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River-Based Cage Aquaculture of Tilapia in Northern Thailand: Sustainability of Rearing and Business Practices

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ABSTRACT

Cage-based aquaculture in rivers raises issues of natural resource management more familiar to fisheries management than does aquaculture in fish ponds on private land. Hybrid red and black Nile tilapias (*Oreochromis niloticus* L) are reared for 4 - 5 months in cages in the upper Ping River in northern Thailand. Observed mean stocking density was 49 ± 16 fish·m^{-3}, feed conversion ratio 1.47 ± 0.43 kg feed per kg fish and yield density 26.6 ± 8.1 kg·m^{-3}. Input costs were dominated by feed (70%) and stock (16%). Most farms borrowed money and participated in contracts. Fish farming was usually a component of a portfolio of household activities but for some a core business. To succeed fish farmers must manage a combination of market, climate and environmental-related risks. Cage-based aquaculture in rivers faces many challenges; further research on farm practices and vulnerabilities, river and water management, and the commodity-chain are needed.

Keywords: Aquaculture; Sustainability; River; Climate Risks; Natural Resource Management

1. Introduction

Cage-based aquaculture in rivers and other public water bodies raises issues of natural resource management that are more familiar to fisheries management than does aquaculture in fish ponds on private land [1]. Successful aquaculture depends on site selection, good quality water and the waste removal services of aquatic ecosystems. As practices expand and intensify, concerns about nutrient pollution, impacts on local ecosystems, and competition with other river and water users increase [2,3].

Understanding of rearing and business management practices in river-based cage aquaculture systems is fairly limited. The vast majority of studies of cage culture have been carried out in ponds, lakes or reservoirs. From these studies a few key messages about how fish rearing and business management practices influence sustainability have emerged.

First, pellet feeds can greatly improve yields but are costly so precise management of feeding regimes and high feed quality are critical to improving feed use efficiency and profits [4-6]. Concerns with feed costs have triggered exploration of alternative feed sources and more integrated culture systems but these have mainly been oriented towards water management in closed pond systems on farms [7-10].

Second, stocking density has a variable influence on yields depending on impacts on water quality and feeding efficiencies, and thus ultimately on profits [11-13]. Relationships between stocking densities and profitability can be expected to be even more complex if feeding efficiencies fall or growth rates slow at high densities given high costs of feed and size-specific prices for harvests [14].

Third, as fish farming commercializes additional business management, knowledge and institutional issues arise for farmers [15,16]. Access to credit and technical support, sometimes in form of contractual arrangements, can be important factors in commercial success [17,18]. Markets for inputs and products, availability of credit and technical support, and government regulations on access to public waterways have a major influence on aquaculture practices and the way an industry develops in particular places [19-21].

This paper analyzes an emerging industry based on cage aquaculture in the Upper Ping River in northern Thailand which helps serve the large and growing demand for farmed fish in Chiang Mai town [14,22]. This industry is based primarily on the culture of an improved strain of red Tilapia (*Oreochromis niloticus* L × *O. mossambicus* and others) popular with consumers and known locally as "Tub-tim". The paper addresses two main questions: 1) What are the rearing and business management practices of river-based fish aquaculture farms? 2) What are the main constraints and opportunities to improve the sustainability of the industry?

2. Methods

This study used mixed methods: we iterated between qualitative and quantitative approaches towards data collection and analysis [23]. Qualitative in-depth interviews and observational time in the field were particularly helpful in understanding the social context in which farmer's rearing practices and business strategies operated whereas quantitative methods helped understand variations in key variables and their association with multiple factors as well as prevalence of key problems and behaviors.

2.1. Study Area

Fish farming practices were observed and farmers interviewed in the seven sub-districts bordering a 50 km reach of the Ping River between Pak Bong, Pasang District, Lamphun Province and Sob Tia in Chom Thong District, Chiang Mai Province in northern Thailand (**Figure 1**). In this region the river forms the boundary between Chiang Mai and Lamphun Provinces. The sub-districts were grouped according to their relative position downstream from Chiang Mai town: Pak Bong and Song Khwae (Upper); Doi Lor and Nam Dip (Middle); and Wang Pang, Kuang Pao and Sob Tia (Lower).

2.2. Survey of Farm Practices

We attempted to collect interviews from 286 farms comprising all of the farms known to have been active around mid-2005. Farms were identified based on lists maintained by the Department of Fisheries and supplemented by inquiries to help locate other farmers who had not formally registered. Eleven farms were not included: we could not contact 3; another 7 farms had not yet completed a first harvest; one was excluded because the questionnaire was not properly completed. The analyses here refer, therefore, to the sample of 275 farms for which completed questionnaires were obtained.

All interviews for the quantitative survey were completed between 7 October and 22 November 2005 after a series of pre-tests. Most questions covered the annual cycle of activities and production risks, but detailed in-

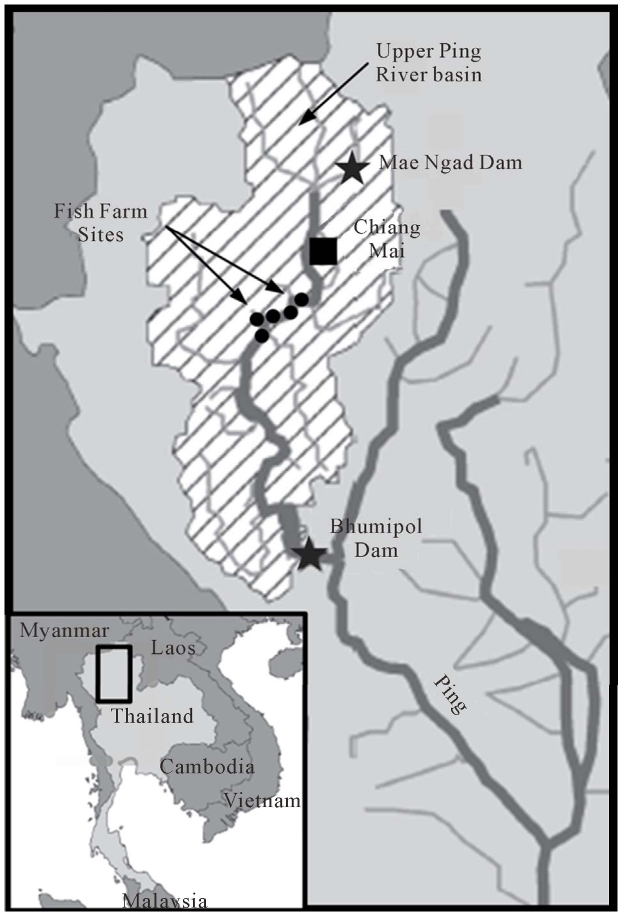


Figure 1. Location of study area in Upper Ping River basin and Southeast Asia (inset).

formation on costs and receipts from sales focused on just the last harvested crop to reduce recall bias as most farmers did not keep detailed records they could simply share. All financial transactions are reported here in the local currency (Thai Baht). Exchange rates during the study period varied between 35 - 39 Thai Baht per US dollar.

Approximately 80% of the harvest reported on occurred between June-October reflecting the main (and most recently finished) cropping season in this river reach. Questionnaires were administered by trained student interviewers and research staff in the field under the guidance of the lead author.

Based on our in-depth interview average interest repayments were around 6% per annum or 3% for a six month crop cycle that includes preparation times. To calculate fixed costs we assumed, based on interviews with farmers, that fish cages and all associated equipment lasted 5 crops. Opportunity cost of unpaid family labor was estimated from a sample-based regression of time spent taking care of fish against number of cages. Generalized linear models were used to explore associations of yield, practices and profitability with multiple candidate predictor variables.

The analysis was organized in three parts. First we explored variation in practices with various contextual factors describing the business context of farm decision-making. Second we analyzed common and unusual features of business management focusing on knowledge sources, loans, and contracts. Third we focused on the outcome of these strategies in terms of profitability, looking more closely at cost structures, selling of harvests, loan and contract arrangements.

2.3. Qualitative Interviews with Farmers and Other Stakeholders

Additional information on rearing practices, business management strategies and how individual households got started in fish farming was obtained through in-depth interviews. Altogether we conducted 82 interviews, each lasting 30 - 60 minutes, with: farmers (n = 40), local government officials including those involved in agriculture extension (n = 12), farmer association leaders (n = 2), department of fisheries staff (n = 4), other government departments (n = 2), bank staff (n = 2), local academics involved in aquaculture, fisheries or farm business management (n = 8), company agents, brokers or input-sellers (n = 10) and retailers (n = 2). Informants were selected purposively to provide a diversity of perspectives on key management and sustainability issues. Most in-depth interviews were done by the lead author during July 2005-June 2007. Qualitative data in the form of fully transcribed scripts of interviews were coded, managed and analyzed using NVIVO software.

2.4. Long-Term Follow-Up

In December 2011, we attempted to contact households which had farmed fish in 2005. Altogether we were able to contact 80. Others had changed phone numbers or did not answer calls. We made some simple checks for possible selection bias by comparing features of farms followed-up (n = 80) versus those not (n = 195). There was no significant difference in education level, age, years of experience, stocking densities, or farm size between followed-up and other farms suggesting the follow-up sample was representative of the 2005 fish farming cohort.

3. Results

3.1. Fish Farmers

Most fish farmers had a modest level of formal education (**Table 1**). Just over a third had received formal training in aquaculture. The industry in the Upper Ping in 2005 was relatively new: farmers had on average only 3.8 years of experience with cage aquaculture and the longest was 6 years. Both men and women were actively engaged in farming fish.

Table 1. Selected features of fish farmers.

Characteristic	% farmers (n = 275)
Education level	
Primary	72.7
Lower Secondary	9.5
Upper Secondary	11.6
Tertiary	5.5
Livelihood apart from fish farming	
Orchards	47
Rice or field crop	22
Small trading business	21
Construction laborer	6
Training in aquaculture (%)	37
Cage aquaculture experience (years)	
1	10.9
2 - 3	32.4
4 - 5	32.7
6	24.0
Age (years)	
<30	3.6
30 - 39	22.5
40 - 49	39.3
50 - 59	27.3
≥60	7.3
Gender	
Female	34.5
Male	65.5

Most (90%) fish farmers had other income sources apart from aquaculture, such as tending orchards, growing rice or field crops, or running a small trading business (**Table 1**). Small (≤4 cages), medium (5 - 12 cages) and large (>12 cages) farms were very similar with respect to all characteristics listed in **Table 1**.

3.2. Rearing Practices

3.2.1. Stocking and Feeding

Fish farms consist of sets of floating open-top cages, usually strapped together in blocks of four. The most common cage sizes used in 2005 were 4 m × 4 m (55%) followed by 3 m × 6 m (23%). Water depth within cages was normally around 2 m. Cages were made from nylon mesh with grid size of 6 - 25 mm depending on size of stocked fry. The last completed production cycle—for which more detailed economic information was collected—on average comprised 61% of the total cages in a farm.

Large farms stocked fish more densely and achieved higher yields per unit volume than small farms (**Table 2**). Survival rates and feed conversion ratios (FCR) were not

Table 2. Rearing practices of different size farms in the Upper Ping River (n = 275). Different letters after means in the same row indicate significant differences according to Tukey's HSD test.

Practice measure	Farm Size (nos. cages)			Average
	Small (1 - 4)	Medium (5 - 12)	Large (13+)	
Stocking density (fish/m^3)	45.6 a	49.6 ab	52.8 b	49.1
Survival rate (%)	94	91	93	92
Feed conversion ratio (kg feed/kg fish)	1.49	1.45	1.53	1.47
Yield (kg/m^3)	25.1 a	26.6 ab	29.0 b	26.6

significantly different across farm sizes.

Farms stocked cages with juvenile fish 30 - 60 mm in length that had been reared in tanks or ponds at hatcheries and nurseries for approximately 3 months prior to release into river cages. Fish fry were either provided by brokers through contract or were purchased independently by farmers. The average length of time juvenile fish were reared in river cages varied slightly with season: warm-wet season only crops (harvested September-November) were significantly shorter than those harvested at other times of year (4.16 vs. 4.90 months, ANOVA, P < 0.01). Fish were usually harvested after they had reached a market standard size of 0.5 kg·per fish.

Average FCR was 1.47 ± 0.43 kg feed per kg fish produced (**Table 2**). Most farmers use two different feed formulations for each crop: smaller pellets for the first month and then a larger pellet formula thereafter. Farmers observed that water conditions affect feeding behavior, for example, in the cool season fish eat less. Farmers adjust feeding rates to compensate and not waste feed.

Farmers rarely hire others for feeding because of concern that feeding will not be done properly. Most hiring was done for just a day to help with harvesting. Many fish farms are run by couples with women often doing a substantial amount of daily feeding and care tasks [16].

Over the previous 12 months prior to the survey hybrid red tilapia were cultured by 94% of farmers and Nile tilapia by 17%. Just over 5% grew other species. For the last crop harvested average feeding intensity was higher for Nile tilapia (1.69) than for red hybrid tilapia (1.44) (ANOVA, P < 0.01); for other measures, there was no significant difference between the two tilapia strains.

Farms increased in size on average by 2.6 cages between 2005 and 2011 (Paired t = 2.1, P < 0.05). Some farms contracted in size. The most significant changes reported by farmers in practices over the six years were decreases in stocking density and increases in use of supplemental feeds, pro-biotics and medication (**Figure 2**). Increases in crop length may have been a management strategy to deal with decreases in observed growth rates.

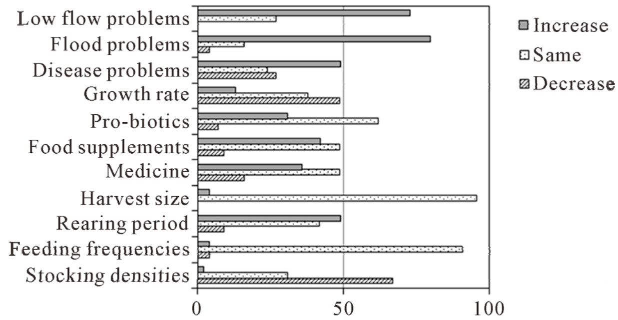


Figure 2. Changes in management practices and problems during past 5 years.

3.2.2. Use of Chemicals and Medication

In 2005, about 62% of the farms used at least one antibiotic. Oxytetracycline was the most common (45%) followed by enrofloxacin (6%) and sulfa-dimethoxine (6%). Antibiotics were primarily used, as expected, to treat disease and infections with common symptoms such as swollen eyes and gills and body lesions noted by respondents. Common fish diseases included those caused by *Streptoccus* and *Flexibacter columnare*. Fish are also infected by *Trichodina* parasites. A 5 - 7 day treatment of oxytetracycline or enrofloxacin was often used when juvenile fish are first added to cages to treat injuries and health problems arising in transport. Vitamin C and multi-vitamin formulations were provided in the first week after fish were released by 79% of farms. Farmers said these helped to make the fish strong and healthy so they would eat and grow well.

Potassium permanganate was used by 13% of farms to treat parasites and disease infections. A variety of other chemicals, including plant and animal extracts, were used rarely.

3.2.3. Managing Water Problems: Floods and Low Flows

Apart from diseases and parasites farmers reported several factors affected fish production. A high proportion of farms had problems with infectious diseases (82%), suspended sediments (74%), and low oxygen levels (75%) during the past year.

High proportions of farms also had problems with low (64%) and high (75%) flows in the last 12 months. Averaged across all farms estimated losses due to low flows in the last year were 8500 Baht. Among those farmers with low-flow related problems most responded by aeration or assisting water circulation (80%) and moving cages towards the mainstream (93%). A few harvested their crops early (12%).

Among those farmers with flood-related problems common kinds of damage and losses were: damage to nets (27%), death of fish (65%) and escapes (22%). Averaged across all farms estimated losses due to high flows or floods were similar to that of low flows of 9640 Baht in the previous 12 months.

Floods, it should be noted, were a recurrent challenge, with most farmers with problems having reported 3 - 5 separate events they had to contend with during the 2005 wet season. According to in-depth interviews floods in 2006, although lower in height, had an even larger impact in key locations when they destroyed a weir in Doi Lor and in the process, the main river channel changed course.

Virtually all farmers (96%) received information or warnings about floods. This information came from several, often multiple, sources and was perceived as helpful (98%). In response to imminent floods farmers moved cages towards banks in slower moving waters (88%) and monitored cages more closely than usual (93%). A few farms took more drastic action: harvesting the crop early (14%) or moving their crop to a pond (8%).

In interviews farmers and other stakeholders emphasized that during floods people in the community helped each other a lot. Farmers also underlined the value of maintaining relationships with local government and agencies like the Department of Fisheries (DOF) suggesting that this was part of their risk management strategy.

Most farms were registered with DOF: 92% in 2005; 98% in 2011. The most common reason (43%) given in 2005 was that officials can be asked for assistance, for example, following flood losses. DOF gives brochures to people who have never reared or are beginning to farm fish. These include suggestions not to rear fish during high flood risk or low flow periods. Officials interviewed from the Department of Fisheries and Local Government would prefer to see less risk-taking because when losses occur farmers turn to them for assistance and compensation.

Respondents in 2011 made similar claims with respect to coverage and sources of early warning. They also reported they paid more attention to water-related news. This implies that since the 2005 major flood warning systems had been well maintained and remained useful in the next major flood which occurred in 2011. At the same time, in 2011, most farmers still reported trends of increasing problems with diseases, floods and low flows (**Figure 2**).

3.2.4. Yields

Variation in yield density was positively associated with stocking density as would be expected: a 10% increase in stocking density implies a 6% increase in yield (**Table 3**). FCR was also significant predictor but had a negative coefficient suggesting current feeding rates were already above optimum once stocking densities were taken into account. Yields were significantly higher in the lower reach and for farmers with many sources of knowledge about rearing. The following other predictors were tested and found not to be significantly associated with yield: aquaculture training, level of formal education, farm size, fish species reared, and wet season cropping time.

Table 3. Estimated coefficients for model of ln (yield density); ANOVA, $F = 72$, $df = 6, 268$; adjusted $r^2 = 0.53$.

Parameter		Coefficient (SE)
Ln (FCR)		−0.225 (0.05)
Ln (Stocking density)		0.640 (0.04)
Reach		
	Upper	−0.100 (0.04)
	Middle	−0.120 (0.04)
	Lower	0
Knowledge sources		
	Few	−0.055 (0.04)
	Several	−0.125 (0.04)
	Many	0

3.3. Business Management

3.3.1. Knowledge Sources

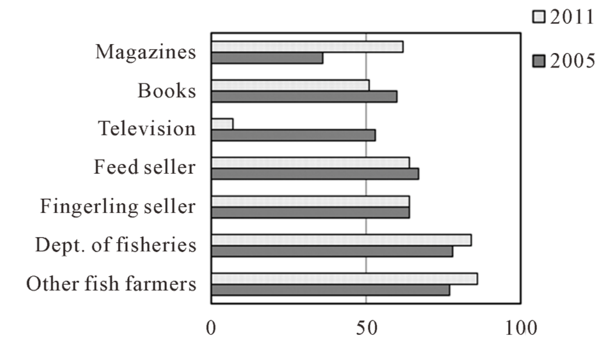
Fish farmers were asked similar sets of questions in 2005 and 2011, about where they obtained knowledge about rearing fish. Other fish farmers and the department of fisheries—already important in 2005—became sources of knowledge for even more farmers in 2011 (**Figure 3(a)**). Sellers of stock and feed remained important. Magazines become a more important source while television declined to be virtually irrelevant. Women and men obtained information from similar sources.

Contracting firms working through their brokers and agents provide feed and fingerlings and are an important source of knowledge to farmers. When getting started in an area companies form farmer working groups, and run trainings and seminars. Support continues after: A CP Manager of several agents told us he shares his mobile number with farmers so people can call him to consult about problems at any time. His agents visit farmers frequently. Brokers and leading farmers emphasized to us the importance of book keeping and market knowledge. Agents train farmers in record-keeping and analysis so they can monitor and forecast their crop's growth and value as well as plan ahead on feed needs.

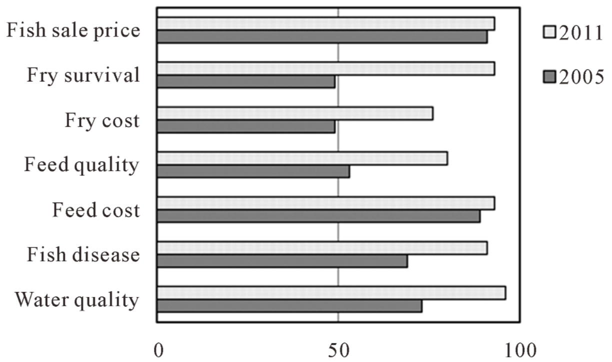
Associations of knowledge-related variables and practices were explored using multiple regression. Fish farmers with training in aquaculture stocked cages at higher rates (52 vs 47 fish·m^{-3}). Farmers who had more years of experience also tended to stock more densely ($b = 1.16$, $F = 4.3$, $P < 0.05$). There were no associations with level of education, number of knowledge sources or age.

3.3.2. Loans

Most farmers (88%) borrowed money from at least one source for their operations. Of those farms taking loans



(a) Knowledge sources



(b) Profit impacts

Figure 3. Changes between 2005 and 2011 in farmers' (a): Sources of knowledge and (b): Perceptions of factors with major impacts on farm profitability.

the Bank of Agricultural Cooperatives (BAAC) was the most common source overall but provided more loans to fish farmers in Chiang Mai (94%) than Lamphun (65%). Loans from the BAAC are made to both individuals and groups of at least 5 people from different households. Group interest rates are nearly half regular commercial rates. Thus the BAAC Office in Chom Tong and Doi Lor had current loans to 6 groups specifically for fish farming and another two for post-harvest processing. In addition more than 200 individuals had taken loans for fish farming activities.

The Village Fund Scheme, the next most important source, was a source for a larger proportion of farmers in Lamphun (39%) than in Chiang Mai (22%). In total the average amount borrowed by farmers in Chiang Mai (131,000 Baht) was more than those in Lamphun (88,000 Baht, ANOVA, $F = 9.84$, $P < 0.01$). Amounts borrowed from the Village Fund are typically smaller than from the Bank. Other rarer sources of loans were relatives (6%) and money lenders (4%). To put these figure in perspective average amounts borrowed represented on average 80% of crop costs (see section below).

From our in-depth interviews in 2006, we were able to extract more detailed information from 25 farms about total loan periods, interest rates and histories of loan and debt cycles. These confirm typical amounts per year, but also underline important year-on-year effects of success and failure on debt burdens and credit cycles, and substantial complexity in combining sources of funds and differing repayment periods. Thus typical annual interest rates in 2004-2005 were around 6% for loans from BAAC, but during 2005-2006 some farmers were facing, for various reasons, effective interest rates of 9% - 12%. Nevertheless, many farms appeared to be successful in making use of BAAC credit for their fish farming operations with some cycling through loans year after year as part of the cash flow management of their farms.

The fraction of fish farmers with loans declined from 88% in 2005 to 60% in 2011. Most continued to obtain loans from BAAC. Village funds and other unofficial sources declined to be of little importance.

3.3.3. Contracts

We heard about two main kinds of business relationships between fish cage farmers and firms with some variations in details of cost-sharing.

When a contracting firm is initially getting established and is recruiting new and often inexperienced partners farmers may be contracted to rear fish for the company. In this contract arrangement farmers do not need to make an initial investment except for cages. All other inputs are supplied by the company and the farmer gets a fixed price per kg (3 - 5 Baht) of the final harvest. We estimate from responses in our quantitative survey that 12% of farmers "reared fish for others" in a relationship of this sort but it was not possible to distinguish if it was with one of the major firms or another grower in our survey data.

The other, more common, contracting arrangement involves farmers putting a down-payment per fish in return for credit on feed and the promise that the crop would be sold back to the firm. The arrangements of the most active broker are illustrative. The initial down-payment of 10 Baht/fish is known locally as "insurance". Prices at harvest are not usually fixed but allowed to vary with current market. The firm pays within 7 days of harvest subtracting costs of advanced feed and fish minus the initial down-payment per fish. On occasions down-payments are temporarily returned to farmers so they can clear old BAAC loans and get a new one. Contracts can be ended and outstanding deposits will be returned. Reputation is crucial to success for a small broker firm.

Another smaller contracting firm placed a strong emphasis on their farmers using the fish fry that come from high quality CP stock. They told us they could tell whether fish were likely to be the CP-strain by their body shape. Fry are normally paid for in cash but feed (from CP) is provided on credit that must be repaid at the next round of purchases (crop) with amounts of up to 40 - 50 bags being advanced (equivalent to 10,000 - 15,000 Baht).

Although several firms told us they often make written contracts these are never used. We probed the sensitive question about selling the harvest outside contracts for higher prices with several farmers. Most farmers said remaining loyal to the contract was important on principle, for future business and because they were in debt. In practice farmers do sell a small amount of product, for example, that which is undersize, to other buyers. Some farmers split their set of cages among different contracting firms so they could compare quality of inputs, juvenile fish, yields, harvest services, and prices.

Most farmers we spoke to were satisfied with their contract relationships. Several academics and government officials we interviewed, in contrast, were critical claiming that brokers and larger firms were making it hard for farmers, by paying lower-than-real market price, over-charging on inputs, and levying hidden fees at harvest times. Farmers who have discontinued fish farming are less enthusiastic about contracts and the pressures of having to repay loans.

In 2005, several types of arrangements could be documented but the proportion of farmers under contract could not be estimated precisely because of ambiguities in our survey. In 2011, 71% had contracts with firms to grow fish. In 2005, certification was not yet in place. In 2011, two-thirds (69%) had received Good Agricultural Practice (GAP) certification.

3.3.4. Markets

Farmers enter into contracts, in part, because independent access to marketing channels is not straightforward. Well established brokers, especially those with extensive contract farming arrangements, claim they are able to pay higher prices to farmers because they also have long-term reliable resell points in the main markets.

In our survey red hybrid tilapia above the industry standard of 0.5 $kg \cdot fish^{-1}$ were sold by farmers for 44 $Baht \cdot kg^{-1}$ during the second half of 2005, whereas smaller sizes sold for 35 $Baht \cdot kg^{-1}$. Prices paid for black Nile tilapia were more variable and lower, averaging 40 $Baht \cdot kg^{-1}$ for standard size and 33.5 $Baht \cdot kg^{-1}$ for smaller fish.

The consumer market for hybrid red tilapia in the Chiang Mai area was estimated by informants in 2005 as typically being between 7 - 10 tonnes of fish per day with most being sold at fresh markets [22]. Consumer demand and prices rise during public festivals. In event of shortfalls fish are imported from other areas like Uttaradit or further south. Major retail outlets make advanced purchase plans and contracts with suppliers every 1 to 2 weeks and adjust retail prices accordingly. Live fish (kept in aerated tanks) in the market place fetched a higher price creating an incentive for supplying live fish.

3.3.5. Costs and Profits

Total variable and fixed costs per volume averaged 1062 (±301 SD) $Baht \cdot m^{-3}$. The average crop, or simultaneously harvested set of cages, cost 146,000 Baht. Feed dominated costs, followed by fish stock and unpaid family labor (**Figure 4**). Cost structures did not vary with farm size but total investments did: large farms spent more (1241) than either medium-size (1078) or small farms (1004) (ANOVA, df = 2, 272, F = 9.1, $P < 0.001$). Farms in the lower reach (1217) spent more than those in middle (1042) or upper reach (1065) (ANOVA, df = 2, 272, F = 6.5, $P < 0.01$).

Feed was bought in 20kg bags. Feed costs on average 20.3 $Baht \cdot kg^{-1}$. At the time of the survey 3 brands were in common use. The brands differed significantly in average price ranging from 19.7 - 21.5 Baht/kg. Pellets for young fish were slightly more expensive than for older fish.

Gross profit per unit volume (including opportunity costs and interest repayments) averaged 72 ± 262 (x ± SD) $Baht \cdot m^{-3}$. The high spread underlines that not everyone makes a profit on each crop: a third of the farms made a loss at their last crop in 2005. The average profit per crop was only 13,241 Baht. Mean relative return on investment ((receipts-costs)/costs) was 9 ± 24 percent per crop or a period of about 6 months if allowing for some repair and cleaning time between crops.

Profitability measured by unit volume and as return on investment are highly correlated ($r = 0.93$). We chose to explore relationships with profitability per unit volume.

Two profitability models were constructed the first including yield and the second stocking density which are highly correlated variables both strongly associated with profitability (**Table 4**). Profitability was then regressed against an additional set of candidate predictors.

No differences were found for reach, education, gender, experience in aquaculture, loans, and other income sources and these factors were dropped from final models (**Table 4**). The results for both models were similar. Survival rate was positively, and FCR inversely, associated with profitability. Rearing red tilapia was more profitable than Nile tilapia. Small farmers had higher profit densities than medium or large farms. Farmers whose last crop fell in the wet season earned more than those whose did not despite problems with floods.

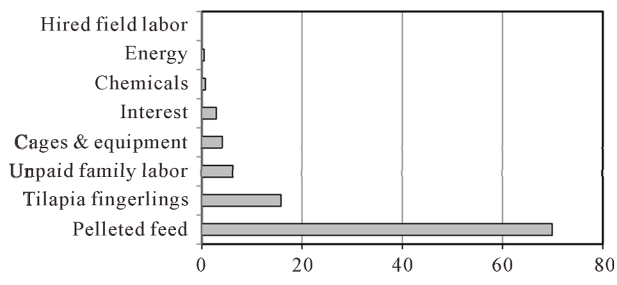


Figure 4. Average cost structure of a fish crop.

Table 4. Estimated coefficients (SE) for model of profit density (Baht/m^3).

Parameter	Model Yield	Model Stocking Density
Yield density	8.02 (1.2)***	-
Stocking density	-	2.44 (0.69)***
FCR	−402 (22)***	−434 (23)***
Survival rate	133 (37)***	245 (43)***
Fish species (Red Tilapia)	90.0 (28)***	67.8 (29)***
Farm size	**	*
Small	97.6 (29)	80.3 (31)
Medium	57.5 (28)	43.7 (27)
Large	0	0
Wet season crop	35.7 (18)*	34.7 (19)^{a}
Aquaculture training	−41.8 (18)*	−40.2 (20)*
Intercept	189 (78)***	258 (91)***
Adjusted r^2	0.68	0.64

$^{***}P < 0.001$, $^{**}P < 0.01$, $^{*}P < 0.05$, $^{a}P = 0.07$.

After taking all the above variables into account, one unusual association pattern remained: those with formal aquaculture training had slightly lower profits than those who did not have such training.

Fish farmers were asked identical questions in 2005 and 2011 about important factors impacting farm profitability. Overall farmers appear to have become more aware of or sensitive to various environmental and market factors (**Figure 3(b)**). In particular farmers' have become much more concerned about feed quality, fingerling cost and survival than they were before. For some other factors like feed price and fish sale price concerns were already high in 2005.

3.3.6. Exit Reasons

Of the 80 households which had farmed fish in 2005, just under half (n = 35) had exited by 2011. Fish farmers offered multiple and many different reasons for stopping. Financial reasons were common in particular suffering economic losses (18) and lack of capital (14). Natural resource constraints were also common, but diverse including: lack of good sites (15), floods (5) and disease (5) and low flows (2). Labor-related issues formed a third category of less common and also diverse reasons such as no time (6), no labor (4), too old (4), poor health or death (3) and finding a better job (3).

Of those who had stopped 63% had no intention of ever resuming, but 9% expected to within the next 2 years and the rest were unsure if they would or not. Ex-fish farmers noted that their main occupation post fish-farming led to reduced income in 77% of cases and to an increase in only 20%. The main occupations followed after leaving fish farming were: orchards (37%), trading (20%), and own small business (20%). Rarer occupations were becoming laborers (9%), rice farmers (6%) or being employed by a company (3%).

Next we compared households that continued to farm fish with those who had stopped. Using binary logistic regression the following variables were not associated with exiting from fish farming: species reared, completed high-school level education, received formal training in aquaculture, farm size, more than 4 years of experience, or having more than 4 knowledge sources.

3.4. Environmental and Social Sustainability

Much of the evidence above is relevant to a consideration of economic sustainability. In-depth interviews with stakeholders directly involved in the industry, other river users and local government officials with area-based management responsibilities suggest there are also a few environmental and social sustainability issues.

First and foremost are concerns that high densities of cages in confined reaches could result in excessive nutrient pollution and possibly other effects from chemical and medication use. Most stakeholders interviewed, including those not engaged in fish farming, believe that fish farming in rivers at current levels is a benign activity; accumulated nutrient inputs are quickly diluted and dispersed. The impacts from fish farming on water quality are believed to be less than from other agricultural activities such as pig farms or run-off from industry. Fish farmers were more concerned with risks to their operations than from them. Localized impacts on water quality are usually during low flow periods in the dry season and these impacts are primarily on fish farms themselves.

Second are concerns with impacts on native fish and local capture fisheries. In this area these are primarily recreational or very small scale supplementary activities. There is some suggestion that presence of cages improves local catches, perhaps by attracting fish, but also because there are some escapees from cages. Impacts on wild fish populations have not been studied in Thailand, but have been detected in other countries, for example, as spread of pathogens from salmon culture [24]. One academic active in river conservation argued that, in any case, it is better to manage the river for wild fish stock than aquaculture.

Third is the issue of access to and use of public waterways and water resources. Major waterways are public spaces and subject to laws to safeguard navigation. Fish farming has largely unfolded with modest monitoring, weak regulation and non-transparent system about where and who can farm fish. Dissatisfaction over access was expressed by a few stakeholders. Conflicts between fishers and boat users appear to be rare. Conflicts over allocation of water to irrigation or other users were not prominent. Theft, labor disputes and other social issues specific to presence of aquaculture appeared to be minor.

4. Discussion

4.1. Economic Sustainability

Cage farming of tilapia in the Upper Ping River can be profitable but it requires good management of costly feed inputs, environmental risks like floods, low water quality and disease which can cause mass mortality and business relationships that affect access to credit and markets.

Farm-level profitability for hybrid red Tilapia is known to be sensitive to feed costs, market prices, yields and survival rates [14]. In this study feed variation in feed costs within brands and size-formulations was low. Variation in market prices within species and size categories was low for red hybrid tilapia but higher for Nile tilapia. As expected yields or stocking densities, survival rate, and FCR were strongly associated with profitability. Those whose last crop was in the wet season, despite many having flood-related losses, had slightly higher profits.

Larger farms stocked more intensively and achieved higher yields than small farms, but achieved lower profit densities than small farms. A common expectation is that small farms would be at a disadvantage in commercialized settings. Studies in other countries have sometimes found that small-scale operations are less economically viable than large farms, for example, because of difficulties in accessing credit [18]. In the Thai case studied here even small farmers had reasonable access to credit as they could apply from BAAC as a group.

The average stocking densities we observed here are similar to those used in experimental work with cages in ponds previously in Thailand where fish are grown to relatively large size [25] but lower than highly intense systems that produce smaller fish at harvest in other countries [12]. Food intensities or food conversion ratios were similar to previous work reported in Thailand for cages suspended in ponds [25,26] and for intense systems of cages in a reservoir in Brazil [12] but often lower than those observed in other countries for cages in ponds, lakes or reservoirs [4,11,13]. Survival rates also vary among studies but several have observed relatively high rates as seen in this study for fish during their period being stocked in cages [11,12,25].

The high observed fraction of feed-related costs is typical of intensive production systems of tilapia [13,14,20]. As observed in this study feed and stocking rates are typically good predictors of yield although whether further increases in feed are sensible or not depends on intensity of existing systems given high costs of feed [5,27,28]. Dependence on pelleted feeds means the competitiveness of farmers is affected by differences in feed prices. Farms in mid-reaches of our study site where concentration of farms is highest were able to buy feed slightly cheaper; there was no advantaged detected, however, for larger farms as might be expected. In interviews academics and other experts often mentioned the potential benefits of farmers learning how to make their own feed. Such a strategy would be most plausible for groups with special or otherwise good access to cheap source of inputs to make feed.

4.2. Dynamic Livelihood Portfolios

Fish farming is usually a component of a household’s portfolio of activities rather than a sole enterprise [9]: as such it may contribute to household resilience, especially if weather events or market conditions which impact on orchards and field crops are distinct from those affecting fish production. The ability to integrate cage fish farming into the daily and seasonal chores related to maintaining orchards or crop farms is important, especially for smaller farms. The time demands may also be a constraint on fine-tuning fish farm management and mobility, especially of women who frequently have feeding and caretaker roles [15,16,29].

Very few previous studies have looked closely at either entry or exit into fish farming. Our follow-up study suggests some aspects of farmer behavior are changing as the fish cage aquaculture industry matures. Farmers appear to be paying more attention to environmental and market factors that pose risks to profitability of their operations. More recognize, for example, the importance of feed and fingerling quality. Among households continuing to farm fish there was evidence of reductions in stocking densities that suggest improved risk management practices. Two major floods in 2005 and 2011 have heightened awareness of the importance of climate related risks.

This study also showed there were substantial dynamics in participation: almost half of the households followed-up had given up fish farming during the six year period of follow-up. Financial reasons were important for exiting, but so were a set of problems related to natural resources: there was a common perception that floods, low flows and disease were becoming more serious problems.

4.3. Climate, Environmental and Economic Risks

Risk-taking behavior with respect to the seasonal monsoon-driven changes in water level and quality is both a market and a governance issue. Low flows and poor water quality in the dry season are important but less spectacular risks than the high levels associated with floods. The prospect of good prices in periods of high risk and demand act as an incentive for farmers to take greater chances with timing of their crops.

Evidence for the 2005 season showed that floods can significantly reduce profits of farms in vulnerable locations. The flood peaks on 14 August and 30 September, 2005, triggered by a tropical depression associated with Typhoon Damrey, it should be noted were the highest in the 1921-2007 flood history records and considered to recur once in a hundred year [30]. At the same time, the 2011 follow-up findings suggest floods are not a dominant reason in themselves for leaving fish farming. Floods appear to be very important, but manageable risks. Exactly how floods and other climate-related risks—such as low flows at the end of the dry season—are assessed and managed by fish farmers deserve further study in the northern region of Thailand.

What is also apparent from this study is that farmers need to manage various water-related risks alongside market and financial risks. Changes in prices and quality of inputs as well as sale prices are major concerns. Interest rates were not mentioned much by farmers but it is clear that proper management of credit is also an important business management task.

Fish farming in the Upper Ping River is maturing as a sector, at least in the sense of standardization. Farmers are more likely to be in contract farming arrangements, less likely to have loans from informal or special sources, and more are certified and registered. Farmers now rely more on each other and what are likely to be technically more reliable and up-to-date sources of knowledge. They are also using more advanced inputs such as food supplements and medication.

4.4. Limitations

This study adopted a mixture of methods. The cross-sectional study helped document variation in practices and prevalence of various production problems; the follow-up cohort study provided evidence about changes in behavior of individuals and reasons for exit. The use of in-depth interviews and event-based observations during major floods in 2005 and 2011, complemented more quantitative calculations of technical and economic performance revealing information about incentives, perceptions and relationships of farmers that are valuable to efforts to improve both farm and water management.

The emphasis on interview-based evidence also has some limitations. The most important for this study were probably errors in recall in responses to questions about stocking densities, yields, prices and receipts that reduced precision. The timing of our surveys, soon after major flood events, had advantages and disadvantages. On the one hand it gave us an opportunity to consider the impacts of major climate events; on the other hand, it may limit the generalizability of some of the findings to other years and locations within Northern Thailand. Further studies in low flow years and other locations are needed to fully understand the set of risks fish cage farmers in rivers face.

5. Conclusions

This is one of the first studies to provide detailed information on farming and business practices of cage culture in rivers. Aquaculture in ponds, reservoirs and rivers differs in key ways that are important to water management under changing conditions. First, despite similarities in key inputs such as feed and stock, flows in rivers imply that diseases, waste effluents and other contaminants generated within aquaculture systems will easily be transported and shared downstream. Second, rivers are a public good important for navigation, recreation and aesthetic uses which may not always be true for water bodies on private land such as farm ponds or small dams. Third, rivers funnel pollutants accumulated through runoff along the banks and further inland in the catchment creating many risks to aquaculture.

These key differences represent both constraints and opportunities for improving the economic, social and environmental sustainability of the river-based cage culture industry. The connectivity between farms means many of the disease, flow and climate-related risks are shared by farmers working in the same river reach. This should stimulate shared concerns and incentives for collective action in support of more sustainable practices. The presence of other river users sets an upper limit on cage densities in particular locations as free passage of boats must be maintained. This helps reduce the incentive to over-stock particular reaches. Management of water for other users, such as irrigation, flood control or hydropower is another significant constraint on expansion that varies spatially depending to proximity to water infrastructure. The high costs of feed and relatively low FCR observed as well as patterns to reducing stocking densities all point towards more sustainable practices. The increased problems with disease and use of medication, however, suggest some key challenges persist. The sensitivity of aquaculture to pollution from within the watershed or river can be seen as a positive pressure for sustainability. If good water quality is maintained aquaculture can continue; if not, it may become impossible.

These latter two pressures are incentives for active engagement of fish farmers in integrated water resources and river basin management activities. Regulation of reach-level cage or stocking density that takes into account seasonally variable discharge volumes may be needed to complement various self-organizing drivers which encourage sustainability at levels above individual farm.

Pressures to expand cage-based aquaculture in rivers around the world are likely to increase, but as shown in this paper, many challenges still exist. Succeed fish farmers must manage a combination of market, climate and environment-related risks. Further research is needed to identify ways in which farms and rivers may be better managed to support sustainable aquaculture.

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