Environmental Impacts of Cage Culture for Catfish in Hongngu, Vietnam

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Final Report

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Abstract

This study was conducted in cage aquaculture villages in Hongngu District, Dong Thap Province of Vietnam during November 2001 to November 2002. Cage culture areas are located in the confluence of So Thuong Canal and one branch of the Mekong River. The purposes of this study were to investigate the cage culture system and its related environmental conditions, to determine the quality and quantity of pollutants produced by cages, to detect the fate of pollutants in the river, and to recommend methods for pollution mitigation in cage culture.

Ninety-five cage farmers were randomly selected for interviews, using a survey to investigate socioeconomic characteristics of farmers, cage culture practices, investment cost and return, problems, and other information. These farmers managed 156 cages out of a total of 204 cages in the study area. The survey consisted of a structured checklist and open-ended questions. The cage culture area was divided into three equal sections (upstream, middle stream, and downstream) in both the So Thuong Canal and the Mekong River. Nine cages—one from each section of the So Thuong Canal and two from each section of the Mekong River—were randomly selected from each section for measurement of water quality and determination of nutrients in fish, feed, and sediments.

The socioeconomic survey showed that the major species cultured in cages are Pangasius spp. catfish in either monoculture or polyculture with P. hypothalamus, P. bocourti, P. conchophilus, or red tail barb (Barbodes altus). Almost all farmers used homemade feed prepared with locally available ingredients, and the homemade feed accounted for about 98% of the total feed input. More than 50% of farmers produced negative net economic returns, and most cage farmers listed lack of capital, unstable costs, and unstable fish prices as the top three constraints for cage culture.

Water quality measurements in the present study showed that there were no significant differences in all water quality parameters among cages in different locations (upstream, middle stream, and downstream), between cage water and open water, or between the water in front of and downstream from the cage culture areas. Waste loadings from cage culture do not appear to have significant impact on fish production and water quality.

Introduction

Cage culture is commonly practiced worldwide in both freshwater and marine environments, including open ocean, estuaries, lakes, reservoirs, ponds, and rivers (Beveridge, 1987). In southeast Asia, cage culture plays an increasingly important role in fish production, which involves many small-scale farmers in Vietnam, Cambodia, Indonesia, and Thailand (Liao and Lin, 2000). However, the environmental impact of cage culture is often ignored and rarely subjected to study.

Cage culture of Pangasius spp. catfish originated many years ago in Cambodia and has spread widely to other Indochinese countries. The best known areas for intensive catfish production from cage culture are in An Giang and Dong Thap Provinces (Andriesz, 2000), where annual production in 2000 was 42,000 and 20,000 tons by 3,000 and 2,000 cages, respectively (Anon., 2000). Total fish production has increased five fold between 1995 and 2000. Most catfish cages are concentrated along the banks of the Mekong River near Chau Doc and Hongngu Districts, which are also the major suppliers of fingerlings for

Table 1. Study areas and distribution of interviewed farmers and cages in Hongngu district of Dongthap province in Vietnam.

River/ Canal	Villages	Number of Interviewed Farmers	Types of Cages					Total Number of Cages	
			Nursery		*Grow-out*				
			Small (< 200 m³)	Medium (200-300 m³)	Small (< 200 m³)	Medium (200-300 m³)	Large (> 300 m³)		
SOTHUONG CANAL	Tanhoi	8	0	1	6	2	4	13	49
	Thuonglac	12	1	0	6	2	7	16	
	Hongngu	18	0	0	8	4	8	20	
MEKONG RIVER	Thuongthoitien	5	0	0	4	1	2	7	107
	Longkhanh A	1	0	0	3	0	0	3	
	Longkhanh B	7	1	0	8	1	4	14	
	Anbinh	2	0	0	2	0	4	6	
	Longthuan	42	20	3	29	9	16	77	
TOTAL	8	95	22	4	66	19	45		156
			26		130				

Table 2. Cages selected for field measurements.

Location	RelativePosition	Geographic Position	Cage Number	Dimensions
So Thuong Canal	Up stream	10°49.892N 105°20.329E	1	18x8x5.5 m
	Middle stream	10°49.380N 105°20.386E	2	16x7x5 m
	Down stream	10°48.735N 105°20.332E	3	18x9x5 m
Mekong River	Up stream	10°48.778N 105°19.752E	4A	14x6x5.5 m
		10°48.778N 105°19.752E	4B	14x6x5.5 m
	Middle stream	10°48.538N 105°19.954E	5A	8x5x4 m
		10°48.538N 105°19.954E	5B	8x4x4 m
	Down stream	10°47.776N 105°20.174E	6A	10x4x3.5 m
		10°47.776N 105°20.174E	6B	8x4x3.5 m

cage stocking. The main species being cultured are P. bocourti and P. hypothalamus along with minor species like Chana micropelpte and Puntius gonionotus.

Cage cultured fish are entirely dependent on formulated diets (Phuong, 1998), and the waste produced from this consumption is released directly into the river. This results in cage culture contributing nutrients, organic matter, and turbidity that may cause deterioration of water quality and biota downstream (Pillay, 1992). The quantity of wastes discharged from a fish cage depends on quantity and quality of feed inputs (Cho et al., 1991). With relatively low protein and high carbohydrate diets, nutrient loading from culture of Pangasius spp. is likely to be much lower than for salmonid culture in cages. However, waste in the form of organic matter, particulate matter and suspended solids may result in sediment accumulation and biochemical oxygen demand near the site of cage culture systems. As a result of rapid expansion of cage culture in Chau Doc and Hongngu Districts, water quality is reported to have deteriorated so much that fish disease outbreaks have occurred during the dry season when the river is low and water flow sluggish. While research has been done on seed propagation and diet formulation, little effort has been expended on mitigation of environmental impacts and improvement of water quality to ensure sustainability of cage culture.

The purposes of this study were to:

1. Investigate the cage culture system and its related environmental conditions;
2. Determine the quality and quantity of pollutants produced by cages;
3. Detect the fate of pollutants in the river; and
4. Recommend methods for pollution mitigation in cage culture.

METHODS AND MATERIALS

This study was conducted in villages from the Hongngu District, Dongthap Province of Vietnam during November 2001 to November 2002. The cage culture areas are located in the confluence of So Thuong Canal and one branch of the Mekong River. Cages were distributed on both sides of the So Thuong Canal and the southern side of the Mekong River. The cage culture areas cover 5,252 m in the So Thuong Canal and 2,530 m in the Mekong River. This study consisted of a socioeconomic survey and field measurements.

The socioeconomic survey was conducted using a structured checklist and open-ended questions in three villages along the So Thuong Canal and five villages along the Mekong River. The questionnaire examined socioeconomic characteristics of farmers, cage culture practices, investment cost and return, problems, and other information. Ninety-five cage farmers, including 38 along the So Thuong Canal and 57 along the Mekong River, were randomly selected for interviews in the survey, which covered 156 out of 204 cages in the study area. Among the 156 cages, 49 were in the So Thuong Canal and 107 in the Mekong River. These included 26 nursery cages and 130 grow-out cages— the proportion of nursery to grow-out cages (Table 1). In addition to surveys, relevant environmental regulations were reviewed and governmental agencies interviewed for the information about regulations, enforcement, and farmers' attitudes.

Field measurements were conducted monthly from November 2001 through November 2002. The cage culture areas in both the So Thuong Canal and the Mekong River were divided into three equal sections: upstream, middle stream, and downstream. Two cages were randomly selected from each section in the Mekong River and one cage from each section in the So Thuong Canal (Table 2). Seasonal patterns of hydrological features such as water currents in both open river water and inside the cages were measured monthly. Composite water samples were taken monthly in the morning at three depths (surface, middle, and bottom of the cages) from incoming water, inside water, and outgoing water of each study cage on each sampling date. One additional water sample was taken at 200 m downstream of the cage culture area in both the Mekong River and the So Thuong Canal. The water samples were analyzed for total suspended solids (TSS), organic suspended solids (OSS), inorganic suspended solids (ISS), total Kjeldahl nitrogen (TKN), total nitrogen (TN), total ammonia nitrogen (TAN), nitrate-nitrogen (nitrate-N), nitrite-nitrogen (nitrite-N), soluble reactive phosphorus (SRP), and total phosphorus (TP) following standard methods (APHA, 1985; Egna et al., 1987). Dissolved Oxygen (DO), pH, and temperature were measured at three depths just prior to taking water samples. Sediment samples were taken bimonthly 20 m downstream of each selected cage, and fish and feed samples were collected from the owners of these cages for analyses of moisture, organic matter, TN, andTP (Yoshida et al., 1976). Mass balance equations were determined for inputs and accumulations in animals, and the resulting loss of materials to the water column were estimated.

MS Excel® was used to store all survey data and to generate tabular and graphical outputs for different types of data. A simple cost-benefit analysis was conducted to compare economic returns of different cage culture practices (Shang, 1990).

Field measurements were analyzed statistically by repeated measurement ANOVA (Steele and Torrie, 1980) using SPSS (version 10.0) statistical software package (SPSS Inc., Chicago, Illinois).

Table 3. Percent of cage farmers of different gender, age and educational backgrounds.

Items	Type of Farmer		Total
	Nursery	*Grow-out*	
GENDER AND GGE (N = 95)			
Man			
20-29 years old	2.11	0	2.11
30-39 years old	4.21	18.95	23.16
40-49 years old	9.47	25.26	34.74
50-59 years old	8.42	15.79	24.21
>60 year old	1.05	5.26	6.31
Subtotal	25.26	65.26	90.53
Woman			
20-29 years old	0	0	0
30-39 years old	1.05	3.16	4.21
40-49 years old	1.05	1.05	2.11
50-59 years old	0	2.11	2.11
>60 years old	0	1.05	1.05
Subtotal	2.1	7.37	9.47
Total	27.37	72.63	100
EDUCATION BACKGROUND (N = 87)			
Primary School	11.49	21.84	33.33
Secondary School	8.05	24.14	32.19
High School	10.34	20.69	31.03
College/Vocational School	0	3.45	3.45
Total	29.88	70.12	100

Table 4. Percent of cage farmers in current and former employment categories.

Items	Type of Farmer		Total
	Nursery	*Grow-out*	
CURRENT SUBSIDIARY OCCUPATION (N = 60)			
Rice Farmer	11.67	43.33	55.00
Businessperson	5.00	13.33	18.33
Hired Laborer	3.33	3.33	6.66
Rice Processing Worker	0	5.00	5.00
Tailor	3.33	0	3.33
Worker	0	3.33	3.33
Government Officer	0	1.67	1.67
Livestock Breeder	1.67	0	1.67
Sawing Factory Worker	0	1.67	1.67
Bull-Dozer Driver	0	1.67	1.67
Wood Seller	0	1.67	1.67
Total	25.00	75.00	100
FORMER MAIN OCCUPATION (N = 91)			
Rice Farmer	9.89	20.88	30.77
Pond Aquaculturist	8.79	16.48	25.27
Businessperson	4.40	18.68	23.08
Government Officer	1.10	4.39	5.49
Sawing Factory Worker	1.10	3.30	4.40
Rice Processing Worker	0	3.30	3.30
Goods Transporter	0	3.30	3.30
Hired Laborer	2.19	1.10	3.29
Fish Sauce Processing Worker	0	1.10	1.10
Total	27.47	72.53	100

Differences were considered significant at an alpha level of 0.05. All means were given with ± 1 standard error (SE).

RESULTS

Socioeconomic Survey

Farmers' Backgrounds

All cages were operated and managed by farmers (owners). The age and gender of farm owners had a bearing on the decision-making process. Men dominated in the cage culture industry, comprising 90.53% compared to 9.47% for women (Table 3). Among the interviewed farmers, ages between 40 to 49 years old were most common (Table 3). Educational background of the owners was poor with only 3.45% of the owners trained at college and vocational schools (Table 3). Among the interviewed farmers, about 38% of nursery farmers had run farms for one to five years, 38% for six to ten years, 12% for 11 to 15 years, and 12% for more than 16 years. In comparison, about 36% of grow-out cage farmers had run farms for one to five years, 36% for six to ten years, 22% for 11 to 15 years, and only 6% for more than 16 years.

Cage culture was the main occupation of cage owners, and all respondents were working part-time in this field, so they also had a subsidiary occupation. About half (55%) were also working in paddy fields and 18% were involved in business (Table 4). Before starting cage culture, about 31% of cage owners were rice farmers, followed by pond aquaculture farmers (25%) and businessmen (23%) (Table 4).

About 35% of the interviewed nursery cage farmers hired permanent workers with an average of 1.4 workers per household, and none of them hired casual workers. Grow-out cage farmers hired both permanent workers (61%) and causal workers (13%). The average number of workers hired by the grow-out farmers was 2.3 permanent workers and 5.7 casual workers per household (Table 5).

Table 5. Employment provided by cage farmers (N = 95).

Items	Type of Farmer	
	Nursery	*Grow-out*
PERCENTAGE OF FARMER HIRING WORKERS (%)		
Permanent Workers	34.62	60.87
Casual Workers	0	13.44
Total	34.62	74.31
MEAN NUMBER OF WORKERS HIRED BY CAGE CULTURE FARMERS (WORKERS / HOUSEHOLD)		
Permanent Workers	1.4±0.2	2.3±0.3
Casual Workers	0	5.7±1.6

Cage Construction and Dimensions

Most cages were topped with wooden houses, thus the cages were also home for the cage farmers. Most cages were constructed using hardwoods with high water resistance, making them strong enough to withstand the constant pressure of water current. Cages could last from 20 to 30 to even 50 years. All cages were rectangular in shape except very small square cages, which had no homes on them.

Cages were categorized as small, medium, and large (Table 6). Small cages had volumes less than 200 m^3, medium cages were 200 to 300 m^3, and large cages were more than 300 m^3. The average dimensions of the small, medium, and large cages were 8.4 × 4.2 × 3.5 m, 11.1 × 5.2 × 4.5 m, and 14.4 × 7.0 × 5.1 m, respectively. Fingerlings were mostly nursed in small and sometimes medium cages but not in large cages (Table 6). Grow-out was practiced in all three sizes of cages (Table 6).

Table 6. Information on cage sizes (N = 95). Mean (±SE) and ranges (in parentheses).

Items	Type of Farmer		Total
	Nursery	*Grow-out*	
PERCENTAGES BY SIZE OF CAGE (%)			
Small	14.10	42.31	56.41
Medium	2.56	12.18	14.74
Large	0.0	28.85	28.85
Total	16.66	83.34	100
MEAN SIZE OF CAGE (M^3 / CAGE)			
Small	109 ± 7.4	137 ± 9.0	—
	(45-180)	(38-200)	—
Medium	252 ± 14.3	255 ± 8.1	—
	(225-292)	(210-300)	—
Large	—	523 ± 38.3	—
	—	(302-1,077)	
MEAN NUMBER OF CAGES PER HOUSEHOLD			
Small	1.6 ± 0.2	1.4 ± 0.1	—
Medium	1.8 ± 0.3	1.6 ± 0.3	—
Large	—	1.8 ± 0.2	—

The mean number of cages was 1.6 small and 1.8 medium cages per household for nursery farmers and 1.4, 1.6, and 1.8 cages of small, medium, and large size, respectively, for grow-out farmers (Table 6).

Table 7. Fish species cultured in cages and sources of seed (N = 95).

Species	Percent of Farmers	Source of Seed	
		Wild Seed (%)	*Hatchery Seed* (%)
P. hypothalamus	57.1	15.0	85.0
P. bocourti	6.5	0	100
Barbodes altus	18.2	16.0	84.0
P. conchophilus	18.2	48.3	51.7

Production Systems

Among the interviewed farmers, most farmers (57.1%) cultured P. hypothalamus in cages, followed by red tail barb (Barbodes altus) and P. conchophilus (18.2% each), and P. bocourti (6.5%) (Table 7). All seed of P. bocourti came from hatcheries, while most seed for P. hypothalamus and B. altus also came from hatcheries, but only half of P. conchophilus seed was from hatcheries (Table 7).

Cage culture operated year round especially with more artificially propagated seed from hatcheries. Although fish could be stocked any time of year, there were two main periods of fish stocking—November to December and April to June. Cage

Table 8. Culture systems in grow-out cages (N = 69).

Cage size	Culture System	Fish Species	Percent	Culture Duration (mons/crop)
SMALL	Monoculture	*P. hypothalamus*	20.29	8.6±1.1 (3-13)
		B. altus	2.90	
	Polyculture	*P. bocourti + P. conchophilus + B. altus*	1.45	
		P. hypothalamus+P.conchophilus+ B. altus	1.45	
		P. hypothalamus+ B. altus	2.90	
		P. hypothalamus+P.conchophilus	4.35	
		P. conchophilus+ B. altus	4.35	
MEDIUM	Monoculture	*P. hypothalamus*	13.04	10.7±1.4 (6-13)
		P. conchophilus	1.45	
	Polyculture	*P. bocourti+ P. conchophilus*	1.45	
		P. bocourti+ P. conchophilus+ B. altus	1.45	
		P. bocourti+ P. hypothalamus+P. conchophilus+ B. altus	1.45	
		P. hypothalamus + B. altus	1.45	
LARGE	Monoculture	*P. hypothalamus*	13.04	10.0±0.7 (6-14)
		P. bocourti	2.90	
	Polyculture	*P. bocourti + P. conchophilus + B. altus*	10.14	
		P. bocourti + B. altus	1.45	
		P. hypothalamus + P. conchophilus + B. altus	1.45	
		P. hypothalamus + P. conchophilus	8.70	
		P. hypothalamus + B. altus	1.45	
		P. conchophilus + B. altus	2.90	
TOTAL			100	

Table 9. Fish stocking, harvest and production in grow-out cages (N = 67).

Culture System	Cage Size	Fish Species	Stocking Size (g/fish)	Stocking Density (fish/m^3)	Harvest Size (g/fish)	Production (kg·m^{-3}·crop^{-1})	Production (kg·m^{-3}·year^{-1})
MONOCULTURE	Small	*P. hypothalmus*	91 ± 15.0	143 ± 26.5	1,064 ± 44.0	90 ± 8.9	152 ± 15.0
		B. altus	12 ± 0.0	922 ± 357.1	67 ± 33.0	27 ± 0.0	45 ± 0.0
	Medium	*P. hypothalmus*	133 ± 31.0	106 ± 7.8	1,094 ± 50.0	118 ± 21.2	135 ± 24.2
		P. conchophilus	100 ± 0.0	33 ± 0.0	700 ± 0.0	19 ± 0.0	22 ± 0.0
	Large	*P. hypothalmus*	126 ± 27.0	87 ± 7.7	1,050 ± 49.0	95 ± 21.9	115 ± 26.6
		P. bocourti	93 ± 8.0	55 ± 11.3	1,400 ± 100.0	59 ± 34.6	72 ± 41.9
POLYCULTURE	Small	*P. hypothalmus*	80 ± 17.0	238 ± 36.9	978 ± 96.8	89 ± 6.9	150 ± 11.6
		P. bocourti	166 ± 0.0		1,200 ± 0.0		
		B. altus	25 ± 5.4		179 ± 12.6		
		P. conchophilus	141 ± 21.5		700 ± 70.7		
	Medium	*P. hypothalmus*	28 ± 5.5	157 ± 29.1	1,350 ± 50.0	103 ± 16.1	118 ± 18.4
		P. bocourti	108 ± 50.7		1,400 ± 100.0		
		B. altus	35 ± 10.1		197 ± 31.2		
		P. conchophilus	107 ± 51.5		900 ± 100.0		
	Large	*P. hypothalmus*	83 ± 0.0	123 ± 23.9	1,178 ± 101.0	93 ± 8.1	113 ± 9.9
		P. bocourti	122 ± 21.5		1,629 ± 128.5		
		B. altus	40 ± 3.4		212 ± 14.5		
		P. conchophilus	122 ± 16.4		780 ± 31.3		

farmers sought the best time to harvest their fish to maximize economic benefits.

Before stocking into grow-out cages, fry were nursed for one to five months depending on fish species, while grow-out lasted for 3 to 14 months, varying with different culture practices (Table 8). Fish nursery was normally done in monoculture cages, while grow-out was practiced in both monoculture and polyculture cages. About 46% of the interviewed cage farmers cultured P. hypothalamus in monoculture, while only 7% monocultured the other three species (Table 8). The remaining 46% polycultured with species in different combinations. Grow-out farmers stocked nursed fingerlings of Pangasius spp. catfish (28 to 141 g in size) and B. altus (12 to 40 g in size) in cages at densities varying from 33 to 238 fish m^{-3} for both monoculture and polyculture (Table 9). Except for the monoculture of B. altus, stocking densities in small cages were higher than those in medium and large cages. Average size of Pangasius catfish at harvest ranged from 700 to 1,629 g, while B. altus had smaller average sizes at harvest (67 to 221 g) (Table 9).

Table 10. Composition of feed and feeding practices (N = 91).

Item	Culture Stage		
	Nursery	*Grow-out 1* (< 500 g)	*Grow-out 2* (> 500 g)
FEED INGREDIENTS FOR HOME-MADE FEED (%)			
Trash Fish	45.37	34.41	33.47
Rice Bran	54.26	65.19	64.66
Vegetables	0.37	0.40	1.87
FEED TYPES (%)			
Home-made	98.50	97.26	
Pelleted	1.50	2.38	
FEEDING RATE (%)	11 ± 0	5.3 ± 0.6	4.8 ± 0.7
FEEDING FREQUENCY (times/day)	4.4 ± 0	2.7 ± 0.1	2.7 ± 0.2

Table 11. Average net returns and percent of cages with negative and positive net returns based on simple cost-benefit analysis (N = 82).

Farmer Types	Cage Sizes	Culture Systems	Negative Net Return		Positive Net Return		N
			Amount (US$/cage)	*Percent*	*Amount* (US$/cage)	*Percent*	
NURSERY	*Small*	Monoculture	-4,432 ± 2,142	71	1,665 ± 762	29	21
	Medium	Monoculture	-5,856 ± 3,070	67	1,216 ± 0.0	33	3
GROW-OUT	*Small*	Polyculture	-5,734 ± 3,375	50	1,121 ± 509	50	10
		Monoculture	-4,855 ± 2,677	56	2,304 ± 1,026	44	16
	Medium	Polyculture	-150 ± 0.0	25	3,157 ± 1,1764	75	4
		Monoculture	-7,242 ± 2,965	30	7,469 ± 3,606	70	10
	Large	Polyculture	-7,357 ± 2,751	87.5	10,012 ± 1,811	12.5	8
		Monoculture	-11,223 ± 3,029	30	11,677 ± 4,674	70	10

Table 12. Constraints faced by cage culture farmers.

Constraints	Nursery Farmers (%, N=26)	Grow-out Farmers (%, N =69)
Lack of Capital	23.92	29.94
Unstable Market	21.75	31.21
Unstable Fish Price	15.22	15.92
Disease	13.04	7.64
Lack of Culture Techniques	6.52	7.64
High Fish Mortality	6.52	0.64
Low Water Quality	6.52	4.46
High Cage Density in Rivers	2.17	1.27
Low Seed Quality	2.17	0
High Feed Price	2.17	0.64
High Interest Rate on Loans	0	0.64
Total	100	100

Feed and Feeding

Almost all farmers used homemade moist feed that they prepared for cage culture. The homemade feeds were prepared using locally available agro- and/or fishery by-products such as rice bran and trash fish (the main ingredients of homemade feeds). Feed formulation varied with different cultured species, fish size, and seasonal supply of ingredients. The average percentages of rice bran and trash fish were 54 and 45% during nursery stage, 65 and 34% during grow-out stage 1 (< 500 g), and 65 and 33% during grow-out stage 2 (> 500 g), respectively (Table 10). Pelleted feed only accounted for 1.5 and 2% of total feed input during nursery and grow-out stages, respectively (Table 10). Average feed conversion ratio for homemade feed was 4.09 ± 0.43, ranging from 3 to 6.

Cost-Benefit Analysis

The overall average net return from cage culture varied with cage size and culture system (Table 11). Overall, about 55% of cages lost money and 45% generated profit. Most nursery farmers lost money, and only about one third produced positive net returns, with average net returns ranging from minus US$5,856 ± 3,070 to US$1,665 ± 762 (Table 11). About half of the small grow-out cages of both polyculture and monoculture produced negative net returns, while more than two-thirds of medium grow-out cages of both polyculture and monoculture produced positive net returns (Table 11). For large grow-out cages, most polyculture cages (87.5%) resulted in negative net returns, while 70% of monoculture cages resulted in positive net returns (Table 11).

Constraints Faced by Cage Farmers

Most cage farmers listed lack of capital, unstable market, and

Table 13. Values of water quality parameters for incoming water, cage water and outgoing water of cages in upstream, middle and downstream areas, and also 200 m downstream from the cage culture areas.

Parameters	Upstream			Middle Stream			Downstream			200 m from the Last Cage (open river)
	Incoming	*Cage*	*Outgoing*	*Incoming*	*Cage*	*Outgoing*	*Incoming*	*Cage*	*Outgoing*	
pH	6.8±0.1	6.9±0.1	6.9±0.1	6.8±0.1	6.8±0.1	6.8±0.1	6.9±0.1	6.9±0.1	6.9±0.1	6.9±0.1
Temp. at 0.5 m (C)	26.4±0.4	26.5±0.4	26.5±0.4	26.8±0.4	26.7±0.3	26.7±0.3	26.9±0.3	26.8±0.3	26.9±0.3	26.6±0.8
Temp. at 2.5 m (C)	26.4±0.4	26.5±0.4	26.5±0.4	26.8±0.3	26.5±0.4	26.8±0.3	26.9±0.3	26.9±0.3	26.9±0.3	26.7±0.6
Temp. at 5.5 m (C)	26.4±0.4	26.5±0.4	26.5±0.4	26.8±0.3	26.8±0.3	26.8±0.3	26.9±0.3	26.9±0.3	26.9±0.3	26.7±0.6
DO at 0.5m (mg/L)	6.7±0.2	6.2±0.2	6.2±0.2	6.3±0.2	6.1±0.1	6.1±0.2	6.3±0.2	6.2±0.1	6.3±0.1	6.9±0.3
DO at 2.5 m (mg/L)	6.3±0.2	5.9±0.2	6.0±0.2	6.1±0.1	5.9±0.1	5.7±0.2	6.0±0.2	5.8±0.2	5.9±0.2	6.7±0.3
DO at 5.5 m (mg/L)	6.2±0.2	5.7±0.2	5.9±0.2	5.9±0.2	5.5±0.2	5.6±0.1	5.8±0.2	5.5±0.2	5.7±0.2	6.3±0.3
Secchi Disk Depth (cm)	33.3±4.7	32.0±4.6	35.2±4.9	34.3±4.1	30.8±3.6	35.6±4.8	33.0±3.7	30.9±3.5	33.6±3.8	42.3±9.5
TSS (mg/L)	79.1±18.1	87.2±23.7	88.0±22.3	121.3±27.3	125.8±27.3	130.2±27.9	88.4±16.7	86.0±16.8	92.1±18.00	81.9±31.1
ISS (mg/L)	61.1±16.2	63.0±16.5	71.2±20.1	98.7±24.1	99.7±24.2	101.5±24.4	61.9±13.8	64.2±13.7	64.6±14.3	60.6±23.9
OSS (mg/L)	18.0±2.3	24.2±9.4	16.8±2.7	22.6±3.5	26.2±4.1	28.7±4.8	26.5±4.3	21.8±4.1	27.5±5.6	21.2±8.6
Percentage of OSS (%)	42.3±5.0	36.6±4.3	39.0±5.5	39.8±4.6	39.7±4.6	39.4±4.0	48.9±4.6	39.2±3.5	45.9±3.9	46.4±6.8
TAN (mg/L)	0.17±0.02	0.19±0.02	0.17±0.01	0.16±0.01	0.17±0.01	0.21±0.03	0.16±0.01	0.16±0.01	0.17±0.01	0.27±0.11
Nitrite-N (mg/l)	0.02±0.00	0.02±0.00	0.02±0.00	0.02±0.00	0.02±0.00	0.02±0.00	0.02±0.00	0.02±0.00	0.02±0.00	0.02±0.00
Nitrate- N (mg/l)	0.88±0.13	0.90±0.13	0.95±0.13	0.97±0.11	0.96±0.12	0.97±0.11	1.09±0.12	1.00±0.10	1.05±0.12	1.13±0.22
TKN (mg/L)	1.17±0.17	1.11±0.18	1.22±0.23	1.15±0.16	1.26±0.20	1.33±0.33	1.24±0.19	1.30±0.20	1.14±0.18	0.99±0.19
TN (mg/L)	2.07±0.20	2.03±0.24	2.19±0.29	2.14±0.17	2.23±0.21	2.32±0.32	2.34±0.19	2.31±0.19	2.20±0.17	2.13±0.28
SRP (mg/L)	0.09±0.01	0.08±0.01	0.08±0.01	0.09±0.01	0.09±0.01	0.09±0.01	0.09±0.01	0.11±0.02	0.10±0.01	0.09±0.01
TP (mg/L)	1.10±0.25	1.20±0.29	1.33±0.33	1.39±0.31	1.50±0.33	1.39±0.27	1.57±0.26	1.49±0.24	1.70±0.27	1.60±0.56

unstable fish prices as the top three constraints to cage culture (Table 12). Among constraints faced by cage farmers, capital and market issues surpassed technical issues for both nursery and grow-out farmers. The same three constraints were the main ones faced by both nursery and grow-out farmers—lack of capital, unstable market prices, and unstable fish prices. Both nursery and grow-out farmers were satisfied with widely used homemade feeds. Only 2.17% of nursery farmers and 0.64% of grow-out farmers indicated that high feed prices were constraints; moreover, none of the cage farmers complained about quality of the homemade feeds (Table 12). Only a few farmers complained about low quality of fish seed, which was probably due to wide availability of artificial seed.

Environmental Awareness

Local government officials at provincial and district levels have been aware of the importance of environmental regulations and enforcement and also showed positive attitudes to environmentally related studies. However, there are no existing regulations or documentation on environmental issues related to cage aquaculture either in rivers or in lakes and reservoirs. Generally, cage farmers have little environmental awareness. In 2002, the Aquaculture Research Institute No. 2 (RIA2), following suggestions from the Department of Science and Technology, Ministry of Fisheries of Vietnam, drafted "Standards for Aquaculture: Cage Culture of Basa Catfish (P. bocourti), Sutchi Catfish (P. hypothalamus) – Conditions for Food Safety" (Anon., 2002). This document outlined basic conditions to secure food safety on cage culture in rivers. However, this document dealt only with requirements for cage culture such as site selection, water quality, and environment but not important issues on environmental impacts such as number of cages and waste loading.

Field Measurements

Water Quality Parameters

Mean values of water quality parameters at different sections of the cage culture area are summarized in Table 13. There were no significant differences in water quality parameters in cage water at upstream, middle stream, and downstream locations throughout the 13-month study period ($P > 0.05$, Table 13). Also, all water quality parameters in the incoming water in front of the cage culture areas were not significantly different from those in the water 200 m downstream from the cage culture areas throughout the study period (P > 0.05, Table 13). Values of all water quality parameters are within the normally required ranges for fish aquaculture.

DO concentrations measured in the morning ranged from 5.5 to 6.9 mg l^{-1} at three depths. Vertical variation of DO was observed but not significant, and DO concentrations were generally higher in the incoming water than in cage water and outgoing water at all three depths (Table 13). DO concentrations in cage water fluctuated between 4 to 8 mg l^{-1} over the study period, and the lowest DO concentrations were recorded in upstream cages in November 2002 (Figure 1). pH in cage water, ranging from 6.3 to 7.4, fluctuated in a similar pattern at all locations and decreased dramatically at the beginning of rainy season (May to October) (Figure 2a). pH reached the lowest level at the middle of rainy season, then increased to the original level at the end of rainy season (Figure 2a).

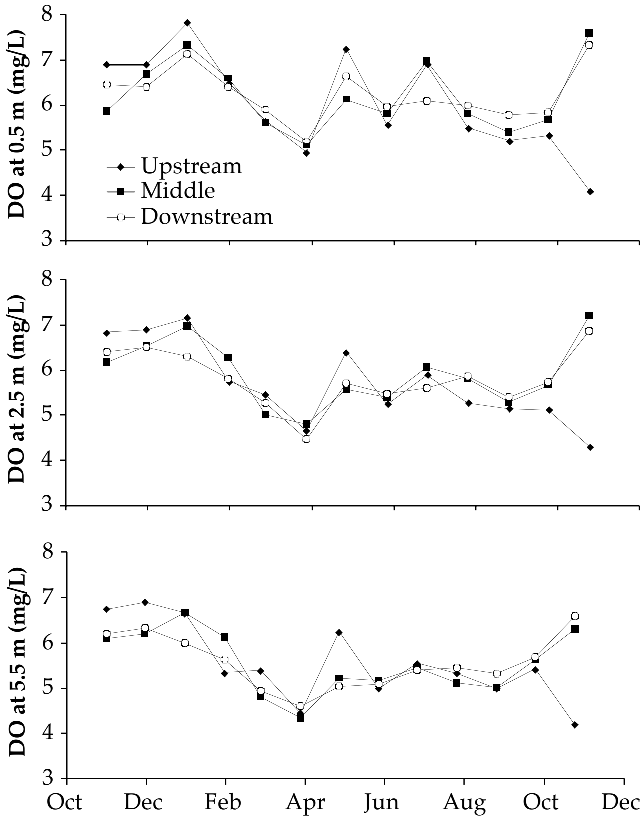

Figure 1. DO concentrations measured at 0.5, 2.5 and 5.5 m dep in cages located at upstream, middle and downstream sections of the cage culture area in Hongngu district, Dong Thap province.

Secchi disk depth in cage water was lower than in open water due probably to addition of feed and resultant waste material (Table 13). Secchi disk depth in cage water increased throughout dry season (November to April), decreased dramatically from about 70 to 10 cm at the beginning of rainy season, and remained stabile throughout the rainy season (Figure 2b). Concentrations of suspended solids (TSS, ISS, and OSS) in cage water were at low levels during the dry season, increased at the beginning of rainy season, peaked in the middle of rainy season, and decreased to original levels at the beginning of

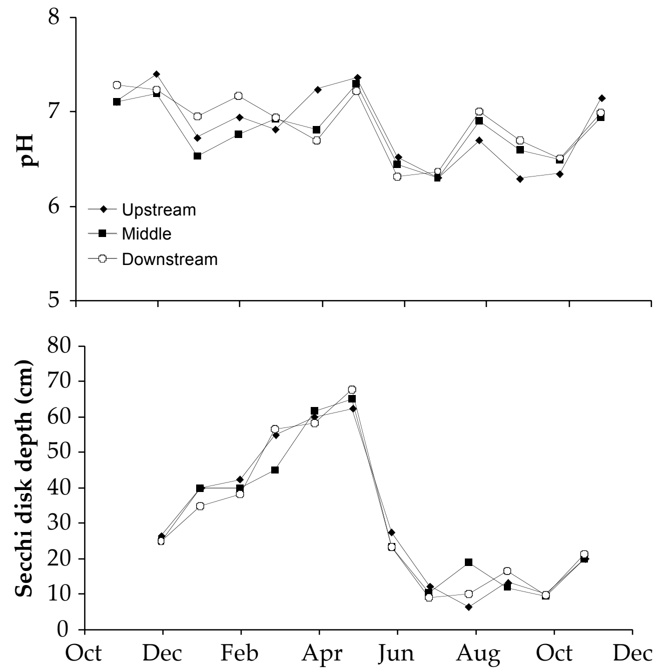

Figure 2. pH and Secchi disk depth in cages located at upstream, middle and downstream sections of the cage culture area.

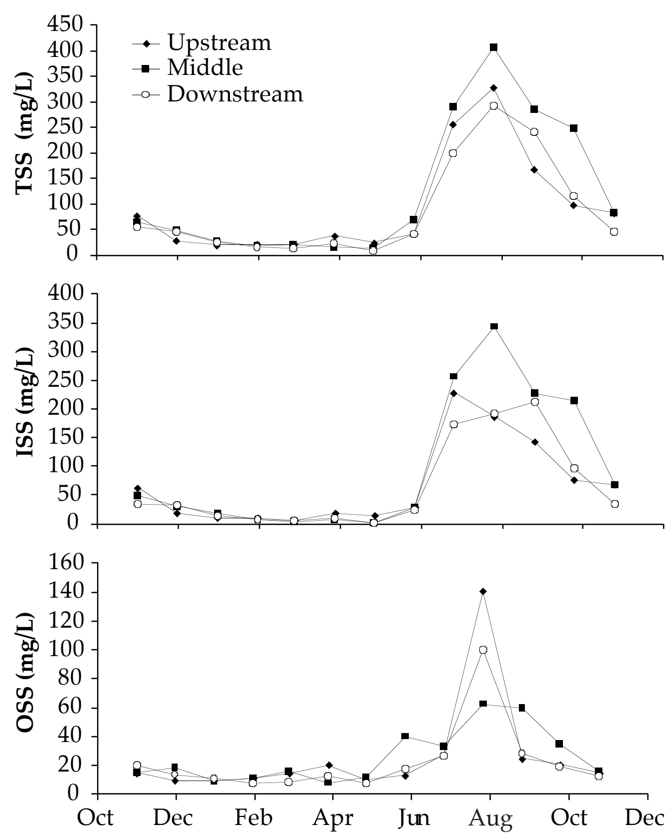

Figure 3. Concentrations of TSS, ISS and OSS in cages located at upstream, middle and downstream sections of the cage culture area.

next dry season (Figure 3). Percentage of OSS ranged from 36.6 to 48.9%, suggesting that organic particulates derived from feeding and vegetation materials with flooding contribute significantly to TSS (Table 13).

TAN concentrations, ranging from 0.16 to 0.27 mg l^{-1}, were similar in incoming water, cage water, and outgoing water (Table 13). TAN concentrations in cage water fluctuated in a similar pattern among the cages at upstream, middle stream, and downstream sections throughout the study period (Figure 4a). TAN values peaked at the end of dry season, decreased dramatically to the lowest level at the beginning of rainy season, then peaked again in the middle of rainy season (Figure 4a). Nitrite-N concentrations fluctuated without a clear trend throughout the study period (Figure 4b). Nitrate-N concentrations showed a clear seasonal pattern—low in the dry season and high in the rainy season (Figure 4c). TKN and TN fluctuated within narrow ranges during most of the study period except at the beginning and middle of rainy season when both concentrations peaked (Figure 5). SRP concentrations remained at low levels throughout the study period (Table 13; Figure 6a). TP concentrations showed an increasing trend downstream in the cage culture area (Table 13). TP concentrations in cage water remained quite stable but at low levels throughout the late rainy season and entire dry season but peaked early in the rainy season (Figure 6).

Current velocity in the open water was 0.338 ± 0.0681 m s^{-1}, and cage frames slowed down the current with an average current velocity of 0.072 ± 0.0128 m s^{-1} in front of cages, 0.010 ± 0.0030 m s^{-1} inside cages, and 0.037 ± 0.0066 m s^{-1} behind cages.

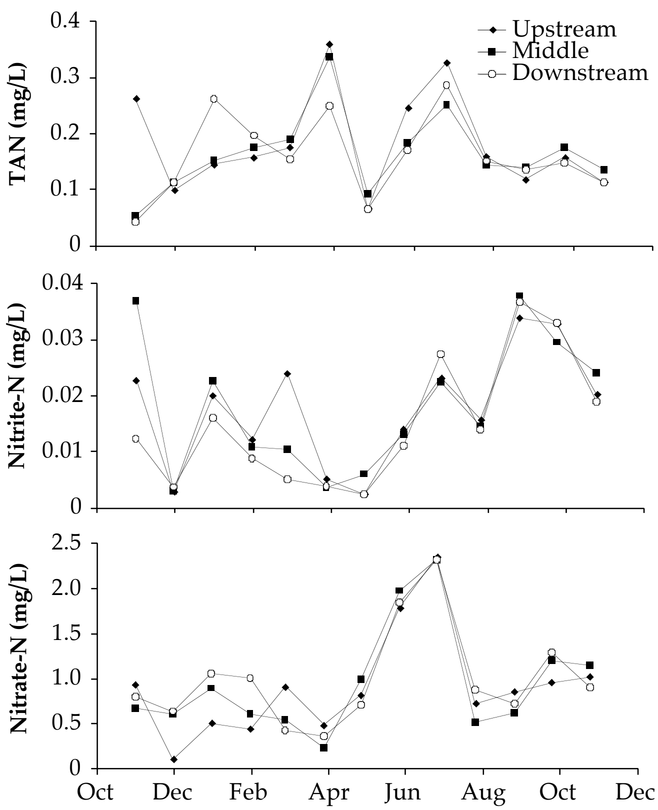

Figure 4. Concentrations of TAN, nitrite-N and nitrate-N in cages located at upstream, middle and downstream sections of the cage culture area.

Current velocity was quite stable near cages, and it increased significantly in open water during the rainy season compared to the dry season (Figure 7). Discharge of the Mekong River was estimated to be 2,362 $m^3 s^{-1}$ in the dry season and 60,697 $m^3 s^{-1}$ in the rainy season.

<u>Sediment Characteristics</u>
The composition of sediments taken 20 m away from cages in upstream, middle stream, and downstream sections and also

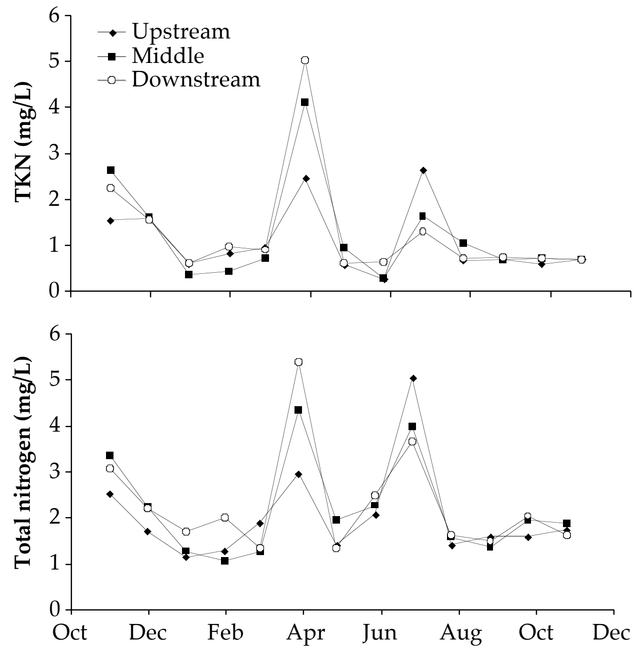

Figure 5. Concentrations of TKN and TN in cages located at upstream, middle and downstream sections of the cage culture area.

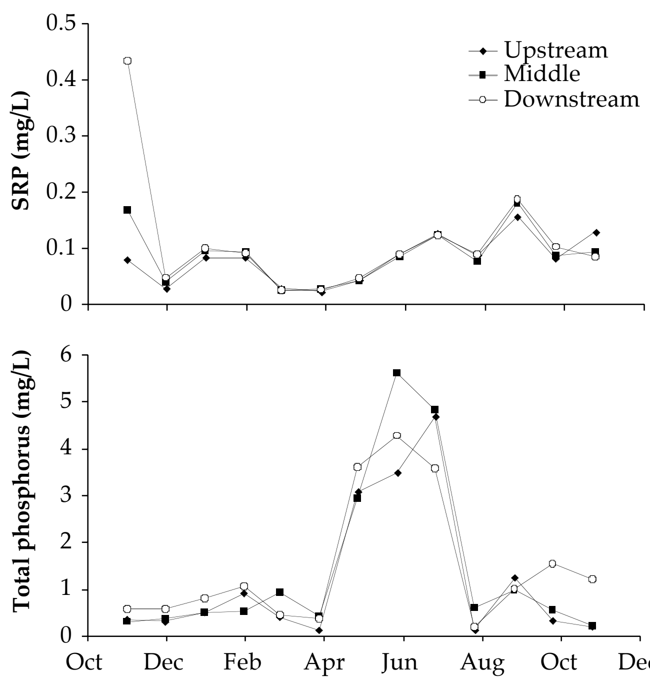

Figure 6. Concentrations of SRP and TP in cages located at upstream, middle and downstream sections of the cage culture area.

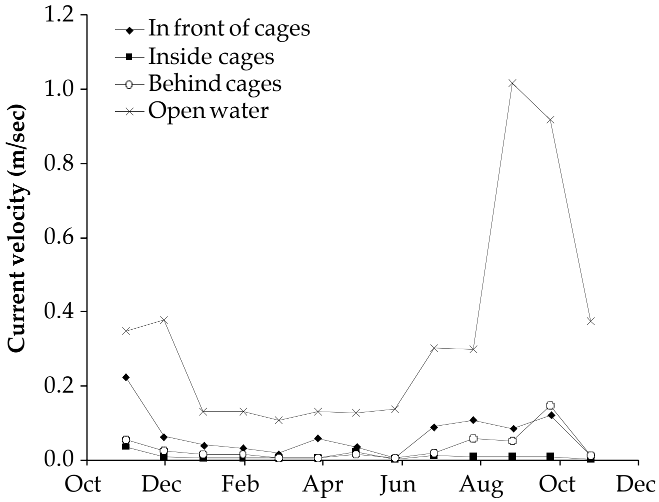

Figure 7. Current velocity in front of, in and behind cages, as well as in open water in the cage culture area.

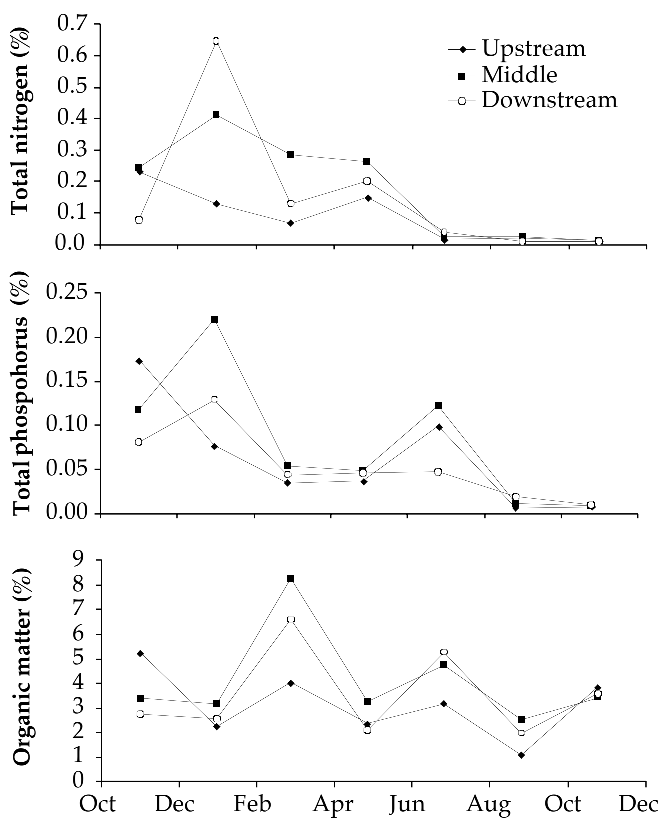

Figure 8. Concentrations of TN, TP and organic matter measured 20 m away from cages located at upstream, middle and downstream sections of the cage culture area.

200 m downstream from the cage culture areas are summarized in Table 14. TP and organic matter did not show significant differences among locations ($P > 0.05$). However, TN content of sediment from downstream cages was significantly higher than that from upstream and middle stream cages and also from 200 m downstream of the cage culture area ($P < 0.05$). These latter values had no significant differences among them ($P > 0.05$; Table 14). TN and TP in sediment were high in the dry season and low in the rainy season, while organic matter content fluctuated throughout the study period with a peak in the dry season (Figure 8).

Waste Loading

Proximate compositions of fish carcasses and feeds are summarized in Table 14. For the total 204 cages in the study area, annual inputs of TN, TP, and organic matter from feed were 416, 88, and 10,706 t yr^{-1}, respectively (Table 15). This included 121 t yr^{-1} N, 13 t yr^{-1} P, and 1,976 t yr^{-1} organic matter incorporated into fish biomass (Table 15). Thus, the annual amount of waste produced by cage culture was 295 t yr^{-1} N, 75 t yr^{-1} P, and 8,730 t yr^{-1} organic matter. On an annual basis, the estimated mean concentrations of N, P, and organic matter added by cage culture were 2.08, 0.53, and 61.76 mg m^{-3}, respectively, in whole water of the Mekong River. Based on the difference between outgoing and incoming water of cages, mean cage dimensions, and mean water flow rate, annual amount of suspended solids released from cages was 10,978 t yr^{-1}, giving a mean concentration of 77.62 mg m^{-3} added to water of the Mekong River (Table 15).

DISCUSSION

Cage culture has a long history in the Mekong Delta, and culture technologies are well known. Until 1996, most seeds of Pangasius spp. catfish were collected from the wild (Phuong, 1996). However, with successful artificial breeding programs, artificially propagated seeds of *P. hypothalamus* and *P. bocourti* are available from local hatcheries year round (Table 7). Successful artificial breeding has provided the potential for further development of cage culture in the area. However, cage culture in the Mekong Delta has become a large-scale commercial production sector of high investment depending on the complicated interaction among biotechnological, socioeconomic, and environmental factors. The development of cage culture for Pangasius spp. catfish in southern Vietnam has fluctuated for decades with the political and economic changes in Vietnam, in the region, and in the world.

Economic analyses in the present study showed that more than 50% of grow-out cages produced negative net returns (Table 11) during 2001 and 2002, which is similar to the situation in 1996 (Phuong, 1998). This is due largely to the reduced export of Pangasius spp. catfish to the USA and thus the drop in selling price. For that reason most cage farmers listed lack of capital, unstable market, and unstable fish price as the top three constraints for cage culture (Table 12).

Pelleted feed has been promoted for cage culture for some years, but the adoption of it has been slow. Pelleted feed only accounted for about 2% of the total feed input in the present study, and the percentage was similar to the 1% reported seven years ago by Phuong (1996). Homemade feeds, prepared by farmers themselves using locally available low-cost ingredients, have many disadvantages such as low and unbalanced nutritional values as well as unstable quality and supply of ingredients. These may cause slow fish growth, high fat deposition in visceral areas of fish, and other problems. A comparison between homemade feed and pelleted feed showed that cost of homemade feed for producing one kg of fish may be higher than that of pelleted feeds. Moreover, use of pelleted feed could not only increase economic returns but also reduce

Table 14. Compositions of dry matter (DM), nitrogen, phosphorus and organic matter (DM bases) in feed, fish carcasses and sediments. Mean values with different superscript letters in the same column within each session were significantly different (P < 0.05).

Parameter	Nitrogen (%)	Phosphorus (%)	Organic Matter (%)	Dry Matter (%)
FEED				
Home-made feed	3.5±0.3	0.8±0.1	88.3±1.1	43.1±1.8
Pellet feed	3.3±0.0	0.2±0.0	91.5±0.0	92.7±0.0
FISH				
P. hypothalamus	6.0±0.1	0.7±0.3	92.1±2.3	30.7±1.0
P. hypothalamus (juvenile)	5.6±0.4	0.7±0.1	89.0±1.8	31.8±3.1
P. conchophilus	5.2±0.0	0.4±0.0	95.6±0.0	26.0±0.0
B. altus	5.2±0.0	0.5±0.2	92.9±0.4	40.6±1.9
P. bocourti	5.7±0.7	0.5±0.0	95.4±0.8	46.5±0.3
P. bocourti (juvenile)	5.7±0.4	0.8±0.1	89.8±0.9	28.4±1.7
SEDIMENT				
Upstream Cages	$0.08±0.02^a$	0.06±0.02	3.23±0.47	62.87±2.38
Middle Stream Cages	$0.16±0.05^a$	0.07±0.02	4.02±0.51	56.12±2.60
Downstream Cages	$0.41±0.07^b$	0.05±0.01	3.56±0.56	60.76±2.04
200 m Downstream	$0.10±0.04^a$	0.03±0.01	3.08±0.75	60.63±1.71

Table 15. Estimated mass balance for all 204 cages in Hongngu district, Dong Thap Province of Vietnam.

Items	Total Nitrogen	Total Phosphorus	Organic Matter	Suspended Solids
Total Inputs from Feed (t/year)	416	88	10,706	—
Total Outputs in Fish (t/year)	121	13	1,976	—
Total Wastes Released (t/year)	295	75	8,730	10,978
Mean Concentrations in Whole River Water (mg/m^3)	2.08	0.53	61.72	77.62

the pressure of catching trash fish from nature, reduce nutrients, organic matter, and solid wastes released into rivers, and reduce other wastes such as ash and fuel produced during preparation of homemade feeds. Adoption of pelleted feed will take considerable promotion and extension effort.

Water quality measurements in the present study showed that there were no significant differences in water quality parameters among cages in different locations (upstream, middle stream, and downstream), between cage water and open water, and between the water in front of and downstream of the cage culture areas. This is due mainly to dilution effects of the Mekong River and the resulting large water exchange for cages. Waste loadings from cage feeding were significant in the present study. If the total number of cages in the Mekong Delta is estimated at about 4,000 (Phuong, 1998), waste loading would increase 20 fold compared to the estimate in Table 15. Such a loading would include 5,784 t N, 1,470 t P, 171,176 t organic matter, and 215,255 t suspended solids annually. This would result in the addition of 41 mg N m^{-3}, 10 mg P m^{-3}, 1,210 mg organic matter m^{-3}, and 1,522 mg suspended solids m^{-3} to the river water.

The flow of water through enclosures is affected by drag forces exerted by the framework and netting, thus cage structures have a considerable impact on local currents (Wee, 1979; Beveridge, 1987). Significant reduction in flow would cause the sedimentation of larger, denser particles in the immediate vicinity of the cages (Beveridge, 1987). Siltation has been reported as a problem with cage culture in many countries such as Egypt, India, Malaysia, Singapore, Sri Lanka, and Thailand (IDRC/SEAFDEC, 1979). In the present study, siltation rate was not measured, but this should be done in future research.

Although waste loadings from cage culture have not been found to have significant impacts on fish production and water quality in the present study, the environmental impact may become significant as cage culture expands in the Mekong Delta. Mitigation measures should be developed. Tucholski et al. (1980a,b) demonstrated that trapping the particulate waste fraction from cages and pumping it ashore is a technically feasible method to reduce environmental impacts of cage farming. However, this is expensive and may not be practical in many places. Integrated approaches, such as placing cages with omnivorous fish species such as common carp (*Cyprinus carpio*) downstream of intensive cages to utilize wastes from the cages, may be a realistic and cheap method to reduce the environmental impacts of intensive cage farming.

Research should be conducted in the Mekong River to determine the appropriate number of cages and/or amount of feed input the river can sustain (the carrying capacity for cages).

Anticipated Benefits

The results of this research provide information to farmers for better management of their cages based on water quality and hydrological features. It also enables managers to estimate carrying capacity of the river for cage culture in order to allow governmental agencies to establish policies and plans for cage culture development. The study provided evidence on the current degree of water quality deterioration due to cage culture and will benefit thousands of catfish cage farmers in Vietnam when the total impact is better understood.

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