Moreover, the shrimp in the Brazilian study may have been cultured at higher densities, leading to greater effluent nutrient concentrations. However, it is promising that nutrient concentrations Yingbin Bay's open seaweed area are at the very least comparable to those in similar seaweed culture systems.

Aquacultural activities in the bay – particularly the large open seaweed farming area – may have a beneficial effect on nutrient-rich freshwater that otherwise would flow directly into the open bay. However, much is still unknown about seaweed filtration of aquaculture and other effluents. Studies examining use of seaweeds as biofilters in nutrient-rich waters point to many successes with biofiltration, but also to a large number of unknowns (Chien Ja 1989, Chopin et al. 2001, Klaus and Pang 2003, Neori et al. 2004, Xiugeng 2004, Yang et al. 2005, Yang 2006). For example, without relatively intensive study it is difficult to know what ratio of seaweed to effluent to use in any given coastal ecosystem in order to achieve maximum absorption of nutrients. Authors stress the need to understand better 1) the effect of nonnative seaweeds on native ecosystems; 2) how to avoid overproduction of seaweed; 3) the life histories of different seaweed species; and 4) how to integrate seaweeds effectively into different types of aquaculture production systems (Chopin et al. 2001, Klaus and Shaojun 2003, Neori et al. 2004). While seaweed overproduction does not seem to be a concern in Yingbin Bay, under-production of *Gracilaria verrucosa* certainly is an important issue. Understanding the life history of *Gracilaria verrucosa* may be key to understanding why it was not thriving in Yingbin Bay. Additionally, the specific abilities of *Gracilaria sp.* and other seaweeds to absorb nutrients is not completely understood. *Gracilaria sp.* appears to work well in some settings (Marinho-Soriano et al. 2002) and not in others (Neori et al. 2000). It may be that a different species of seaweed would be more suited to the bay.

Generally speaking, the study area appeared effective in reducing ammonia and phosphate concentrations, which is promising. However, the significance of these reductions is unknown. Moreover, dam management, water circulation, tidal fluctuations, and nutrient fluctuations (including seaweed uptake) in the bay must be better understood before conclusions can be drawn regarding the effectiveness of seaweed as a biofilter for aquaculture effluents.

Chapter 5 Conclusion: Integrating Socioeconomic Data

Similar to the benefits of integrating culture of multiple species, there are numerous benefits to integrating ecological and socioeconomic research in order to study the effects of aquaculture practices. Even through a short-term, preliminary study of aquaculture practices such as this one, the ability to compare and contrast pond quality data with farmers' understanding of environmental quality is extremely valuable.

First, the socioeconomic data collected from my survey suggest that at least some farmers in Yingbin Bay believed strongly that integrated aquaculture both improved water quality and led to better production rates for all species involved. Secondly, the data conveyed that these farmers were aware of negative environmental conditions in the bay, and also were interested in finding ways to overcome and resolve these environmental problems.

The ecological data suggest that shrimp farmers in Yingbin Bay use integrated culture techniques with some success to grow high trophic level organisms that require good water quality, such as shrimp. However, the prevalence of WSSV in the area is a major hindrance to shrimp production. Disease outbreaks have been a major obstacle to shrimp production in Asia, as outbreaks have often increased when growout densities increased and water quality decreased (Kautsky et al. 2000). In the past, high stocking rates (such as seen in this study) and poor water quality were correlated with disease outbreaks in Hainan Province (Kautsky et al. 2000).

Indeed, concern about disease spread is one of the reasons that commercial, intensive shrimp farmers create highly controlled, non-integrated pond environments – quite different from those in Yingbin Bay (Kautsky et al. 2000, Boyd and Clay 2002). At least one recycled-water shrimp farming system, Belize Aquaculture Ltd., has been described in the literature, but in this system water is cleaned using an energy-intensive filtration system, not a low trophic species (Boyd and Clay 2002). A laboratory-scale, super-intensive, zero exchange system that treats water with UV light and microbial floc has also been described (Wasielesky et al. 2006). In general, examples of successful, fully integrated shrimp culture in the literature tend to be closed laboratory or on-station (as opposed to on-farm) farming systems such as that described by Wasielesky et al. (2006) and Neori et al. (2000).

Most frequently, on-farm studies of integrated shrimp farming focus on systems that utilize low trophic organisms for biofiltration, but do not re-use water for shrimp production (Jones et al. 2001, Nelson et al. 2001, Jones et al. 2002, Marinho-Soriano et al. 2002). In this way, shrimp effluent experiences some biofiltration, but is not reused again for shrimp production. In some cases, large quantities of low trophic level organisms, such as seaweeds or mangroves, are cultured not in ponds, but in surrounding ecosystems (such as bays) that receive shrimp effluent from many farms (Gautier et al. 2001, Fei 2004). The goal in these situations is to lessen the negative impacts of shrimp farming by providing effluent filtration, but not to reuse effluent in pond environments. In general, commercial shrimp farmers must be extremely cautious in avoiding disease outbreaks because they produce such large quantities of shrimp. Thus, as the cost to access clean water increases, and the vectors for disease grow, commercial shrimp producers may prefer high density, energy intensive water filtrations systems for shrimp monoculture (Wasielesky et al. 2006). However, small-scale farmers such as those in Yingbin Bay will not likely have access to and financial resources for such technology.

As coastal populations continue to grow, environmental degradation continues to occur, and small-scale farmers continue to want to grow cash crops such as shrimp, farmers will need additional low-cost, low energy techniques for shrimp production that allow for water filtration but also reduce disease incidence. Integrated aquaculture – as is evidenced by the Area B shrimp, seaweed, and duck system – is a promising option already being used by farmers in Yingbin Bay. It allows them to grow multiple marketable products and also provides stability in case one crop becomes diseased.

Interestingly, casual conversation with farmers suggested that they were beginning to perceive farming seaweed as lower risk and more profitable than farming shrimp. This is surprising given that, according to our survey results, shrimp farmers theoretically can make much more money than seaweed farmers. If the high likelihood of viral infection (and the continued prosperity of the local abalone farm that purchases seaweed) convinces farmers to switch from shrimp to seaweed farming, water quality in the bay could benefit as a result. Yingbin Bay may serve as a case in which the environmental impacts of shrimp farming can no longer be externalized simply by flushing away effluent.

Collectively, the farmers in Yingbin Bay have created a large, integrated culture system that is effective in reducing concentrations of at least some nutrients. Further refinement in how they manage the bay could bring them even greater success. Understanding and reducing phosphorus sources and fluctuations in the bay should be a top priority. Seaweed farmers could experiment with a different species of seaweed, or could alternate species such that *Gracilaria verrucosa* is grown during the cooler months and a heat-tolerant seaweed is grown in the summer. For example, Fei (2004) suggested the species *Gracilaria tenuistipitata* var. for use in southern Chinese provinces in conjunction with shrimp farming. Moreover, there is an opportunity for the seaweed farmers to work hand-in-hand with the abalone farm. Research suggests that at least one species of abalone, the South African abalone *Haliotis midae* (Linnaeus), grows best on a diet of multiple fresh seaweeds, as opposed to a single seaweed species or formulated feed (Naidoo et al. 2006). Thus, it could be that growing multiple seaweed species in Yingbin Bay might help seaweed farmers improve production and also lead to improved abalone growth.

The literature suggests that integrated systems are most effective when they are managed in an iterative way (utilizing both on-field and on-station experiments) such that species composition and ratio, water exchange rates and circulation patterns can be adjusted as results are monitored (Neori et al. 2000, Chopin et al. 2001, Jones et al. 2001, Jones et al. 2002, Marinho-Soriano et al. 2002, Fei 2004). Hainan University researchers and students are in the unique position of being located only a few kilometers from Yingbin Bay and could assist farmers in developing more iterative management strategies.

Most importantly, the results of this study demonstrate the benefits of conducting integrated aquaculture research in a holistic, interdisciplinary manner. Farmer responses to socioeconomic questions directly informed researchers understanding of ecological issues in the bay. Likewise, information provided by farmers regarding disease prevalence, low seaweed production and crop sales shed light on the motives for integrated aquaculture in the bay.

It is likely that farmers' perceptions of integrated aquaculture and its relative usefulness will influence their decisions to use or not use integrated farming practices – whether or not these perceptions concur with results from scientific studies. Thus, if researchers hope to promote integrated aquaculture with the purpose of improving environmental quality, they will need to work with farmers to develop integrated systems that not only reduce nutrient loading, but are also *perceived* by farmers as beneficial and profitable. Involving local experts in fields outside of aquaculture production technology, such as experts in local ecology, economics and anthropology, will likely lead to new and innovative ways of engaging farmers and a heightened understanding of how farmers make decisions.

Pursuing research of integrated aquaculture in an interdisciplinary manner could lead to impressive results, far beyond the scope and scale of this study. Moreover, publishing results of these studies in an integrated way (not as separate economic, ecological and cultural articles appearing in separate journals for separate disciplines) could improve specialists' knowledge and understanding of other relevant fields. The end result could be more effective research that helps to achieve new on-the-ground benefits for farmers in developing countries.

Literature Cited

Allison, E.H., and McBride, R.J., 2003. Education reform for improved natural resource management: fisheries and aquaculture in Bangladeshi Universities. Society and Natural Resources 16: 249 – 264.

Bailey, C., 1988. The social consequences of tropical shrimp mariculture development. Ocean & Shoreline Management 11: 31 – 44.

Biao, X. and Kaijin, Y., 2007. Shrimp farming in China: Operating characteristics, environmental impact and perspectives. Ocean & Coastal Management 50: 538 – 550.

Biao, X., Zhuhong, D., and Xiaorong, W., 2004. Impact of intensive shrimp farming on the water quality of adjacent coastal creeks from Eastern China. Marine Pollution Bulletin 48: 543 – 553.

Boyd, C.E., 2003. Guidelines for aquaculture effluent management at the farm level. Aquaculture 226: 101 – 112.

Boyd, C.E., and Clay, J.W., 2002. Evaluation of Belize Aquaculture, Ltd.: A Superintensive Shrimp Aquaculture System. Report prepared under the World Bank, NACA, WWF and FAO Consortium Program on Shrimp Farming and the Environment, Bangkok, Thailand.

Boyd, C.E., and Egna, H., 1997. Dynamics of Pond Aquaculture. CRC Press, Boca Raton, Florida.

Brzeski, V., and Newkirk, G., 1997. Integrated coastal food production systems – a review of current literature. Ocean and Coastal Management 34 (1): 55 – 71.

Carr, A., and Wilkinson, R., 2005. Beyond participation: boundary organizations as a new space for farmers and scientists to interact. Society and Natural Resources 18: 255-265.

Chen Jia, X., 1989. *Gracilaria* culture in China. NACA-SF/WP/89/12.

Chopin, T., Buschmann, A.H., Halling, C., Troell, M., Kautsky, N., Neori, A., Kraemer, G.P., Zertuche-González, J.A., Yarish, C., and Neefus, C., 2001. Integrating seaweeds into marine aquaculture systems: a key toward sustainability. Journal of Phycology 37: 975 – 986.

Clark, M., 2003. A study of aquaculture brownfields: abandoned and converted shrimp ponds in Thailand. Unpublished Master's thesis, University of Michigan, Ann Arbor.

Clough, B., Johnston, D., Xuan, T.T., Phillips, M.J., Pednekar, S.S., Thien, N.H., Dan, T.H., and Thong, P.L., 2002. Silvofishery Farming Systems in Ca Mau Province, Vietnam. Report prepared under the World Bank, NACA, WWF and FAO Consortium Program on Shrimp Farming and the Environment. Work in Progressfor Public Discussion. Published by the Consortium. 70 pages.

Cooley, D.R., 1999. Shrimp aquaculture, coastal communities, and competing stakeholders: applying cultural models to coastal zone management. Culture and Agriculture 21(2): 13 – 18.

Costa-Pierce, B.A., 2002. Ecological Aquaculture. Blackwell Science, Oxford, UK.

FAO, 2003. Review of the State of World Aquaculture. FAO Fisheries Circular No. 886, Rev. 2, Rome.

FAO, 2004. The State of World Fisheries and Aquaculture. FAO Fisheries Department, Rome.

FAO, 2006. State of World Aquaculture 2006 (Advance Copy). FAO Fisheries Technical Paper No. 500, Rome..

Fei, X., 2004. Solving the coastal eutrophication problem by large scale seaweed cultivation. Hydrobiologia 512: 145 – 151.

Frankic, A., and Hershner, C., 2003. Sustainable aquaculture: developing the promise of aquaculture. Aquaculture International 11: 517 – 530.

Funge-Smith, S.J., and Briggs, M.R.P., 1998. Nutrient budgets in intensive shrimp ponds: implications for sustainability. Aquaculture 164: 117 – 133.

Gautier, D., Amador, J., and Newmark, F., 2001. The use of mangrove wetland as a biofilter to treat shrimp pond effluents: preliminary results of an experiment on the Caribbean coast of Colombia. Aquaculture Research 32: 787-799.

Gautier, D. 2002. The Integration of Mangrove and Shrimp Farming: A Case Study on the Caribbean Coast of Colombia. Report prepared under the World Bank, NACA, WWF and FAO Consortium Program on Shrimp Farming and the Environment. Work in Progress for Public Discussion. Published by the Consortium, 26 pp.

Giap, D.H., 2005. Analysis of sustainability of the shrimp farming systems in Haiphong, Vietnam. Unpublished doctoral dissertation, Asian Institute of Technology, Pathumthani, Thailand.

Hernández, I., Fernández-Engo, M.A., Pérez-Lloréns, J.L., and Vergara, J.J., 2005. Integrated outdoor culture of two estuarine macroalgae as biofilters for dissolved nutrients from *Sparus aurata* waste waters. Journal of Applied Phycology 17: 557 – 567.

Jackson, C., Preston, N., and Thompson, P.J., 2004. Intake and discharge nutrient loads at three intensive shrimp farms. Aquaculture Research 35: 1053 – 1061.

Jiarong, C., 1996. The Instructional Book of Water Quality Analysis (manual). China Agriculture Science and Technology Publishing House, Beijing.

Jones, A.B., Dennison, W.C., and Preston, N.P., 2001. Integrated treatment of shrimp effluent by sedimentation, oyster filtration and macroalgal absorption: a laboratory scale study. Aquaculture 193: 155 – 178.

Jones, A.B., Preston, N.P., and Dennison, W.C., 2002. The efficiency and condition of oysters and macroalgae used as biological filters of shrimp pond effluent. Aquaculture Research 33: 1 – 19.

Kautsky, N., Rönnbäck, P., Tedengren, M., and Troell, M., 2000. Ecosystem perspectives on management of disease in shrimp pond farming. Aquaculture 19: 145 – 161.

Li, M.S., and Lee, S.Y., 1997. Mangroves of China: a brief review. Forest Ecology and Management 96: 241 – 259.

Li, S.F., 2003. Aquaculture research and its relation to development in China, Agricultural Development and the Opportunities for Aquatic Resources Research in China. World Fish Center Conference Proceedings 65: 17 – 28, Shanghai, China.

Lin, Y., 2002. Water Quality Monitoring and Analysis Methods, Standard Practice Handbook (manual). China Environmental Science Publishing, Beijing.

Liu, X., 2007. Granting quasi-property rights to aquaculturists to achieve sustainable aquaculture in China. Ocean & Coastal Management 50: 623 – 633.

Lüning, K., and Pang, S., 2003. Mass cultivation of seaweeds: current aspects and approaches. Journal of Applied Phycology 15: 115 – 119.

Marinho-Soriano, E. Morales, C., and Moreira, W.S.C., 2002. Cultivation of *Gracilaria* (Rhodophyta) in shrimp pond effluents in Brazil. Aquaculture Research 33: 1081 – 1086.

Martinez-Cordero, F.J., and Leung, P., 2004. Sustainable aquaculture and producer performance: measurement of environmentally adjusted productivity and efficiency of a sample of shrimp farms in Mexico. Aquaculture 241: 249 – 268.

Metaxa, E., Deviller, G., Pagand, P., Alliaume, C., Casellas, C., and Blancheton, J.P., 2006. High rate algal pond treatment for water reuse in a marine fish recirculation system: Water purification and fish health. Aquaculture 252: 92 – 101.

Naidoo, K., Maneveldt, G., Ruck, K., and Bolton, J.J., 2006. A comparison of various seaweed-based diets and formulated feed on growth rate of abalone in a land-based aquaculture system. Journal of Applied Phycology 18: 437 – 443.

Naylor, R., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Mooney, H., and Troell, M., 2000. Effect of aquaculture on world fish supplies. Nature 405: 1017 – 1024.

Neori, A., 1996. Seaweed biofilters as regulators of water quality in integrated fish-seaweed culture units. Aquaculture 141: 183 – 199.

Neori, A., Chopin, T., Troell, M., Buschmann, A.H., Kraemer, G.P., Halling, C., Shpigel, M., and Yarish, C., 2004. Integrated aquaculture: rationale, evolution and state of the art emphasizing seaweed biofiltration in modern mariculture. Aquaculture 231: 361 – 391.

Neori, A., Shpigel, M., and Ben-Ezra, D., 2000. A sustainable integrated system for culture of fish, seaweed and abalone. Aquaculture 186: 279 – 291.

Paez-Osuna, F., 2001. The environmental impact of shrimp aquaculture: causes, effects, and mitigating alternatives. Environmental Management 28 (1): 131 – 140.

Primavera, J.H., 2006. Overcoming the impacts of aquaculture on the coastal zone. Ocean & Coastal Management 49: 531 – 545.

Rukun, L., 2000. Soil Agrochemistry Analysis Method (manual). China Agriculture Science and Technology Publishing House, Beijing.

Ryder, E., Nelson, S.G., McKeon, C., Glenn, E.P., Fitzsimmons, K., and Napolean, S., 2004. Effect of water motion on the cultivation of the economic seaweed *Gracilaria parvispora* (Rhodophyta) on Molokai, Hawaii. Aquaculture 238: 207 – 219.

Sato, K., Eksangsri, T., and Egashira, R., 2006. Ammonia-nitrogen uptake by seaweed for water quality control in intensive mariculture ponds. Journal of Chemical Engineering of Japan 39(2): 247 – 255.

Schneider, O., Sereti, V., Eding, E.H., and Verreth, J.A.J., 2005. Analysis of nutrient flows in integrated intensive aquaculture systems. Aquacultural Engineering 32: 379 – 401.

Shpigel, M., Neori, A., Popper, D.M., and Gordin, H., 1993. A proposed model for "environmentally clean" land-based culture of fish, bivalves and seaweeds. Aquaculture 117: 115 – 128.

Schuenhoff, A., Shpigel, M., Lupatsch, I., Ashkenazi, A., Msuya, F.E., and Neori, A., 2003. A semi-recirculating, integrated system for the culture of fish and seaweed. Aquaculture 221: 167 – 181.

Schwantes, V., 2007. Social, economic, and production characteristics of freshwater prawn *Macrobrachium rosenbergii* culture in Thailand. Unpublished Master's thesis, University of Michigan, Ann Arbor.

Stonich, S., and Bailey, C., 2000. Resisting the Blue Revolution: Contending coalitions surrounding industrial shrimp farming. Human Organization 59 (1): 23 – 36.

Tain, F., and Diana, J.S., 2007. Impacts of extension practices: lessons from small farm-based aquaculture of Nile tilapia in Northeastern Thailand. Society & Natural Resources 20: 583 – 595.

Tobey, J., Clay, J., and Vergne, P., 1998 Maintaining a Balance: The Economic, Environmental and Social Impacts of Shrimp Farming in Latin America. Coastal Management Report #2202 , Coastal Resources Management Project II, USAID/G/ENV and Coastal Resources Center, University of Rhode Island, Kingston, RI.

Troell, M., Halling, C., Neori, A., Chopin, T., Buschmann, A.H., Kautsky, N., and Yarish, C., 2003. Integrated mariculture: asking the right questions. Aquaculture 226: 69 – 90.

Turongruang , D., and Demaine, H., 2002. Participatory development of aquaculture extension materials and their effectiveness in transfer of technology: the case of the AIT Aqua Outreach Programme, Northeast Thailand. In: Edwards, P., Demaine , H., Little, D.C. (eds.), Rural Aquaculture, 307-322. Wallingford, UK: CABI Publication.

Wasielesky Jr., W., Atwood, H., Stokes, A., and Browdy, C.L., 2006. Effect of natural production in a zero exchange suspended microbial floc based super-intensive culture system for white shrimp *Litopenaeus vannemei*. Aquaculture 258: 396 – 403.

Wu, M., Ka Kan Mak, S., Zhang, X., and Quian, P., 2003. The effect of co-cultivation on the pearl yield of *Pinctada martensi* (Dumker). Aquaculture 221: 347 – 356.

Xie, B., Zhuhong, D., and Xiaorong, W., 2004. Impact of the intensive shrimp farming on the water quality of the adjacent coastal creeks from Eastern China. Marine Pollution Bulletin 48: 543 – 553.

Yang, H., Zhou, Y., Mao, Y., Li, X., Liu, Y., and Zhang, F., 2005. Growth characters and photosynthetic capacity of *Gracilaria lemaneiformis* as a biofilter in a shellfish farming area in Sanggou Bay, China. Journal of Applied Phycology 17: 199 – 206.

Yang, N.S., 2003. Research priorities of the Chinese Academy of Fishery Sciences (CAFS), Agricultural Development and the Opportunities for Aquatic Resources Research in China. World Fish Center Conference Proceedings 65: 29 – 36.

Yang, Y., 2006. Growth of *Gracilaria lemaneiformis* under different cultivation conditions and its effects on nutrient removal in Chinese coastal waters. Aquaculture 254: 248 – 255.

Yu Feng, Y., Chun Hou, L., Xiang Ping, N., Dan Ling, T., and Ik Kyo, C., 2004. Development of mariculture and its impacts in Chinese coastal waters. Reviews in Fish Biology and Fisheries 14: 1 – 10.

Yi, Z., Yang, H., Hu, H., Liu, Y., Mao, Y., Zhou, H., Xu, X., and Zhang, F., 2006. Bioremediation potential of the macroalga *Gracilaria lemaneiformis* (Rhodophyta) integrated into fed fish culture in coastal waters of north China. Aquaculture 252: 264 – 276.

Zhu, Y., O'Connor, P., and Cao, J., 2007. Where do Chinese scientists publish their research in environmental science and technology? Environmental Pollution 147: 1 – 3.

Appendix A:
Water and Sediment Chemistry in Area A Ponds

Table 9. Water chemistry monitoring results for intensive shrimp ponds A1, A2, and A3 (integrated shrimp and abalone production). All values are in mg/L except where noted.

Site	Sampling Month	Salinity (ppm)	DO (surface, middle, bottom)	Total Ammonia	Nitrite	Nitrate	Phosphate	Total Phosphorus	TSS	COD
Pond A1	March	29.0	-	0.237	0.0027	0.012	0.0111	0.149	177	14.6256
	April	30.0	5.28, 5.11, 4.92	0.4354	0.0003	0.0042	0.0639	1.514	78	23.0832
	May	20.0	11.10, 1.82, 0.90	0.6408	0.0315	0.0277	0.538	0.811	151	24.1718
	June	10.0	5.63, 2.83, 1.84	0.5736	0.5514	-	0.015	1.693	84	10.448
Pond A2	March	26.0	-	0.298	0.0037	0.012	0.0093	0.081	223	18.0576
	April	28.5	5.52, 5.49, 5.43	0.9701	0.0011	-	0.0416	1.5628	59	23.6712
	May	20.0	13.08, 12.48, 7.77	0.7108	0.0132	0.035	0.4216	0.7137	144	23.8928
	June	8.0	8.46, 6.18, 7.19	0.5687	0.5619	-	0.0622	1.5295	68	11.2877
Pond A3	March	28.0	-	0.457	0.0009	0.003	0.0019	0.118	196	11.9856
	April	30.0	5.52, 5.36, 5.30	0.463	0.0021	0.0042	0.049	1.3542	150	23.772
	May	20.0	13.47, 9.50, 4.13	0.5923	0.0308	0.0326	0.4025	0.6758	159	23.0557
	June	10.0	6.42, 4.89, 4.66	0.6174	0.2526	-	0.2861	0.9915	76	23.5987

Table 10. Water chemistry monitoring results for outflows from intensive shrimp ponds (A1OUT, A2OUT and A3OUT) and abalone farm effluent (A4). All values are in mg/L except where noted.

Site	Sampling Month	Salinity (ppm)	Total Ammonia	Nitrite	Nitrate	Kjeldahl N	Phosphate	Total Phosphorus	TSS	COD
A4 (Abalone Inflow)	March	35.0	0.457	0.0055	0.047	1.764	0.013	0.037	183	8.6592
	April	35.0	1.3228	0.0116	0.0515	0.7	0.0149	1.5762	105	13.9728
	May	16.0	0.6838	0.0152	0.0892	0.868	0.0354	0.0865	143	13.7776
	June	35.0	0.2917	0.0405	0.1005	0.644	0.0393	0.0685	43	10.1626
A1OUT (Pond A1 Outflow)	April	-	0.4299	0.0066	0.0021	3.164	0.2407	0.4173	72	22.3272
	May	-	1.3085	0.0085	0.0012	5.208	0.7364	4.7743	155	26.4216
	June	-	0.7924	0.5562		7.7	0.0383	2.3839	112	11.9136
A2OUT (Pond A2 Outflow)	April	-	0.2866	0.0034	0.1229	3.556	0.321	0.5372	61	23.9064
	May	-	1.2762	0.0372	0.0277	6.496	0.5971	1.914	149	25.6717
	June	-	1.0694	0.5468		11.004	0.0278	2.1993	95	12.0115
A3OUT Pond A3 Outflow	April	-	0.2811	0.0008	0.0063	4.116	0.3165	0.586	145	22.3944
	May	-	1.8523	0.0247	0.0283	6.692	0.6181	3.3955	168	24.9392
	June	-	0.8361	0.2449	-	10.136	0.005	1.5611	106	23.7293

Table 11. Sediment chemistry in Area A ponds at harvest.

Site	Sampling Month	Bulk Density (g/cm^3)	Total Nitrogen (g/kg)	Total Phosphorus (g/kg)	Organic Matter (g/kg)
Pond A1	July	1.5770	6.0675	0.1395	16.3200
Pond A2	July	1.5890	4.4108	0.0400	3.6580
Pond A3	July	1.5400	7.0840	0.2820	19.1860

Appendix B:
Water and Sediment Chemistry in Area B Ponds

Table 12. Water chemistry monitoring results for pond B1, B3, and the water exchange canal (B2). All values are in mg/L except where noted.

Site	Sampling Month	Salinity (ppm)	DO (surface, middle, bottom)	Total Ammonia	Nitrite	Nitrate	Phosphate	Total Phosphorus	TSS	COD
Pond B1	March	10.00	10.85, 10.74, 11.11	0.0210	0.0018	0.0040	0.0538	0.1250	78	18.8848
	April	5.00	6.71, 6.53, 6.45	0.1543	0.0050	0.0032	0.0654	0.5994	33	22.0080
	May	5.00	11.34, 11.21, 10.23	0.3285	0.0187	0.0289	0.1068	0.2541	75	22.8464
	June	-	-	-	-	-	-	-	-	-
Pond B3	March	9.00	14.84	0.5400	0.0352	0.0560	0.0798	0.1590	122	19.3072
	April	10.00	4.20	0.5181	0.0042	0.0042	0.1605	1.4918	30	22.1928
	May	9.50	10.10	0.1238	0.0025	0.0247	0.2980	0.4920	62	22.9859
	June	12.80	12.34	0.1264	0.0030	0.0613	0.2625	0.4377	38	22.0973
B2	March	3.00	3.09	0.8780	0.0343	0.3610	0.0872	0.1550	45	15.2416
	April	4.00	6.39	0.6449	0.0295	0.2804	0.2080	1.2698	36	20.9664
	May	0.50	7.34	0.8831	0.0674	0.4884	0.2248	0.3893	69	21.8174
	June	5.00	2.58	0.4667	0.0543	0.4763	0.1785	0.4061	44	21.6403

Table 13. Sediment chemistry in Area B sampling sites at the beginning of the study and after harvest.

Site	Sampling Month	Bulk Density (g/cm^3)	Total Nitrogen (g/kg)	Total Phosphorus (g/kg)	Organic Matter (g/kg)
Pond B1	March	1.4900	0.4254	0.1188	13.7641
	June	1.6380	2.8526	0.0560	35.4580
Pond B3	March	1.6620	1.0662	0.1318	10.9491
	June	1.6300	7.3582	0.0375	14.0420
B2	March	1.2600	1.8018	0.0767	14.2300
	June	1.4160	7.6217	0.0195	17.2350

Appendix C:
Water and Sediment Chemistry in Open Water Sampling Sites

Table 14. Water chemistry monitoring results for open water sampling sites. All values are in mg/L except where noted.

Sampling Site	Sampling Month	Salinity (ppm)	DO	pH	Total Ammonia	Nitrite	Nitrate	Kjeldahl N	Phosphate	Total Phosphorus	TSS	COD
C1	March	0.00	0.46	7.1	2.3200	0.0491	0.0680	-	0.0817	0.1620	45	20.6976
	April	6.00	0.95	7.2	1.7472	0.0955	0.1554	-	0.2556	0.9412	71	18.9168
	May	0.50	4.02	7.0	1.8685	0.1012	0.0657	-	0.1364	0.8488	69	20.7187
	June	0.00	0.90	8.2	0.4375	0.0029	0.0288	-	0.1372	0.6065	73	23.1091
C2	March	12.00	7.12	8.7	0.8430	0.0427	0.0140	-	0.0928	0.2640	103	19.5536
	April	10.50	6.75	7.8	1.0142	0.0311	0.0399	-	0.3180	1.0123	41	20.3448
	May	12.00	8.45	8.6	0.5277	0.0066	0.0344	-	0.4491	0.8164	58	20.3448
	June	8.00	4.23	8.0	1.0986	0.0439	0.0325	-	0.4416	0.8649	58	20.3448
B2	March	3.00	3.09	7.4	0.8780	0.0343	0.3610	-	0.0872	0.1550	45	15.2416
	April	4.00	6.39	7.5	0.6449	0.0295	0.2804	-	0.2080	1.2698	36	20.9664
	May	0.50	7.34	7.8	0.8831	0.0674	0.4884	-	0.2248	0.3893	69	21.8174
	June	5.00	2.58	6.9	0.4667	0.0543	0.4763	-	0.1785	0.4061	44	21.6403
W1	March	12.00	-	9.3	0.4340	0.0027	0.0360	7.5180	0.0557	0.0910	73	16.8256
	April	12.00	8.06	8.3	0.4740	0.0026	0.0063	0.5320	0.1025	1.5495	42	11.7936
	May	10.00	8.20	8.9	0.1077	0.0079	0.0319	1.3160	0.1180	0.1784	81	22.1837
	June	9.50	8.20	8.6	0.1653	0.0087	0.0454	1.4000	0.1138	0.2373	55	23.9578
W2	March	10.00		9.3	0.2240	0.0033	-	7.7000	0.0631	0.0980	80	14.9776
	April	13.00	4.29	7.1	0.1709	0.0053	0.0063	0.9800	0.1471	1.1188	25	22.1592
	May	10.30	8.15	8.7	0.0538	0.0179	0.0344	1.0920	0.0805	0.1568	75	22.6546
	June	7.80	7.07	8.5	0.1799	0.0103	0.0588	1.9600	0.0441	0.1265	67	23.2723
C3	March	13.00	-	9.2	0.1050	0.0027	0.0320	-	0.0089	0.0640	94	11.3168
	April	13.00	7.72	8.3	0.2094	0.0043	0.0084	-	0.0936	1.6960	45	19.8408
	May	12.00	8.43	8.8	0.0754	0.0091	0.0591	-	0.1210	0.1405	73	15.6088
	June	12.00	8.43	8.8	0.1264	0.0042	0.0466	-	0.0768	0.1476	46	19.0944

Table 15. Sediment chemistry for open water sampling sites at the start and end of the study. No sediment samples were taken at C3, the sampling site furthest downstream at the dam, as the substrate was large boulders.

Sampling Site	Sampling Month	Bulk Density (g/cm^3)	Total Nitrogen (g/kg)	Total Phosphorus (g/kg)	Organic Matter (g/kg)
C1	March	0.6930	2.9514	0.1480	45.6479
	June	1.5270	11.0497	0.0810	27.1530
C2	March	1.1060	1.8637	0.0896	23.9538
	June	1.0210	7.8306	0.0710	42.6680
B2	March	1.2600	1.8018	0.0767	14.2300
	June	1.4160	7.6217	0.0195	17.2350
W1	March	1.5800	0.0447	0.0940	16.4800
	June	1.4770	5.8856	0.0265	23.6490
W2	March	1.5470	0.4621	0.0715	14.5958
	June	1.5940	6.6734	0.0595	12.1310

Appendix D:
Example Farmer Questionnaire

SAMPLE
SOCIO-ECONOMIC AND TECHNICAL SURVEY OF SHRIMP-SEAWEED CULTURE
IN HAINAN PROVINCE, CHINA

Farmer Code: ___ _____ Province: ___ ___

Interviewer name: Date of interview

Location of farm:
Distance of farm from Haikou (main city):
Farm type:

A. Farmer Background
1.1 Farmer Name : Sex ___ Age

Address:

Status: ☐ Owner ☐ Manager ☐ Owner/manager

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

1.2 Level of your education (grade):__________________________
☐ Elementary ☐ High School☐ Vocational/University

1.3 When did you begin as a shrimp-seaweed culture manager?: (year)

1.3a Do you always farm shrimp and seaweed together? ☐ No ☐ Yes

If no, when do you choose to farm shrimp and seaweed together?
____

When do you choose to farm only shrimp or only seaweed?
____

1.4. How frequently do you farm shrimp and seaweed together? (cycles/year),

1.5 Did you get any training on shrimp-seaweed farming before starting shrimp-seaweed culture?
☐ No ☐ Yes (question continued on next page)

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

1.6 What was your main occupation before shrimp-seaweed culture management?

□ Agriculture activity □ Fish Culture □ Fish seed producer
□ Government employee □ Business □ Other_______________

1.7 Number of present subsidiary occupations: (#) _____

1.8 Ownership

□ Sole □ Lease □ Company □ Other______________

1.9 Land Ownership

□ Owner □ Rent if rent, how much?
□ Owner/rent _____________ RMB /ha/year?

1.10 Type of management:

□ Private □ Cooperative □ Public company
□ Other______________

1.11 From your experiences, what are the major problems faced by shrimp-seaweed farmers?

□ Seed supply:___________ □ Low production □ Poor water quality:__________________

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

□ Low economic return □ Market problems □ Other _________________

1.12 Have you ever experienced significant low shrimp and seaweed production or crop collapses? □ No □ Yes, why___

1.13 Do you wish/plan to make any improvements to your farm in the future? □ No □ Yes

1.13a **If yes**, what are your plans?

1.14 Do you have a source of energy for your farm operation? □ No □ Yes, **if yes**

□ Electricity □ Own generator Energy Cost RMB /month

1.14a Was there a source of energy for your farm when you first began? □ No □ Yes

1.15 What machinery or equipment is used on the farm?

□ Generators___________(Number) □ Pump______(Number)

□ Compressor___________(Number) □ Aerators___________(Number)

☐ Vehicles_______(Number) ☐ Computers__________(Number)

☐ Printers__________(Number) ☐ Telephone______(Number)

1.16 Total area of your farm , used for;

☐ Water storage ____________ponds _____________volume/pond
☐ Effluent treatment ____________ponds _____________volume/pond
☐ Seaweed pond ponds, /pond
☐ Shrimp pond ponds, /pond
☐ Duck pond ____________ponds _____________ /pond
☐ Nursery pond ____________ponds _____________ /pond
☐ Others ____

1.17 How many laborers work on your farm (please specify gender), including farmer?

☐ Labor in family persons , RMB/person/month

☐ Permanent labors _________persons ___________ RMB /person/month

☐ Casual labors _________persons ____________ RMB /person/day

1.17a When you first began farming, how many laborers worked on your farm (incl. gender) including farmer?

☐ Labor in family persons , RMB /person/month

☐ Permanent labors _________persons ___________ RMB /person/month

☐ Casual labors _________persons ____________ RMB /person/day

B. Integrated Shrimp-Seaweed Culture

2.1 Why do you practice integrated shrimp-seaweed culture? Rank each reason from 1 (concern), 2 (little concern), to 3 (no concern).

Reduce disease	*1*	*2*	*3*
Improve water quality	*1*	*2*	*3*
Reduce environmental impact	*1*	*2*	*3*
Improve pond productivity	*1*	*2*	*3*
Produce two marketable crops	*1*	*2*	*3*
Reduce operational costs	*1*	*2*	*3*
Improve economic return	*1*	*2*	*3*

Other ____

2.2 For this production cycle (Mar – May 2006), describe your entire production system:

2.3 What species /or strains do you use for integrated shrimp-seaweed culture, and what are the stocking sizes and seed prices of shrimp and seaweed?

Shrimp size price RMB/PL

Seaweed size price RMB/kg

Other________________size ________price ________RMB/species

2.3a Do you always use these species? ☐ No ☐ Yes

If no, what other species do you use?____________________________ And what influences your decision to use other species? _____________________________________

2.3b Do some species of shrimp and seaweed work better for integrated culture than others? ☐ No ☐ Yes **If yes**, explain

2.4 At what density do you stock shrimp for integrated culture?

2.5 At what density do you stock seaweed for integrated culture?

2.6 How did you decide upon these stocking densities?

2.7 From your experience, what is average survival rate of shrimp over 30-day culture?

☐ 50-55 % ☐ 55-60 % ☐ 60- 65% ☐ 65-70% ☐ 70-80% ☐other _____%

2.8 From your experience, what is the average weight of 30-day shrimp (pcs/kg)?

2.9 When do you first harvest shrimp?
2.9a When do you first harvest seaweed?
2.10 How long do you culture shrimp and seaweed per cycle?
☐ Shrimp /cycle ☐ Seaweed /cycle

2.11 What is the production of shrimp?

1nd_____________harvest_____________total______________males

_______________females_____________ shrimp

2nd_____________harvest_____________total______________males

_______________females_____________ shrimp

2.11a What is the production of seaweed?

1st harvest _____________total ______________

2nd harvest _____________total ______________

3rd harvest _____________total ______________

2.12 What is the average weight of shrimp (pcs/kg)?

2.13 Where do you sell your shrimp?

2.13a Where do you sell your seaweed?

2.14 Currently, what is the price of shrimp? RMB/kg

2.14a Currently, what is the price of seaweed? RMB/kg

2.15 Do you have large fluctuations in shrimp production between years?

☐ No ☐ Yes **If yes,** How much in kg/ha:_

2.15a Do you have large fluctuations in seaweed production between years?

☐ No ☐ Yes **If yes,** How much

2.16 Do you rotate your crops?

☐ No ☐Yes (please describe):____________________________

2.16a If crop rotation is utilized, why? Rank each reason from 1 (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 ____

C. Feeding regimes of fish

3.1 Do you feed shrimp with supplemented feed?

☐ No ☐ Yes

If yes, what types of feed do you use?

☐ Pellet feed ☐ Rice bran ☐ Other _________ **If no**, please give the reason why? ____

3.2 What is the difference in size between polyculture/integrated shrimp and monoculture shrimp? ☐ Integrated shrimp/kg ☐ Monoculture shrimp/kg

3.2a What is the difference in size between polyculture/integrated seaweed and monoculture seaweed? ☐ Integrated ☐ Monoculture

3.3 What is the survival rate of shrimp in integrated versus monoculture systems?

Integrated Monoculture

3.4 From your experience, what is the yield of shrimp from integrated versus monoculture systems? ☐ Integrated ☐ Monoculture

3.4a From your experience, what is the yield of seaweed from integrated versus monoculture systems? ☐ Polyculture ☐ Monoculture

3.5 If you practice integrated shrimp-seaweed culture, what is the trend in disease problems, relative to monoculture? ☐ Increase ☐ Decrease ☐ No change

3.6 What types of parasite do you have, during the integrated shrimp-seaweed growout period? ☐ Parasite names :

3.7 If you practice integrated shrimp-seaweed culture, what is the trend in parasite problems, relative to monoculture? ☐ Increase ☐ Decrease ☐ No change

D. Pond and Water Management

4.1 What are the sources of freshwater for your farm?

☐ River ☐ Lake ☐ Reservoir ☐ Dam

☐ Ground water:- ☐ Shallow well ☐ Deep Well

☐ Other ____

4.2. What ratio of fresh to saltwater do you use in your seaweed ponds?

4.2a What ratio of fresh to saltwater do you use in your shrimp ponds?

4.3 How often do you exchange water between your shrimp and seaweed ponds?

4.4 How much of the of the shrimp pond water goes into the seaweed ponds?

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

☐ No impact ☐ Moderate ☐ Severe impact

4.6 What pollution source(s) most affect your operation (check all that apply)?

☐ Agriculture ☐ Industry ☐ Domestic waste

☐ Aquaculture ☐ No effect

4.7 What nuisance plants affect your operation (check all that apply)?

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

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

☐ Periphyton growing on seaweed

4.8 Do you have a water storage pond?

☐ No, go to 4.10 ☐ Yes, go to 4.9

4.9 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____

4.9a 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 ____

4.10 On what types of soil are your ponds located?
☐ Clay ☐ Silt/sand clay ☐ Loam ☐ Others_________________

4.11 What is the average depth of your ponds?
4.12 How do you prepare your shrimp ponds to begin culture?
a. Dry pond

b. Mechanical removed mud __ per ______crop/s expenditure _______yuan/time

c. Flushing removed mud , expenditure,

d. Tilling or plow the soil , expenditure

e. Repair dikes________ per ______crop/s expenditure _______yuan/time

4.12a How do you prepare your seaweed ponds to begin culture?
a. Dry pond __________days/crop

b. Mechanical removed mud ____ per ______crop/s expenditure _______RMB/time

c. Flushing removed mud __ per ______crop/s expenditure _______ RMB /time

d. Tilling or plow the soil ____ per _______crop/s expenditure ______RMB/time

e. Repair dikes _____ per ______crop/s expenditure _______ RMB /time

4.13 How do you apply chemicals to pond water in preparation for each cycle?

a. Lime ____________kg/pond or price __________ RMB/kg

b. Teaseed cake ____________kg/pondor price ___________ RMB /kg

c. Dolomite ____________kg/pondor price ___________ RMB /kg

d. Rice Bran ____________kg/pondor price ___________ RMB /kg

e. Fish meal ____________kg/pondor price ___________ RMB /kg

f. Salt ____________kg/pondor price ___________ RMB/kg

g. Other ____________kg/pond or price ___________ RMB /kg

4.14 What types of fertilizer do you apply to ponds in preparation for stocking shrimp and during culture?

□ Organic ______________________ _______ kg/pond price _____ RMB /kg

□ Inorganic ______________________ _______ kg/pond price _____ RMB /kg

□ Other _____ _________________ _________kg/pond price _______ RMB /kg

□Do you use fertilizers (Why?) ____

4.14a What types of fertilizer do you apply to ponds in preparation for stocking seaweed and during culture?

□ Organic _________________________ _________kg/pond price _____ RMB /kg

□ Inorganic _________________________ _________kg/pond price _____ RMB /kg

□ Other __________________________ _________kg/pond price _______ RMB /kg

□ Do not use fertilizers (Why?) ____

□ Do not use fertilizers (Why?) __________ __________________________________

4.15 How soon do you stock shrimp after filling ponds with water?

4.16 Do you use an aerator to increase oxygen in shrimp ponds?

□ No, go to 4.18 □ Yes, go to 4.17

4.17 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 ______________________________

4.17a How often do you run the aerators? _______________/day

4.18 What types of chemicals do you apply to the shrimp ponds during poor water quality; low pH and disease outbreaks?

 Lime __________kg/pond/time_____time/cycle___________ RMB /kg

 Dolomite __________kg/pond/time_____time/cycle___________ RMB /kg

 Zeolite __________kg/pond/time_____time/cycle___________ RMB /kg

 Other ___________kg /pond/time_____time/cycle___________ RMB /kg

4.19 Do you every apply chemicals to the seaweed ponds? Yes No

If yes, please describe:

4.20 How often do you exchange water between the shrimp and seaweed ponds? How many centimeters? Use WATER PUMP or GRAVITY? (circle one)

4.20a If you use water pumps, how often do you run the pumps each day?

4.21 What is the estimated capacity of your pumps? (m^3/hr)

4.22 Where do you discharge the water from the seaweed ponds?

 Fish pond Treatment pond Drainage canal Sea

 No-discharged, (reused water on farm) Other

4.23 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 ____________________________________

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

Reduce 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 ____

4.25 Do you measure the water quality in **seaweed** ponds? No Yes

If yes, how long ago did you start?_ years. Why did you start?________ __________________

If yes, what parameters do you measure? Alkalinity pH

 Temperature Dissolved oxygen Secchi disk transparency Ammonia

 Nitrite Nitrate Chlorophyll Phosphorus Other_____

How often do you measure these parameters? ☐ **Daily** ☐ **Weekly** ☐ **Bi-weekly** ☐ **Monthly** ☐ **Other**

If you don't measure water quality, why?

4.25a Do you measure the water quality in **shrimp** ponds? ☐ No ☐ Yes

If yes, how long ago did you start? Why did you start? ________________________

If yes, what parameters do you measure?

☐ Alkalinity ☐ pH ☐ Temperature ☐ Dissolved oxygen

☐ Secchi disk transparency ☐ Ammonia ☐ Nitrite ☐ Nitrate

☐ Chlorophyll ☐ Phosphorus ☐ Other ______________________________

How often do you measure these parameters? ☐ **Daily** ☐ **Weekly** ☐ **Bi-weekly** ☐ **Monthly** ☐ **Other** **If you don't measure water quality**, why?

4.26 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 ____

4.27 If you test water quality, what is the typical pH in your shrimp ponds?

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

4.27a If you test water quality, what is the typical pH in your seaweed ponds?

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

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

☐ Apply acid ☐ Add organic material

☐ Apply lime ☐ Other _________________

E Parasite and Disease Problems:

5.1 From your experience, what is the trend in disease problems compared to when you started farming? ☐ Increase ☐ Decrease ☐ No change Please explain.

5.2 What types of disease do you find on 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

5.3 From No. 5.2, which treatments were most successful? _______________

F: Other

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

☐ No ☐ Yes

If no, why not?

6.2 Do you have local management meetings with nearby farmers?

☐ No ☐ Yes

6.2a. If yes, how often do you meet? How many people attend?

6.3 Where do you get information on shrimp culture? ☐ Government ☐ Magazine

☐ Neighbors ☐ University ☐ Television ☐ Other ___

6.3a. Whose advice are you most likely to follow when making decisions about your farm

☐ Government ☐ Magazine ☐ Neighbors ☐ University ☐ Television ☐ Other _____

6.3b. Who do you trust the most to give you sound advice about managing your farm

☐ Government ☐ Magazine ☐ Neighbors ☐ University ☐ Television ☐ Other

6.4 What do you like most about integrated shrimp-seaweed farming?

6.4a What do you like least about integrated shrimp-seaweed farming?

6.5 What kind of information do you want for your integrated shrimp-seaweed farming business? ☐ Technical information ☐ Marketing ☐ Other___________________

6.6 Does your government require you to have effluent permit? ☐ Yes ☐ No

6.6a If yes, what qualitative standards are specified for effluents in the permit?

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

☐ Other ________________ ☐ Does not contain qualitative criteria

6.6b 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

6.7 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

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

6.9 Do you have any suggestions?