Experiment on an Integrated Ricefish Polyculture System (6 Species, 1– 2 fish/m²) in the Mekong Delta

D.N. Long*, N.V. Lanh*, L.M. Lan* & J.-C. Micha**

Keywords: Ricefish culture– Fish polyculture– Fish production– Cost ratio profit

Summary

Our ricefish polyculture (6 species) results at two stocking densities (1 and 2 fish/m^2) show that: The water quality in a ricefish polyculture system, such as water temperature (29.1 – 29.0 °C), water pH (6.6 – 6.7), water transparency (18.0 – 20.8 cm), dissolved O_2 (4.7 – 4.6 ppm), CO_2 (22.8 – 23.1 ppm), COD (11.9 – 12.7 ppm), are similar at both densities and acceptable for the 6 tropical fish species. Ammonium and phosphorus concentrations are statistically higher at 1 fish/m^2 (0.4 and 0.2 ppm). The primary productivity is similar for both densities (6.5 – 6.8 g O_2/m^3/day) and suitable for fish culture. The phytoplankton biodiversity is relatively high and at the same level for both treatments (74 – 63 taxa), but the densities of phytoplankton, of zooplankton, and the biomass of zoobenthos are lower at the highest density (2 fish/m^2), probably due to a higher predation by fish.The fish yield (808 kg/ha) at 2 fish/m^2 is higher than at 1 fish/m^2 (482 kg/ha). The cost ratio benefit (1.84) and the cost ratio profit (1.81) for farm households at 1 fish/m^2 are lower than those values at 2 fish/m^2 (2.1 and 2.05 respectively). Regarding the aquaculture extension program, the model of the ricefish polyculture (6 species) system with the stocking density of 2 fish/m^2 could be extended in the rice fields to improve farmer's income in the Mekong delta.

Résumé

Rispisciculture intégrée avec 6 espèces à 2 densités de mise en charge (1 et 2 poissons/m²) dans le delta du Mékong

Nos résultats de rizipisciculture (6 espèces) à 2 densités de mise en charge (1 et 2 poissons/m^2) montrent que: la qualité de l'eau dans notre système rizipiscicole, tels que la température de l'eau (29,1 – 29,0 °C), pH de l'eau (6,6 – 6,7), transparence (18,0 – 20,8 cm), O_2 dissous (4,7 – 4,6 ppm), CO_2 (22,8 – 23,1 ppm), DCO (11,9 – 12,7 ppm) est semblable aux 2 densités et acceptable pour les 6 espèces de poissons tropicaux. Les concentrations en ammoniaque et en phosphore sont statistiquement plus élevées à 1 poisson/m^2 (0,4 et 0,2 ppm). La production primaire est semblable aux 2 densités (6,5 – 6,8 g O_2/m^3/j) et adéquate pour l'élevage de poisson. La biodiversité du phytoplancton est relativement élevée et plus ou moins semblable aux 2 densités (74 – 63 taxa) mais les densités de phytoplancton, de zooplancton et la biomasse des macroinvertébrés benthiques sont plus faibles à la densité de 2 poissons/m^2, ce qui est probablement dû à la prédation plus élevée des poissons. La récolte de poissons est plus élevée (808 kg/ha) à 2 poissons/m^2 qu'à 1 poisson/m^2 (482 kg/ha). Le rapport coût bénéfice (1,84) et le rapport coût profit (1,81) sont plus faibles à 1 poisson/m^2 qu'à 2 poissons/m^2 (2,1 et 2,05 respectivement). En conclusion, le modèle de rizipolyculture à 6 espèces avec une mise en charge de 2 poissons/m^2 a été recommandé pour le programme de vulgarisation en vue d'améliorer les revenus des rizipisciculteurs du delta du Mékong, Vietnam.

Introduction

Most aquaculture has been developed in a freshwater environment in particular through integrated cultivation of rice and fish, the two dietary mainstays, which are traditional in many parts of South and Southeast Asian countries, such as China, Vietnam, Thailand, Indonesia, Malaysia, Bangladesh, India, the Philippines, Korea and Cambodia (14, 43).

The ricefish culture system has been carried out for a long time in the south of Vietnam (11, 16, 58). Rice and fish production in this system have been considered highly efficient in improving the farmers' net income and their lives in the rural areas of the Mekong delta region (11, 45, 58). Some authors (11, 16, 58) showed that, if ten years ago about 20 – 30% of the rural farmers adopted the model of integrated ricefish culture system now, about 70 – 80% of fish farmers are utilizing this model in the Mekong delta. Nevertheless, according to the West-East-South Project (WES) survey data (1997) on the ricefish polyculture system in the Mekong delta, the fish stocking density was unsuitable and needed to be improved. Some authors (4, 16, 47, 55) reported that fish stocked at 1.8 to 4.8 fish/m^2 produce fish yields of 99 to 730 kg/ha but, in most cases, the fish yields fluctuated from 230 to 324 kg/ha (10, 16, 37, 41, 42, 47).

* Institute of Aquaculture and Fisheries Science, College of Agriculture, Can Tho University, CAN THO, Vietnam.

** URBO, FUNDP, Rue de Bruxelles, 61 B-5000 NAMUR, Belgique.

Received on 26.07.02 and accepted for publication on 14.08.02.

We therefore designed different experiments to improve the productivity and the cost ratio profit of this ricefish culture system in a sustainable way. We present the results of the first experiment with 6 fish species stocked at 2 densities (1 and 2 fish/m^2) and fed at a very low level (3% of body weight) with fresh agricultural by-products. To understand the effect of fish treatments on the production of the system, we have investigated and compared the water quality, primary productivity, phytoplankton, and zooplankton density, zoobenthos biomass, fish growth, fish yield and, finally we analyzed the household income of the integrated ricefish polyculture system.

Materials and methodology

Experimental designed on ricefish culture system

The experiment on the ricefish culture system was carried out at two sites. The O-mon experimental research station (O-mon CADET), and WES demonstration farms in O-mon district, Can Tho province (Figures 1 and 2). Six rice fields were used for the experiments in which three rice fields (3 replications) from the O-mon CADET with an average area of 1,500 m^2 each and three rice fields belonging to the WES ricefish demonstration farms of 3,000 m^2 each. The technically designed structures inside the rice fields were the same for both experiments, with 4 trenches along the dikes of each rice field. The width of the trenches was about 2.8 – 3 m at the surface and about 2.2 – 2.4 m at the bottom. The total area of the rice field trenches occupied about 25 – 28% of the former rice field areas. The water depth of trenches was about 1.0 – 1.2 m. Treatment 1 (1 fish/m^2) was conducted in 3 rice fields in the O-mon experimental research station, while treatment 2 (2 fish/m^2) was conducted in 3 other rice fields of WES's ricefish demonstration farms. During the experiment, the water level in these rice fields was controlled through the sluice gate that is connected to a water irrigation canal following the technical protocol rice cultivation adopted by the Crop Science Department, College of Agriculture, Can Tho University.

The polyculture experiment was carried out in 1997 - 1998 with 6 species and included two treatments at two different fish stocking densities of 1 and 2 fish/m^2. The fish species were:

Cyprinidae, silver barb (*Puntius gonionotus* Bleeker), with a diet of mainly aquatic macrophytes; common carp (*Cyprinus carpio* L.), feeding mainly on zoobenthos (41); silver carp (*Hypophthalmichthys molitrix* (S.) Harmaldi), feeding mainly on phytoplankton (61).

Cichlidae, tilapia (*Oreochromis niloticus* L.), feeding mainly on phytoplankton (3, 61).

Anabantidae, snakeskin gouramy (*Trichogaster pectoralis* Regan), feeding mainly on waste matter (24, 32, 39, 61).

Helostomatidae, kissing gouramy (*Helostoma temmincki* Cuvier), feeding on waste matter and phytoplankton (39, 61).

On the basis of the ecological characteristics of these species in the natural water bodies, and on the WES survey data in the Mekong delta and on the availability fingerlings from hatchery, the fish species were stocked as shown in table 1.

Table 1

Fish species and stocking structures of a polyculture experiment (6 species) in the ricefish culture system

Fish species	Treatment 1: 1 fish/m^2	Treatment 2: 2 fish/m^2
	Stocking rate (%)	Stocking rate (%)
Silver barb	40	40
Tilapia	20	20
Common carp	15	15
Silver carp	10	10
Snakeskin gouramy	10	10
Kissing gouramy	5	5

Rice field preparation

The experimental rice fields were carefully prepared by clearing away aquatic macrophytes and wild grass that appeared around and inside the rice fields, draining out the water, catching predators such as snakehead, Asian catfish, climbing perch, then sloughing and harrowing 10 – 15 cm of the surface soil of flatform and removing and leveling mud at the bottom of the trenches of the rice fields, based on the methods of Tuan and Tam (56). We supplied lime only to the trenches at the rate of 10 - 15 kg/100 m^2 then dried the rice fields for 3 - 5 days, fertilizing with dried pig manure at the rate of 1.2 – 1.5 t/ha. After that, the rice fields were filled with water and the level maintained in the trenches at 100 – 120 cm.

Experimental rice

The Farming System Research Institute produces a high yield rice seed CS 69 that is used in our experimental ricefish system following the protocol of the rice culture technique used by the Crop Science Department, College of Agriculture, Can Tho University. Rice fields were set out in rows, with rice seed sowed at a rate of 140 – 150 kg/ha after 3 to 5 days of rice field preparation. Inorganic fertilizers such as Urea (46% of nitrogen), super phosphate (16% of P_2O_5) and potassium chloride (60% of K_2O) were supplied to rice fields three times with different rates of urea (200 kg/ha), super phosphate (135 kg/ha) and KCl (100 kg/ha). Regarding the pesticides, insecticides and herbicides that are used in the experimental rice fields, the method of IPM (Integrated Pest Management) was applied. Rice was harvested after 100 – 105 days.

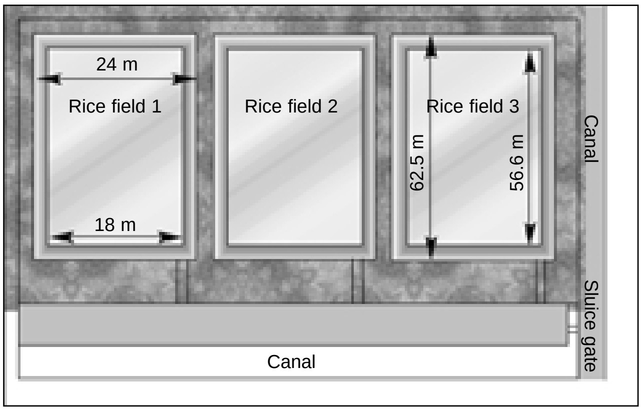

Figure 1: Ricefish fields at O-mon experimental station, CanTho University.

Figure 2: WES ricefish fields demonstration in O-mon district, Can tho province.

Experimental fish and feeding regime

Fish fingerlings were produced by Can Tho experimental fish hatchery, Can Tho University. The average initial weight of fish fingerlings was 1.7 – 4.6 g/fish. All fingerlings were stocked in the rice fields after rice seed sowing of 25 – 30 days in June according to the stocking rate of table 1. During cultured periods, the agricultural by-products, such as rice bran, broken rice, waste vegetables, freshwater spinach (*Ipomoea aquatica* Forskal), fresh sweet potato leaves, freshwater trash fish, mud crab and freshwater local snails, sometimes golden apple snails were used as supplementary feed for fish at a feeding rate of 3% total fresh body weight/day. Fish production was harvested at the end of the culture cycle in February of the following year.

Water quality and natural productivity determination

The physical parameters of water in the culture system such as water temperature (°C), water pH, and water transparency (cm), were determined monthly by using a portable pH meter and Secchi disc. The chemical parameters such as DO, CO_2, COD, NH_4^+, PO_4^{3-} (ppm), were also collected and analyzed monthly following the general methods (6, 13). Phytoplankton, zooplankton and zoobenthos were collected and analyzed monthly using the methods of (44, 46). Primary productivity was measured monthly in accordance with the classical methods (37, 38).

Evaluation of fish growth parameters

Fish samples were collected monthly to determine individual weight and total length by using a measuring board and an electrical balance (Model PC 4400, sensitivity 0.01 g). All fish species were harvested at the end of the experiment in order to measure the yield (kg/ha). To evaluate fish growth, the parameters of the daily weight gain (g/day), the specific growth rate (%/day), the survival rate (%), and the fish production (kg/ha/year) were calculated following the method of Long (24).

Household level financial analysis of the experiment

All the data were collected to calculate the total investment cost occasioned by the culture system, and at the end of the experimental ricefish culture, all productions were harvested to calculate the total output from this system. The parameters such as gross benefit return, net benefit return, cost ratio benefit and cost ratio profit for farm households were calculated according to Rainboth, and Xuan (41, 60).

Data analysis

The data obtained from the experiment were collected on Excell 5,0 and analyzed by using one-way ANOVA (34) and T- tests ($p < 0.05$) with the software package of statistica 5.5 to determine the significant factors between both treatments (1 and 2 fish/m^2) in this ricefish polyculture system (6 species) in the Mekong delta.

Results

Water quality parameters

The results presented in table 2 show that the mean values of water temperature and water pH in both treatments ranged from 29 to 29.1 °C and 6.6 to 6.7 respectively. There were no significant differences in parameters of water temperature (°C) and water pH ($p > 0.05$) between both treatments. These values are relatively stable and within acceptable levels for fish growth and development in the culture system (3, 5, 38, 57). However, the water transparency (cm) was significantly higher ($p < 0.05$) in treatment 1 (20.8 cm) than in treatment 2 (18 cm).

Regarding the chemical parameters of water (Table 2) show that the mean concentrations of dissolved oxygen (DO), carbon dioxide (CO_2) and chemical oxygen demand (COD) in two treatments ranged from 4.6 to 4.7 ppm, 22.8 to 23.1 ppm and 11.9 to 12.7 ppm respectively. The mean values were slightly higher in treatment 1 than in treatment 2, but with no significant difference ($p > 0.05$) between both treatments. Based on the eco-biological characteristics of the culture fish species, these results are acceptable values for fish growth and development in the ricefish culture system (3, 5, 38, 53, 54, 57).

The availability of ammonium (NH_4^+) and phosphorus (PO_4^{3-}) is an important factor for primary production in the ricefish culture system (17). In this experiment, the mean value (Table 2) of ammonia in treatment 1 (1 fish/m^2: 0.39 ppm) was higher than in treatment 2 (2 fish/m^2: 0.24 ppm) and the differences were statistically significant ($p < 0.05$). The mean value of PO_4^{3-} in treatment 1 (0.17 ppm) was higher than in treatment 2 (0.11 ppm), the differences being statistically significant ($p < 0.05$).

Primary production and natural foods in the rice-fish culture system

Primary production in the rice fish culture system

The results (Table 2) show that the mean values of primary productivity (6.76 g O_2/m^3/day) in treatment 1 are a little higher than in treatment 2 (6.46 g O_2/m^3/day), but the differences are not significant ($p > 0.05$).

Natural food in the rice fish culture system

a) Phytoplankton taxa and density

The results in table 2 show that the number of phytoplankton taxa was higher in treatment 1 (74 taxa) than in treatment 2 (63 taxa), but with no significant differences ($p > 0.05$). The highest diversity of phytoplank-

Table 2
Mean and standard deviation (STD) of water quality parameters and natural foods in a ricefish system (3 replications) at 2 stocking densities (1 and 2 fish/m^2)

Parameters	Treatment 1: 1 fish/m^2	Treatment 2: 2 fish/m^2
Water quality		
Water temperature (°C)	29.1 (3.3)	29 (3.4)
Water pH	6.6 (0.3)	6.7 (0.2)
Water transparency (cm)	20.8 (14.4) *	18 (7.8) *
Dissolved oxygen (ppm)	4.7 (1)	4.6 (1.2)
CO_2 (ppm)	23.1 (3.9)	22.8 (3.3)
COD (ppm)	12.7 (4.03)	11.9 (1.8)
NH_4^+ (ppm)	0.39 (0.23) *	0.24 (0.14) *
PO_4^{3-} (ppm)	0.17 (0.06) *	0.11 (0.04) *
Primary productivity (gO_2/m^3/day)	6.8 (3.5)	6.5 (2.7)
Natural foods		
Taxa of Phytoplankton	74	63
Phytoplankton density (cell/l)	48796 (15490) *	22337 (6689) *
Cyanophyta	8278 (2536)	5163 (1601)
(%)	16.9	24.00
Chlorophyta	11771 (6249)	5230 (2352)
(%)	23.6	22.6
Euglenophyta	16279 (8227)	6026 (2028)
(%)	33.3	27.1
Bacillariophyta	12476 (5539)	5918 (2359)
(%)	26.0	26.4
Taxa of Zooplankton	51	46
Zooplankton density (ind./l)	414 (233) *	364 (107) *
Rotatoria	70 (17)	70 (14)
(%)	19.0	21
Cladocera	86 (34)	87 (28)
(%)	22.5	23.9
Copepoda	184 (85)	153 (85)
(%)	40.3	40.1
Protozoa	75 (43)	54 (21)
(%)	17.8	15.2
Taxa of Zoobenthos	7	10
Zoobenthos biomass (g/m^2)	24.4 (15.8) *	13.3 (12.8) *
Oligochaeta	0.5 (0.5)	0.4 (0.2)
(%)	2	16
Gastropoda	23.6 (15.8)	13 (13)
(%)	95.5	80.1
Insecta larvae	0.3 (0.6)	0.3 (0.6)
(%)	2.5	3.9

ANOVA significance levels: (*) < 0.05 and (**) < 0.01

ton was observed for Chlorophyta (39.2% to 42.3% for T1 and T2), followed by Bacillariophyta (24.3% to 22.2% for T1 and T2) and Euglenophyta (18.9% to 20.6% for T1 and T2), and finally Cyanophyta (17.6% to 15.9% for T1 and T2). Typically, the main species of Chlorophyta are *Closterium moniliforme* (Bory) Her. *Spirogyra protecta* Wood, *Pediastrum boryanum* Raciborshy, for Bacillariophyta: *Nitzschia acicularis* Smith, *Navicula gastrum* Hustedt, for Euglenophyta: *Euglena acus* Ehr, *Euglena oxyuris* Schmarda, *Euglena hyaline* Ehr, Cyanophyta: *Oscillatoria limosa* Ag., *Spirulina major* Kutz, *Merismopedia elegans* Braun (45, 47). These results were approximately the same results as those obtained from the natural water bodies of the Mekong delta (4, 25, 26).

The mean density of phytoplankton in treatment 1 (48,796 cell/l) is higher than in treatment 2 (22,337 cell/l) and the difference was significant (p< 0.05) between both treatments. The highest phytoplankton density in treatment 1 was Euglenophyta, (33.3 %) followed by Bacillariophyta (26%), Chlorophyta (23.6%) and finally Cyanophyta (16.9%). In treatment 2, the highest percentage of phytoplankton density was also Euglenophyta (27.1%), followed by Bacillariophyta (26.4%) Cyanophyta (24%) and finally Chlorophyta (22.6%).

b) Zooplankton taxa and density

The results of table 2 show that the taxa of zooplankton in treatment 1 (51 taxa) are higher than in treatment 2 (46 taxa), but without a significant differences (p> 0.05) between both treatments. Rotatoria and Cladocera are the 2 main zooplankton orders with the greatest diversity compared to Copepoda and Protozoa. Typically, for Copepoda, the main species are: *Cyclops vernalis* Fischer, *Limnoncaea genuine*, *Sinodiatomus chaffanjon* Richard, for Cladocera: *Moina mocrocopa* Straus, *Moina brachiata* Jurine, *Diaphanosoma brachyurum* Lieven, for Rotatoria: *Brachionus plicatilis* Pallas, *Brachionus falcatus* Zacharis, *Brachionus quadridentatus* Hermann and, finally, for Protozoa: *Tintinnopsis cylindrata,* Kofoid and Campabell; *Arcella polypora* Penard (40, 44, 46).

The mean zooplankton density in treatment 1 (414 ind./l) was higher than the density in treatment 2 (364 ind./l) and the differences were significant (p< 0.05). The highest percentages were for Copepoda, ranging (40.1 – 40.3%), followed by Cladocera (22.5 – 23.9%), Rotatoria (19 – 21%) and finally for Protozoa (15.2 – 17.8%).

c) Zoobenthos taxa and biomass

The results presented in table 2 show that the mean biomass of zoobenthos in treatment 1 (24.39 g/m^2) was significantly (p< 0.05) higher than in treatment 2 (13.33 g/m^2). The highest biomass was observed for Gastropoda (80.1 – 95.5%) in both treatments, followed by Oligochaeta (2 – 16%) and finally Insecta larvae (2.5 – 3.9%). The main species of Gastropoda are: *Cipangopaludina iecythoides* Benson, *Pila conia* Gray, *Sinotaia aeruginosa* Reeve, for Oligochaeta: *Branchiura sarwerbgii* Beddard, *Aulodrilus limnbius* Bretscher, *Limmodrilus hoffmeisteri* Claparede and finally Insecta: *Chironomus sp* only (44).

Fish production

The results presented in table 3 show that the average final body weight of silver barb, tilapia, common carp and silver carp in treatment 1 (177.5, 172.3, 443.7 and 446.7 g/fish respectively) were higher than in treatment 2 (155.8, 158.1, 425.8 and 428.3 g/fish respectively) with statistical differences (p< 0.05) in mean body weight at p< 0.05 for silver barb, tilapia and common carp and at p< 0.01 for silver carp. The mean final body weight of snakeskin gouramy and kissing

Table 3

Average and standard deviation (STD) of fish weight (g/fish) stocked at two fish stocking densities (1 and 2 fish/m^2) in a ricefish polyculture (6 species) system

Fish species	Stocking rate (%)	Initial weight (g/fish)	Weight at harvest (g/fish)
Treatment 1: 1 fish/m^2			
Silver barb	40	1.73 (0.8)	177.5 (4.8) *
Tilapia	20	2.4 (0.6)	172.3 (9.8) *
Common carp	15	3.5 (0.9)	443.7 (9.3) *
Silver carp	10	4.6 (0.7)	446.7 (8.1) *
Snake skin gouramy	10	3.6 (1.0)	52.6 (1.5)
Kissing gouramy	5	3.8 (0.9)	142.6 (1.7)
Treatment 2: 2 fish/m^2			
Silver barb	40	1.7 (0.8)	155.8 (5.1) *
Tilapia	20	2.4 (0.6)	158.1 (9.2) *
Common carp	15	3.5 (0.9)	425.8 (3.9) *
Silver carp	10	4.6 (0.7)	428.3 (3.6) *
Snake skin gouramy	10	3.6 (1.01)	56.3 (0.7)
Kissing gouramy	5	3.8 (0.9)	156.8 (2.4)

ANOVA significance levels: (*) < 0.05 and (**) < 0.01

Table 4

Survival rate (%) with standard deviation (STD), yield and annual fish production at two densities (1 and 2 fish/m^2) in a ricefish polyculture (6 species) system

Fish species	Survival rate (%)	Yield of fish (kg/ha)	Fish production (kg/ha/year)
Treatment 1: 1 fish/m^2			
Silver barb	26 (1.0)	184.6	221.5
Tilapia	31 (2.7) *	106.6	130
Common carp	9 (1.0)	60	72
Silver carp	20 (2.7) *	89.3	107
Snake skin gouramy	31 (3.6) *	16.3	19.6
Kissing gouramy	35 (3.6)	25	30
Average survival rate	25.3 (9.5) *		
Total fish yield		482	
Total fish production			580
Treatment 2: 2 fish/m^2			
Silver barb	24 (2.3)	299	359
Tilapia	28 (2.7) *	176.6	212
Common carp	8 (1.0)	102	122.4
Silver carp	17 (2.0) *	145.3	174.3
Snake skin gouramy	28 (2.6) *	31.5	37.8
Kissing gouramy	34 (2.0)	53.3	64
Average survival rate	23.2 (9.3)*		
Total fish yield		807	
Total fish production			969.5

ANOVA significance levels: (*) < 0.05 and (**) < 0.01

gouramy at the harvesting time in both treatments (52.6 – 56.3 g/fish and 142.6 – 156.8 g/fish respectively) was not statistically significant (p> 0.05).

Moreover, the mean survival rates (Table 4) show that tilapia, silver carp and snakeskin gouramy in treatment 1 were significantly higher (p< 0.05) than in treatment 2. Finally, the total fish yield and annual fish production (Table 5) obtained in treatment 1 were 482 kg/ha and 580 kg/ha/year respectively, while in treatment 2 these results show a better fish yield (807 kg/ha) and a higher fish production (969.5 kg/ha/year).

Rice production

The results presented in table 5 show that the mean rice yields during the dry and wet crop seasons obtained in treatment 1 (5,563 kg/ha and 3,782 kg/ha respectively) are a little lower than in treatment 2 (5,600 kg/ha and 3,800 kg/ha respectively), but the differences are not significant (p> 0.05). These rice yields are relatively similar to those of (15, 52) in O-mon district, Can Tho province, in the Mekong delta.

Table 5

Rice yield and rice production in a ricefish polyculture (6 species) system at two fish densities (1 and 2 fish/m^2) at different crop seasons

Items and crop seasons	Treatment 1 (1 fish/m^2)	Treatment 2 (2 fish/m^2)
Dry season (winter – spring crop)		
(October – January: 4 months)		
• Yield of rice (kg/ha)	5,563 (x)	5,600 (x)
Wet season (summer – autumn crop)		
(March – July: 4 months)		
• Yield of rice (kg/ha)	3,782 (y)	3,800 (y)
"Chet" rice after summer-autumn crop		
(August – September: 2 months)	700 – 800	700 – 800
(Not harvested and estimated kg/ha)	(Fish food only)	(Fish food only)
Total annual rice yield (kg/ha)	9,345	9,400
Total annual rice production (kg/ha/year)	14,212	14,296

(x) WES (1996 – 1997), O-mon agricultural extension station, O-mon district, (1997-1998)
(y) Yield of rice in an experiment on a ricefish culture system
ANOVA significance levels: (*) < 0.05 and (**) < 0.01

Table 6

Farm household income analysis (in VND, 1USD = 11,000 VND) of the ricefish polyculture (6 species) system at two fish stocking densities (1 and 2 fish/m^2)

Items	Treatment 1 (1 fish/m^2)	Treatment 2 (2 fish/m^2)
Investment cost for operation system		
Investment cost for rice (VND/ha)	6,890,000	6,890,000
Investment cost for fish (VND/ha)	2,810,000	3,230,000
Total investment cost for ricefish system	9,700,000*	10,120,000*
Production system		
Gross rice production		
Gross rice yield per ha (kg/ha)	9,345	9,400
Gross rice production (kg/ha/year)	14,212	14,296
Net rice production		
Net rice yield (kg/ha)	9,195	9,250
Net rice production (kg/ha/year)	13,984	14,067
Gross fish production		
Gross fish yield per ha (kg/ha)	482 *	807 *
Gross fish production (kg/ha/year)	580	969.5
Net production of fish culture		
Net fish yield (kg/ha)	470 *	784 *
Net fish production (kg/ha/year)	564	946
Gross return to ricefish households		
Rice production		
Rice yield (VND/ha)	13,083,000	13,160,000
Rice production (VND/ha/year)	19,896,000	20,014,000
Fish production		
Fish yield (VND/ha)	4,810,000	8,077,000
Fish production (VND/ha/year)	5,800,000	9,695,000
Net return to ricefish households		
Rice yield (VND/ha)	12,873,000	12,950,000
Rice production (VND/ha/year)	19,577,600	19,693,800
Fish yield (VND/ha)	4,700,000 *	7,841,000 *
Fish production (VND/ha/year)	5,640,000	9,460,000
Total farm net income		
Ricefish system (VND/ha)	17,573,000 *	20,791,000 *
Ricefish system (VND/ha/year)	25,217,600	29,153,800
Cost ratio benefit for ricefish system		
Cost ratio benefit for ricefish system/ha	1.84 *	2.10 *
Cost ratio benefit for culture system/ha/year	2.64	2.94
Cost ratio profit for ricefish system		
Cost ratio profit for ricefish system/ha	1.81*	2.05*
Cost ratio profit for culture system/ha/year	2.60	2.88

(Average price of fish 1 kg= 10,000 VND and 1 kg rice= 1,400 VND in 1997 - 1998)

Income of farm households

The total investment cost includes: rice field preparation for rice cultivation and fish culture, rice seeds and fish fingerlings, fertilizers, water supply, transportation, harvesting, etc… Our results (Table 6) show that the total investment cost for treatment 1 (1 fish/m^2) is 9,700,000 VND/ha, while for treatment 2 (2 fish/m^2) is 10,120,000 VND/ha. The total net rice yield in treatment 2 (9,250 kg/ha) was higher than in treatment 1 (9,195 kg/ha). The total net fish yield in treatment 1 (470 kg/ha) is significantly ($p< 0.05$) lower than in treatment 2 (784 kg/ha). The total farm net income was 17,573,000 VND/ha for treatment 1 and 20,791,000 VND/ha for treatment 2. The net return to the ricefish farmers from fish production was 4,700,000 VND/ha in treatment 1 (26.8% of the total income) and 7,841,000 VND/ha (38% of the total income) in treatment 2. The cost ratio benefit per ha was 1.84 for treatment 1 and 2.1 for treatment 2. Obviously, the cost ratio profit for farm household is lower in treatment 1 (1.81) than in treatment 2 (2.05).

Discussion

Water quality parameters

The productivity of the ricefish polyculture system depends on a considerable number of eco-technological parameters, such as the designed structures, the water quality factors, the inorganic and organic nutrient inputs, the quality and quantity of fish stocked in the system (20, 38, 43).

The results of water temperature (29.1 – 29.0 °C), water pH (6.6 – 6.7), water transparency (18.0 – 20.8 cm), dissolved oxygen (4.7 – 4.6 ppm), carbon dioxide (23.1 – 22.8 ppm) and chemical oxygen demand (12.7 – 11.9 ppm) are stable. They are within acceptable values for tropical fish, and will not affect the fish growth and their productivity in both treatments (3, 5, 7, 17, 38, 50). These values are approximately the same as those reported in respect of the ricefish culture system in Malaysia and Vietnam (1, 4, 24, 25, 57). Regarding the dissolved oxygen factor, some authors (1, 27) have also measured in the rice fields, 3 to 4 ppm in the morning and saturation in the afternoon due to photosynthesis activity. Moshin and Ambak (32) also noted that DO is not an important factor in ricefish farming. On the other hand, the water pH is slightly acid (6.6 to 6.7) in the experimental rice fish fields, probably due to the presence of humus left over from weeding and harvesting as well as the marshy origin of the eco-system (1, 18).

Fish yields in the ricefish system depend on the natural productivity of the rice fields, since supplementary feeding is zero or very low (1, 22). In the rice field ecosystem, nitrogen is the most important element utilized by both rice crops and weeds, in the early stages of growth. Nitrogen and phosphorus play a significant role as nutrient sources for the aquatic primary producers. This explains why the standing crop, primary productivity and natural foods in the ricefish culture system depend on the availability of these two nutrients in the aquatic ecosystem. The mean values of ammonia (NH_4^+: 0.4 ppm) and phosphorus (PO_4^{3-}: 0.2 ppm) in treatment 1 are statistically higher ($p< 0.05$) than in treatment 2 (0.2 ppm and 0.1 pmm respectively). But due to the low quantity and quality of these agricultural by-products (80 – 90% rice bran and chopped fresh water spinach or sweet potato leaves mainly), the affected levels of nutrients (ammonia particularly) are still very limited (5, 53). Hence, the higher fish stocking density (2 fish/m^2) requires higher nutrient sources for the increase natural foods in the culture system (3, 9), that result in lower phytoplankton density (22,337 cell/l vs 48,796 cell/l), lower zooplankton density (364 ind./l vs 414/ind./l) and then biomass of zoobenthos (13.3 g/m^2 vs 24.4 g/m^2) to improve the primary productivity through the process of photosynthesis that could be probably explainable for the lower ammonia and phosphorus concentrations in treatment 2 (2 fish/m^2). These results are similar to those of the previous experiments on the natural nutrients mentioned that have been carried out in the rice fish fields in Indonesia and in the south of Vietnam (2, 26, 41, 42, 54). Some authors (1, 5, 7) indicated that liming releases some of the phosphates absorbed by the mud that results in a higher concentration of solute orthophosphate in the water. This orthophosphate is the main nutrient source for phytoplankton growth in the culture water bodies (5, 12). Therefore, the intense competition for nutrient sources between rice crop and phytoplankton distributed in the rice fields decreases the nutrient levels of NH_4^+ and PO_4^{3-} it also decreases the photosynthesis process of phytoplankton, reducing primary production and phytoplankton density in both treatments. These results of low primary productivity and low density of phytoplankton were also determined by the planktivorous species of tilapia and silver carp. These species at higher density (treatment 2: 2 fish/m^2) are probably responsible for reducing phytoplankton density on mainly Chlorophyta, Euglenophyta and Bacillariophyta (30).

Abundance and availability of micro-crustaceans and rotifers for fish larvae and planktivorous adults play an important role in fish production (1, 21). Early food availability determines the year-class strength of fish populations and affects fish yields (1, 21). Micro-crustaceans (Cladocerans and Copepods) and rotifers constitute the early diet for fish larvae and fingerlings (1, 31). Most rice field fish species, such as silver barb, common carp, snake skin gouramy, kissing gouramy, feed on rotifers as early as the sixth day after hatching (1, 24). Rotatoria, Copepoda and Cladocera dominate zooplankton biocenosis in our experimental ricefish culture in both treatments, so fish fingerlings had relatively good natural food for their growth and development in the system (31). But, in our experiment, the zooplankton density decreases at higher fish stocking densities and the fish production seems higher for Copepoda particularly. These results are similar to those of the experiment in the ricefish culture system in Malaysia (1, 31).

Fish and rice production

Regarding fish production, the mean final body weight of silver barb, tilapia, common carp and silver carp in treatment 1 (1 fish/m^2) were higher than in treatment 2 (2 fish/m^2). These results indicate that the higher fish stocking density leads to an increase in the competition process for natural food sources between cultured fish species in treatment 2. This is probably the main factor that affects the fish growth, which is lower in treatment 1. The mean weight of snakeskin gouramy is low in both treatments due to the lack of detritus sources in the rice fields. This result is similar to those on snakeskin gouramy of (1,14, 23, 24, 57).

On the other hand, the low survival rate (%) of fish species such as tilapia, silver carp and snakeskin gouramy (31%, 20% and 31% respectively in treatment 1 and 28%, 17% and 28% respectively in treatment 2) show that the system is limited by nutrients and by the low quality of agricultural by-products. These conditions lead to an intense competition between the cultured fish species, especially the herbivorous species, at higher stocking density (2 fish/m^2), which affects their lower mean final body weight and survival rate. However, the survival rate of silver barb, common carp and kissing gouramy is not significantly different between both treatments ($p> 0.05$). Nevertheless, the larger quantities of all these fishes surviving in treatment 2 partially explain the higher yield in treatment 2 (807 kg/ha) compared with that in treatment 1 (482 kg/ha).

Table 7
Compared fish yields (kg/ha) of the ricefish polyculture system in different countries of Asia

Countries	Density (fish/m^2)	Periods (days)	Fish species	Fish yield (kg/ha)	References
Malaysia	1.5- 3	180- 300	S. skin gouramy Snakehead Asian catfish	302- 470	(14)
India	1	–	*Clarias batrachus* *H. fossilis*	1,260	(14)
Cambodia	0.25- 1	180	Silver barb Tilapia Common carp S. skin gouramy Silver carp	200- 400	(35)
Vietnam	1- 4.8	210- 300	Silver barb Tilapia Common carp S. skin gouramy Silver carp Giant gouramy	280- 677	(49, 50)
Vietnam	1- 5	180- 240	Silver barb Tilapia Common carp S. skin gouramy	230- 324	(59, 60)
Vietnam	2	180	Silver barb Tilapia Common carp	319- 541.8	(42, 43)
Vietnam	1- 2	300	Silver barb Tilapia Common carp S. skin gouramy Silver carp K. gouramy	481- 807.7	This experiment

In comparison with the fish yields in the ricefish system in other Asian countries (Table 7) the fish yield in our study is higher than in Malaysia (302 – 470 kg/ha) (14, 22), than in Cambodia (200 – 400 kg/ha) (35) and especially higher than fish yields in the Mekong delta in the past that reported by (4, 47) (280 – 677 kg/ha); (47, 58) (230 – 324 kg/ha) and (41, 42) (319.9 – 541.8 kg/ha). But our result is lower than fish yields in China (1,800 kg/ha) (9, 27) and in India (1,260 kg/ha) (14, 19) probably due to the higher feeding rate (5% /total body weight/day).

The rice production in the dry crop season (Winter – Spring crop) is higher than in the wet crop season (Summer – Autumn crop) (15, 41, 52, 60), but there is no difference related to the fish stocking density.

Income of farm households

Integration of rice and fish culture can help farmers to generate more farm household income (14). Increasing the total household net benefit can only be done with an integrated, diversified and efficient production system (16). That is why ricefish culture is lucrative and economizes investment cost for the crops (14, 20). Our results on the farm household levels illustrate that the net farm income from the ricefish culture system is significantly higher than from the rice monoculture system in the Mekong delta. Compared to other authors, our results are better at least at the highest density (2 fish/m^2) than in South East Asia, where the farm net income from fish production in the ricefish culture system is 25% (22), 14.94% from the ricefish semi – intensive culture system in the Mekong delta (48, 49), 6% from the ricefish extensive culture system in the Mekong delta (41, 42). This lower income results from a lower fish stocking density and a lack of foods. The benefit cost ratio for farm household income was 1.7 in a ricefish culture system in Tien giang province, Vietnam (58), 1.07 – 1.39 from the model of rice fresh water prawns in Tam Binh district, Vinh Long province (58) and 1.1 from the model of rice-fresh water prawn in Dai Thanh village, Can Tho province, Vietnam (45). Our research shows that the fish production contributes to the total farm net income from ricefish fields is 26.8% in treatment 1 (1 fish/m^2), 38% in treatment 2 (2 fish/m^2), with the cost ratio benefit per ha increasing from 1.84 for treatment 1 to 2.1 for treatment 2. According to the WES survey data (1997) there are a large number of eco-technological factors that could affect the fish production and the benefit return in the ricefish culture system (4, 48, 49).

Designed structure and preparing rice fields for rice cultivation and fish culture.

Improving the natural nutrient sources through fertilization for increasing primary productivity and producing natural foods in ricefish culture system.

Setting-up the culture system within the fish species stocking density, fish stocking structures.

Using on-farm agricultural by-products (rice bran, vegetables, chet rice etc) to decrease production costs and increase cost ratio profit for farmers.

But, there are still some constraints for the model of the ricefish culture in the Mekong delta especially, on the fish market price. Some fish species such as silver carp and kissing gouramy, are very difficult to sell and then only a very low price (48, 49).

Literature

1. Ali B., 1990, Seasonal dynamics of microcrustacean and rotifer communities in Malaysian rice fields used for ricefish farming. Hydrobiology 206,139-148 p.
2. Andarias I., 1989, The effect of urea and triple superphosphate fertilizers on standing crop and chlorophyll content of klekap. Hasanudin University, Indonesia. Scientific report, 10 p.
3. Barnabe G., 1994, Aquaculture Biology and Ecology of Cultured Species. Ellis Horwood, 403 p.
4. Be N. V., Cong N. V., Dung D. T., Sinh L. X., Pekar F. & Olah J., 1997, Fish Farming Households in the Mekong River Delta Region, Part 2. Eco-Technological Aspects of Fish Farming Systerms. WES, 28 p.
5. Boyd C. E. & Tucker C. S., 1992, Methods for analyzing water quality in Aquaculture. Birmingham Publishing Co.
6. Boyd C. E., 1990**,** Water Quality in Ponds for Aquaculture. Birmingham Publishing Co, 482 p.
7. Brune D. E. & Tomasso J. R., 1991, Aquaculture and water quality. The World Aquaculture Society, 606 p.
8. Cagauan A. G., 1999, Production, economics and ecological effect of nile tilapia, the fern azolla and mallard duck in integrated low land rice-based farming system in the Philippines. Doctoral thesis, 388 p.
9. Chen H. & Charles A. T., 1995, Chinese integrated fish farming: a comparative bioeconomic analysis. Aquaculture Research. 26, 81-94.
10. Chi H. H., 1997, The present status of rice – fish farming system in Song Hau state farm, Can Tho province, south of Vietnam. Can Tho University. Scientific report, 12 p.
11. Chiem N. H., 1994, Former and present cropping patterns in the Mekong delta. Southeast Asian studies, Vo. 31, N° 4. Scientific report, 39 p.
12. Chiou C. Boyd & C. E., 1974, The utilization of phosphorus from muds by the phytoplankter, *Scendedesmus dimorphus*, and the significance of these findings to the practice of pond fertilization. Hydrobiologia, 45, 345-355.
13. Clesceri L. S., Greenberg C. A. E. & Eaton A. D., 1998, Standard Methods for the Examination of Water and Wastewater. American Public Health Association, 320 p.
14. Cruz R. D., Lightfoot C., Costa-Pierce B. A., . Carangal V.R & Bimbao M.A.P., 1992, Rice-Fish Research and Development in Asia. ICLARM, 457 p.
15. Duong L.T., Nhan D. K., Rothuis A. J., Quang P.M., Giau T. Q., Chi H. H. & Thuy L. T., 1998, Integrated rice fish culture in the Mekong delta: problem, constraints and opportanity for sustainable. 33 p.
16. Egna H. S. & Boyd C. E., 1997, Dynamics of pond aquaculture. Lewis Pulishers in an imprint of CRC press. 411 p.
17. Fernando C. H., Furtado J. I. & Lim R. P., 1979, The aquatic fauna of the world's rice fields. Malaysia, 105 p.
18. Gupta M.V., Sollows J. D., Mazid M.A., Rahman A., Hussain M.G., Dey M. M., 1998, Integrating Aquaculture with Rice Farming in Bangladesh. Feasibility and Economic Viability, Its Adoption and Impact. ICLARM, 90 p.
19. Halwart M., 1998, Trends in Rice-Fish Farming. Scientific report, 9 p.
20. Hepher B., Milstein A., Leventer H. & Teltsch B., 1989, The effect of fish density and species combination on growth and utilization of natural food in ponds. Aquaculture and fisheries management, 20, 59-71.
21. Khoo K. H. & Tan E. S. P., 1980, Review of rice fish culture in Southeast Asia. International workshop on integrated Agriculture – Aquaculture farming system, ICLARM manage. 1-14.
22. Little D. & Muir J., 1987, A Guide to Integrated Warm Water Aquaculture. Institute of Aquaculture Publications University of Stirling, 238 p.
23. Little D. & Yoonpundh R., 1997, Trends in the farming of the Snakeskin gouramy (*Trichogaster pectoralis*) in Thailand. NAGA. Scientific report, 7 p.
24. Long D. N., 1996, Technical aspects for the ricefish culture in the Mekong delta. The workshop on ricefish culture in the Mekong delta. CanTho University. Scientific paper report. 12 p.
25. Long D. N., Son V. N. & Oanh D. T. H., 1999, Accessment of the development of aquatic fauna and flora in problem soil areas and in relation with aquaculture aspects. Sarect project, Can Tho University. Scientific report annually, 83 p.
26. Mackay K. T., 1995, Rice-Fish Culture in China. International Development Research Centre, 265 p.
27. Mathias J. A., Charles A. T. & Baotong Hu, 1998, Integrated Fish Farming. CRC, 420 p.
28. Mekong Delta Farming System Research Institute, 2001, Development of new technologies and their practice for sustainable farming systems in the Mekong delta. JIRCAS – CLRRI – CTU-SOFRI. Proceedings of the 2001 annual workshop of Jircas Mekong delta project, 350 p.
29. Milstein A., Hepher B. & Teltsch B., 1985, Principal component analysis of interactions between fish species and the ecological conditions in fish ponds: I. Phytoplankton. Aquaculture and fisheries management, 1985. 16, 305-317.
30. Milstein A., Hepher B. & Teltsch B., 1985, Principal component analysis of interactions between fish species and the ecological conditions in fish ponds: II. Zooplankton. Aquaculture and fisheries management, 16, 319-330.
31. Milstein A., Hepher B. & Teltsch B., 1988, The effect of fish species combination in fish ponds on plankton composition. Aquaculture and fisheries management. 19, 10 p.
32. Mohsin A. K. M. & Ambak M.A., 1983, Freshwater fish of Peninsular Malaysia, 284 p.
33. Naca, 1989, Integrated fish farming in China. Naca technical Manual 7. A world Food Day Publication of the network of Aquaculture Centers in Asia and the Pacific, Bangkok, Thailand. 278 p.
34. Nedeco, 1993, Master Plan for the Mekong Delta in Vietnam, 168 p.
35. Nesbitt H.J., Rice Production in Cambodia. IRRI-AUSAID, 112 p.
36. Neter J., Kutner M. H., Nachtssheim C. J. & Wasseman W., 1996, Applied linear statistical models. McGraw-Hill publication. 525 p.
37. Nhan D. K. & Duong L.T., 1998, Rice – fish farming system in the Mekong delta, Vietnam. Identification of constraints. Can Tho University. Scientific report, 9 p.
38. Olah J., Zsigri A. & Kintzly A.V., 1978, Primary production estimations in fish pond by the mathematical evaluation of daily DO curves. Aquaculture Hungarica. Scientific report, 13 p.
39. Pekar F., Be N.V., Dung D.T., Cong N.V., Long D.N., 1998, The eco-technological analysis of fish farming households in the Mekong delta, Vietnam. WES scientific report, Can Tho University, 16 p.
40. Rainboth W. J., 1996, Fishes of the Cambodian Mekong. FAO, 265 p.
41. Randall E., Brummett & Mattson N., 1996, Zooplankton population Periodicity in a tropical pond. ICLARM, N° 1256. Scientific report, 2 p.
42. Rothuis A. J., Nhan D. K., Richter C. J. J. & Ollevier F., 1998, Rice with fish culture in the semi-deep waters of the Mekong delta, Vietnam: a socio-economical survey. Aquaculture research. 1998, 29, 47-57.

43. Rothuis A., Ollevier F. & Richter C. J. J., 1998, Rice-Fish Culture in the Mekong Delta, Vietnam: Contraint Analysis and Adaptive Research. Katholieke Universiteit Leuven, Belgium, 107 p.

44. Ruddle K., 1982, Traditional integrated farming system and rural development: The example of ricefields fisheries in Southeast Asia. Agric. Admin. 10, 1-11.

45. Sanh N.V., 1996, History and future of the farming systems in the Mekong delta. Scientific report on the workshop of Jircas project – Can Tho University, 8 p.

46. Sharma O. P., 1986, Textbook of Algae. Tata McGraw-Hill Publishing Company Limited, 396 p.

47. Shirota T., 1966**,** Plankton in the south of Vietnam. 598 p.

48. Sinh L. X., Tuan N. A., Pomeroy R. S., Genio E., Garces A. & Agbayani R. F., 1997, Marketing Freshwater Table Fish in the Central Area of the Mekong River Delta. WES, 41 p.

49. Sinh L. X., Pomeroy R., Garces A., Agbayani R., Toan N. T. & Hien T.T.T., 1996, Fish Farming Households in the Mekong River Delta Region, Part 1: Socio-Economic Analysis. WES, 43 p.

50. Sinh L.X. & Van M.V., 2000, The socio-economical aspects on rice – fish farming system in the Mekong Delta, Vietnam. Scientific report on rice – fish farming system in the Mekong delta on 18 – 19/12/2000 in Can Tho University, 9 p.

51. Soliman K.A., 2000, Effects of introducing ducks into fish ponds on water quality, natural productivity an fish production together with the economic evaluation of the integrated and non-integrated systems. Aquaculture international 8, 315-326, 2000.

52. Symoens J. J. & Micha J. C., 1995, The Management of Integrated Freshwater Argo-Piscicultural Ecosystems in Tropical Areas. FAO-TCTA-ARSOM, 587 p.

53. Tadao Kon, 1998, Rice cropping in the Mekong delta. Jircas project, Can Tho University. Scientific report, 18 p.

54. Thanh D. N., 1979, General Hydrobiology. Technology and Sciences Publishing House, Hanoi, Vietnam. 215 p.

55. Thanh D. N., 1983, Capacity of productivity in the water bodies in relation to Aquaculture. Technology and Sciences Publishing House, Hanoi. 258 p.

56. Tuan N. A. & Tam B. M., 1993, Integrated rice – wild fish in Ca Mau province, south of Vietnam. Scientific report, 6 p.

57. Vincke P. & Micha J. C., 1985, Fish culture in rice fields. Proceedings of the 16th Session of the international rice commission 10 – 14 June 1985, 17 p.

58. Xuan L. N., 1994, The biological characteristics and technical aspects of the freshwater fish species in the Mekong Delta, south of Vietnam. An Giang Company Limited Publishing, 182 p.

59. Xuan V.T. & Matsui Shigeo, 1998, Development of Farming Systems in the Mekong Delta of Vietnam. Ho Chi Minh City Publishing House, Saigon Times Group and Vietnam Asia Pacific Economic Center, 318 p.

60. Xuan V.T., 2000, Development of New Technologies and Their Practice for Sustainable Farming Systems in the Mekong Delta. JIRCAS-CTU-CLRRI, 323 p.

61. Yamasaki R. & Thanh D.N., 1998, Agricultural structure of the Mekong Delta: a case study of the Thot Not district, Can Tho province.

62. Yen M.D., 1983, Commercial fish in Vietnam. Scientific and Technical Publishing House, 220 p.

D.N. Long, Vietnamese, Master of Aquaculture Sciences, Vice-Director of Institute of Aquaculture and Fisheries Sciences, Can Tho University, Vietnam.

N.V. Lanh, Vietnamese, Bachelor of Aquaculture Sciences, Researcher of Institute of Aquaculture and Fisheries Sciences, Can Tho University, Vietnam.

L.M. Lan, Vietnamese, Master of Aquaculture Sciences, Researcher of Institute of Aquaculture and Fisheries Sciences, Can Tho University, Vietnam.

J.-C. Micha, Belgian, Ph D in Biology, Professor of Aquatic ecology at FUNDP, Namur; and at UCL, Louvain-La-Neuve, Belgium.