TILAPIA-SHRIMP POLYCULTURE IN THAILAND

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Abstract

A survey on tilapia-shrimp polyculture was conducted in Thailand from March until June 2002, to assess the current status of Thai farmers' practices of tilapia-shrimp polyculture. Sixty-one farmers who culture fish in their shrimp farms in 12 provinces of Thailand were selected and interviewed using a structured checklist and open-ended type of questionnaires.

Results showed that three versions of tilapia-shrimp polyculture, namely: a) simultaneous, b) sequential, and c) crop rotation systems, are practiced by Thai shrimp farmers. Among the farmers, 42.6% use a simultaneous polyculture system, while percentages of farmers using sequential and crop rotation systems are 34.4 and 6.6%, respectively. The remaining 16.4% of farmers stock fish in reservoir ponds and use a monoculture system for shrimp. Among the farmers who adopt the simultaneous tilapia-shrimp polyculture system, 76.9% released tilapias directly into shrimp ponds, and 23.1% stocked tilapias in cages suspended in shrimp ponds. Tilapia-shrimp polyculture is practiced in a wide range of salinity levels from 0 to 30 %. Tilapias used in the polyculture include red tilapia (*Oreochromis* spp.), Nile tilapia (*O. niloticus*), and Mossambique tilapia (*O. mossambicus*).

The survey revealed that shrimp production and economic returns from the two simultaneous polyculture systems and in sequential polyculture systems were higher than those in their respective shrimp monoculture systems practiced previously. Also shrimp production and economic returns from these polyculture systems were higher than those in the crop rotation polyculture system and in the currently practiced monoculture system. For many farmers, tilapia-shrimp polyculture could improve water quality in shrimp ponds, reduce diseases, and reduce the use of chemicals. In the direct style of tilapia-shrimp polyculture, about 40% farmers believed that tilapias compete for feed with shrimp, while the remaining 60% were not aware of such feed competition.

It can be concluded from the survey that polyculture of shrimp with tilapias may provide an alternative approach for shrimp farming, which could ultimately lead to a more sustainable shrimp industry. However, further research is needed on the merits for converting from shrimp monoculture to polyculture with tilapia.

Introduction

Shrimp (*Penaeus monodon*) aquaculture has been devastated in many countries due to decreasing yields resulting from disease infestation, poor management such as overstocking, and environmental degradation. Polyculture of shrimp with tilapias may provide an opportunity to develop a sustainable aquaculture system (Fitzsimmons, 2001).

There are several variations of tilapia-shrimp polycultures: simultaneous, sequential and crop rotation. In the simultaneous polyculture for instance, the fish and shrimp are grown together in a pond or raceway; in the sequential system water is moved from one growing unit to another, and in the crop rotation system, tilapia and shrimp are grown alternately. There appear to be distinct advantages of each of these systems over the other.

In a polyculture setting, tilapia and shrimp can utilize different niches in the culture setting. In an extensive farm, tilapia can filter phytoplankton and zooplankton in the upper water column. Shrimp spend most of the time in the pond bottom grazing on bacterial films on the bottom substrate and on the detritus settling from above. In a more intensive system receiving pelleted feeds, tilapia monopolize the feed, especially if it is a floating feed. However, some feed particles always get to the bottom where the shrimp gets it. More importantly, the fecal matter from the tilapia contributes to the detrital rain that supports the shrimp. *Macrobrachium*-tilapia polyculture reduces the yield of prawns compared to monoculture, but increases total yield of fish and prawns (Garcia-Perez *et al*., 2000). A similar effect may occur with brackish water polyculture of tilapia and shrimp (Yap, 2001). Akiyama and Anggawati (1999) reported that yields of shrimp increased when tilapias were stocked into existing shrimp ponds.

From the disease aspect, tilapias seem to provide advantages in several ways. Growers in Ecuador have reported that tilapias will consume dead or moribund shrimp in polyculture ponds. Cannibalism is one of the primary vectors for transmission of shrimp diseases. Tilapias, which do not appear to be susceptible or carriers of these viruses, disrupt cannibalism as a mode of transmission. Tilapias also consume small crustaceans in shrimp ponds. These crustaceans are of concern as potential vectors. Having tilapia directly in the ponds or alternating with shrimp in a crop rotation can be effective in reducing crustacean populations. Bacterial infections also may be impacted by polyculture. *Vibrio* and most other bacterial pathogens common in shrimp culture are gram negative while waters which have been used for fish culture tend to be predominated by gram positive bacteria. Using water from a fish culture pond seems to reduce the prevalence of luminous *Vibrio* bacterial infections in shrimp ponds (Yap, 2001). Growers in Asia and South America have provided anecdotal reports that shrimp production increases due to higher survival in some of these polyculture systems, however, carefully controlled and replicated trials are needed to better study these systems and confirm the results.

There may also be physical factors that improve shrimp survival and growth in polyculture. Tilapia disturbs bottom sediments to a greater degree than shrimp, both in foraging and nest building activities. This may be beneficial in several ways. Disturbing the bottom could improve oxidation of the substrate and interrupt life cycles of shrimp pathogens and parasites. It could also release nutrients into the water column that could improve algae blooms. However, it is also possible that these activities may be detrimental. Disturbing bottom sediments could also negatively impact water quality, lowering dissolved oxygen levels, increasing turbidity from sediments and reducing algae blooms, ability to remove fish and shrimp, and most certainly increase the need to repair pond bottoms between crops. This particular aspect would require close attention and careful experimentation to gain a clear understanding.

The main purpose of this survey was to assess the current status of farmers' practice on tilapia-shrimp polyculture in Thailand.

Materials and methods

The survey was conducted in the central inland, central estuarine, eastern coast and southern coast areas covering 12 provinces of Thailand from March-until June 2002. Farmers who have already tried tilapia-shrimp polyculture were identified by contacting with farmers' associations, community leaders and private sectors. Preliminary information regarding their culture systems were gathered to ascertain whether they were suitable for the purposes of the study and their availability. Farmers were using a structured checklist and open-ended type of questionnaires. The questionnaires consisted of farmers' background, tilapia-shrimp polyculture systems, pond and water management, feed and feeding management, parasite and disease problems, harvest and production, economic returns and other information.

MS Excel was used to store all the data, and to generate tabular and graphical representation of different types of data. A partial budget analysis was conducted to compare economic benefits of different tilapia-shrimp polyculture systems.

Results

Tilapia-shrimp polyculture systems

Approximately 26.2% of the interviewed farmers have been operating the tilapia-shrimp polyculture for less than 1 year, 18 % for 1-2 years, 14.8% for 2-3 years, 9.8% for 3-4 years and 31.2% for more than 4 years. Most farmers attributed reasons for adopting tilapia-shrimp polyculture to improving water quality (49.5%), reducing nutrients in effluents (22.6%) and reducing disease outbreak (11.8%). Three major tilapia-shrimp polyculture systems, namely: simultaneous, sequential and crop rotation, were observed. Among the farmers, 42.6% used simultaneous polyculture system, while 34.4% and 6.6% used sequential and crop rotation systems, respectively, and the remaining 16.4% just stocked fish in reservoir ponds and used monoculture system for shrimp.

Two types of simultaneous polyculture were observed in wide ranges of salinity between 0-30 ppt (Tables 1 and 2). Among the farmers who adopt this system, 76.9% released tilapias directly into shrimp ponds, and 23.1% stocked tilapias in the cages suspended in shrimp ponds. Three tilapia strains were cultured, namely, Nile tilapia (*Oreochromis niloticus*), Mossambique tilapia (*O. mossambicus*) and red tilapia (*O. spp.*). In the direct simultaneous polyculture, shrimps were stocked at high densities with the average of 40.7 pcs/m^2 ranging from 31.0 to 62.5 pcs/m^2, and tilapias were stocked at low densities with the average of 0.37 fish/m^2 at least 20 days after stocking shrimp. However, in most cases, stocking densities of tilapias were less than 0.10 fish/m^2. In one case (9), shrimps were stocked at 10.4 pcs/m^2, while red tilapia and milkfish (*Chanos chanos*) were stocked at a density of 3.1 fish/m^2, resulting in very high fish production of more than 13 tons/ha in four months. From Table 1, it is difficult to assess the role of tilapia in shrimp ponds, due to controversial results from different farmers, however, it can be seen that it was better to stock large size tilapia at the later part of the culture cycle. In this system, a very important issue was whether tilapias compete expensive feeds with shrimps. About 40% of the farmers observed such feed competition, while 60% were not aware of this feed competition.

In the cage-cum-pond polyculture system, four 25-m^2 cages were placed in different locations of a shrimp pond of 0.64 ha in surface area in case 1, while only 1 cage ranging from 2.3 to 105 m^2 was suspended in one pond with surface area between 0.40 and 0.96 ha (Table 2). In four out of six cages, tilapias and shrimps were stocked at the same time, while tilapias were stocked 28 days after stocking shrimps in the other two cases. The stocking densities of both shrimps and tilapias varied largely, ranging from 5.2 to 47.0 pcs/m^2 and from 2.0 to 40.0 fish/m^2, respectively. The highest production of both shrimp and tilapia was achieved in a 0.64-ha pond with shrimp stocked at 62.0 pcs/m^2 and Nile tilapia at 10 fish/m^2 in a 100-m^2 cage at 5-10 ppt salinity (Table 2).

In the sequential culture system, shrimps were stocked at different densities ranging from 14.3 to 62.5 pcs/m^2, giving largely varied production from 1,458 to 8,125 kg/ha/crop (Table 3). In fish ponds, tilapia species (Nile tilapia and red tilapia) were cultured with several other species (Table 3). The highest fish production was 13,461 kg/ha in a one-year cycle with supplemental feeds. Salinity in shrimp ponds ranged from 0-20 ppt, while salinity was 0-5 ppt in most fish ponds. Nutrient-rich water in shrimp ponds was pumped into fish ponds. In turn, water in fish ponds was pumped back to shrimp ponds. The frequency of water exchange between shrimp and fish ponds ranged from 1 to 76 times/shrimp crop.

Table 1. Stocking and harvesting data in the simultaneous tilapia-shrimp polyculture with tilapia stocked directly in shrimp ponds.

Case	Salinity (ppt)	Shrimp stocking		Tilapia stocking				Shrimp production (kg/ha/crop)	Shrimp size (g/pcs)	Fish production (kg/ha/crop)	Fish size (g/pcs)	Culture period (month)
		Density (pcs/m^2)	Size (PL)	Species	Density (pcs/m^2)	Size (cm)	Timing (DASS)*					
1	0-5 (20%)	31.0	14	Nile	0.09	1	28	3,125	20.0	228	250	4
2		31.3	15	Nile	0.02	1	28	7,793	25.0	1,289	n.a.	4
3		31.3	15	Red	0.02	3	28	3,646	16.7	156	n.a.	4
4		43.6	17	Nile	1.25	4	56	5,000	15.4	3,125	333	4
5	6-10 (20%)	36.1	16	Nile	0.03	7.5	84	7,813	25.0	60	200	3.5
6		46.9	18	Red	0.02	5	56	4,688	18.5	n.a.	n.a.	3.3
7		50.0	15	Nile	1.56	1	28	4,688	22.2	1,172	200	4
8		46.6	15	Nile+Mossambique	n.a.	n.a.	56	5,000	19.6	n.a.	n.a.	4
9	11-20 (35%)	10.4	11	Red+Milkfish	3.1	2.5	0	2,813	35.7	13,203	500	4
10		37.5	15	Red	0.02	2	56	5,000	n.a.	n.a.	n.a.	4
11		34.4	15	Red	0.02	2	56	5,625	n.a.	n.a.	n.a.	4
12		62.5	16	Red	0.03	n.a.	28	7,500	18.2	n.a.	n.a.	5
13		45.0	16	Nile+Mossambique	n.a.	10	45	5,000	25.0	n.a.	n.a.	4
14		35.0	15	Nile+Mossambique	0.5	10	56	6,250	25.0	n.a.	n.a.	3
15		47.0	12	Red	0.01	6.3	56	4,735	16.7	75.8	800	3.5
16	21-30 (25%)	62.5	15	Red	0.03	1	45	6,094	18.9	n.a.	n.a.	4
17		37.5	15	Red	0.01	2.5	20	6,875	26.3	125	500	4
18		42.5	15	Nile+Mossambique	0.01	10	42	5,938	23.3	n.a.	n.a.	4
19		45.0	15	Red	0.01	17	56	6,250	n.a.	n.a.	1,000	4
20		37.5	17	Red+Mossambique	0.01	15	28	3,688	20.8	n.a.	n.a.	3.5
Mean		40.7±2.6	15±0.3		0.37±0.19	5.6±1.2	43±4.2	5,376±326	22±1.2	2,159±1,420	473±104	3.9±0.1

*DASS – days after stocking shrimp.
Red = red tilapia; Nile = Nile tilapia; Mossambique = Mossambique tilapia.

Table 2. Stocking and harvesting data in the simultaneous tilapia-shrimp polyculture with caged tilapia in shrimp ponds.

Case	Salinity (ppt)	Pond size (ha/pond)	Cage (m^2/pond)	Shrimp stocking		Tilapia stocking				Shrimp production (kg/ha/crop)	Shrimp size (g/pcs)	Fish production (kg/ha/crop)	Fish size (g/pcs)	Culture period (month)
				Density (pcs/m^2)	Size (PL)	Species	Density (pcs/m^2)	Size (cm)	Timing (DASS)*					
1	0-5 (33%)	0.64	4 x 25	47.0	15	Red	40.0	12	0	5,078	16.7	1,094	752	4
2		0.96	105	5.2	15	Red+Nile	23.8	n.a.	0	3,438	n.a.	208	833	4
3	6-10 (17%)	0.64	100	62.0	20	Nile	10	n.a.	0	6,250	16.7	3,906	333	4
4	11-20 (17%)	0.40	105	6.3	12	Red	28.6	1	0	>2,500	n.a.	2,000	800	4
5	21-30 (33%)	0.40	2.3	37.5	15	Red	6.7	7.5	28	5,000	21.7	38	1,000	3.5
6		0.56	15	45.0	15	Red	2.0	15.0	28	On-going				
Mean		0.60±0.01	71±20	33.8±9.5	15±1		18.5±6.0	9±3	9±6	4,942±516	18.4±1.7	1,449±707	744±111	3.9±0.1

*DASS – days after stocking shrimp
Red = red tilapia; Nile = Nile tilapia

Table 3. Stocking and harvesting data in the sequential tilapia-shrimp polyculture.

Case	Shrimp pond					Fish pond						Water exchange (times/shrimp cycle)	
	Salinity (ppt)	Area (ha)	Density (pcs/m^2)	Cycle (mo)	Production (kg/ha/crop)	Salinity (ppt)	Area (ha)	Species	Density (fish/m^2)	Cycle (mo)	Production (kg/ha/crop)	Shrimp to fish	Fish to shrimp
1	0-5 (62%)	0.48	43.8	3.8	5,625	0-5	0.48	NT	2.19	9	8,571	1	8
2		1.2	33.3	3.8	5,625	0-5	1.20	NT,SB,RO,CC,MR	4.7	12	13,461	1	8
3		2.08	62.5	4	5,625	0-5	0.32	NT	3.13	12	n.a.	n.a.	n.a.
4		1.6	46.9	3.8	2,917	0-5	4.8	NT,SB,RO,CC,MR	1.04	8	3,750	76	76
5		0.96	46.9	4.3	n.a.	0-5	0.96	NT,RT,SB,RO,CF	n.a.	n.a.	n.a.	n.a.	n.a.
6		0.4	46.9	4	4,688	0-5	0.16	NT,CF	0.06	4	n.a.	16	16
7		2.4	31.3	4	3,750	0-5	1.2	NT,SG	n.a.	12	n.a.	n.a.	12
8		1.68	14.3	3.5	3,571	0-5	3.2	RT	2.34	12	6,250	n.a.	n.a.
9		3.84	31.3	5	4,375	0-5	0.96	RT	0.06	7	3,125	n.a.	n.a.
10		0.34	34.4	4	5,938	0-5	0.34	RT	0.63	6	n.a.	15	15
11		3.84	31.3	4	3,646	0-5	9.6	NT,SB,RO,CC,MR	3.13	10	5,208	15	15
12		1.6	62.5	4	5,313	0-5	1.6	NT,SB,SH,MR	n.a.	n.a.	n.a.	n.a.	75
13		0.72	n.a.	3.5	8,125	0-5	0.16	RT	n.a.	5	n.a.	n.a.	5
14	6-10 (19%)	2.4	25.0	4	5,000	0-5	1.92	RT	3.1	4	n.a.	n.a.	n.a.
15		0.72	25.0	3.8	1,458	0-5	1.2	NT	n.a.	8.5	n.a.	8	8
16		4.8	62.5	3.3	4,063	0-5	0.48	NT,RT	0.63	7.5	7,500	10	10
17		0.96	62.5	4	5,924	6-10	0.32	NT,CF,SG	n.a.	12	n.a.	n.a.	1
18	11-20 (19%)	2.24	34.4	3	6,250	0-5	2.72	NT,CF	1.25	12	n.a.	n.a.	4
19		0.96	31.3	3.5	2,188	0-5	1.60	NT,RT,SE,RO	n.a.	10	3,125	5	11
20		1.76	43.8	3.8	2,188	0-5	0.80	RT	0.19	n.a.	n.a.	7	7
21		4.8	46.9	4.3	4,375	6-10	2.72	NT	0.77	3	313	9	9
Mean		1.9± 0.3	40.8± 3.1	3.9± 0.1	4,532± 362		1.7± 0.5		1.66± 0.39	8.6± 0.7	5,700± 1,282	15±6	18±6

Note: NT = Nile tilapia; RT = Red tilapia; SB = Silver barb; SE = Seabass; CF = Hybrid catfish; CC = Chinese carps; RO = rohu; SH = Snakehead; MI = mrigal; SG = Snakeskin gourami.

Table 4. Stocking and harvesting data in the crop rotation tilapia-shrimp polyculture.

Case	Shrimp pond					Fish pond					
	Salinity (ppt)	Area (ha)	Density (pcs/m^2)	Cycle (mo)	Production (kg/ha/crop)	Salinity (ppt)	Area (ha)	Species	Density (fish/m^2)	Cycle (mo)	Production (kg/ha/crop)
1	0-5 (25%)	0.85	29.5	4	2,621	0-5	4.16	NT,SE,SB,RO,JA	n.a	8.5	4,128*
2	6-10 (50%)	0.53	46.9	4	3,314	0-5	1.6	NT,SE	9	18	4,735
3		0.26	62.5	4	2,813	0-5	0.8	RT,CF,SB,SE	2	11	n.a.
4	10-20 (25%)	2	50.0	4	4,688	0-5	n.a.	NT	1	4.5	2,813*
Mean		0.91±0.38	47.2±6.8	4±0	3,359±466		2.19±1.01		4.0±2.5	11±3	3,892±567

Note: NT = Nile tilapia; RT = Red tilapia; SB = Silver barb; SE = Seabass; CF = Hybrid catfish; RO = rohu; JA = Jalamed.
* supplemental feeds were given to fish.

Four farmers (6.6%) have practiced the crop rotation style of tilapia-shrimp polyculture. The pond areas of shrimp and fish culture were 0.91 ha and 2.19 ha per farm, respectively (Table 4). One farmer cultured Nile tilapia in the monoculture system, while the other farmers practiced polyculture Nile tilapia or red tilapia with several other fish species (Table 4). Average stocking densities of shrimp and fish were 47.2 pcs/m^2 and 4.0 fish/m^2, respectively. Average production of shrimp and fish was 3,359 and 3,3892 kg/ha/crop, respectively.

Comparison of shrimp production between polyculture and monoculture

Compared to monoculture system, shrimp production has increased after using simultaneous and sequential tilapia-shrimp polyculture systems. Production from both simultaneous and sequential tilapia-shrimp polyculture systems was also higher than that from the current monoculture system. For the crop rotation system, the data of previous monoculture system was not available, thus no comparison could be done. However, the shrimp production from the crop rotation system is similar to that from the current monoculture system. The highest shrimp production was achieved in the direct polyculture system, intermediate in the cage-cum-pond system and sequential system, and lowest in the crop rotation system (Table 5). The highest increase of shrimp production was 29.0% in the direct polyculture system, followed by 24.2% in the sequential system and 18.6% in the cage-cum-pond system. It is surprising that feed conversion ratio (FCR) was low in the two simultaneous systems and sequential systems, that is, 1.49 in the direct polyculture, 1.92 in the cage-cum-pond polyculture, and 1.32 in the sequential system, compared to 2.04 in the crop rotation system and 2.40 in the monoculture.

Table 5. Comparison of shrimp production (kg/ha/crop) between, before and after using polyculture, and between monoculture and polyculture.

Current culture systems	Before using polyculture (monculture)	After using polyculture (polyculture)
Simultaneous system		
Direct polyculture	4,169±733 (n=8)	5,376±326 (n=20)
Cage-cum-pond	4,167±1,667 (n=2)	4,942±516 (n=4)
Sequential system	3,648±890 (n=5)	4,532±362 (n=20)
Crop rotation system	----	3,359±466 (n=4)
Monoculture	3,524±331 (n=10)	

Partial budget analysis in polyculture systems

To conduct the partial budget analysis, several assumptions were made due to limited data available. It was assumed that feed conversion ratio, shrimp stocking density, pond inputs except feed, unit prices of all revenue and cost items were the same before and after adopting different styles of tilapia-shrimp polyculture systems. Likewise, the unit prices of all revenue and cost items, and pond inputs except feed were assumed to be the same among all farms of different polyculture systems. The costs of hapas used for nursing shrimp larvae and cages used for confining tilapia were ignored.

All farmers adopting both simultaneous and sequential tilapia-shrimp polyculture systems had increased profit ranging from 3,280 to 5,187 US$/ha/crop, compared to their respective previous monoculture system (Table 6). The increased profit was higher in the two simultaneous systems than in the sequential system (Table 6). Compared to the current monoculture system, the two simultaneous systems (direct polyculture and cage-cum-pond polyculture) and sequential system have attained an increase in profit ranging from 6,573 to 9,758 US$/ha/crop, while the crop rotation polyculture system has only marginal increase of profit (Table 7). Again, the increased profit was higher in the two simultaneous systems than in the sequential system (Table 7). In the simultaneous tilapia-shrimp polyculture system, the direct polyculture style had produced higher profit than in the cage-cum-pond style (Table 7).

Discussion

Nearly half of interviewed farmers (49.5%) said that tilapia can improve water quality, and also reduce nutrients in pond effluents (22.6% farmers). This shows that Thai farmers understand the potential or efficiency of tilapia thus, it could sustain the shrimp production for them. Tian *et al.* (2001a) investigated the water quality in a closed polyculture system containing Chinese penaeid shrimp (*Penaeus chinensis*) with Taiwanese red tilapia (*O. mossambicus* x *O. niloticus*) and constricted tagelus *(Sinonovacula constricta*). They found that bacteria and organic matter were significantly reduced in the polyculture system compared to monoculture. In addition, N and P levels were measured in sediments of the polyculture enclosure and found to be 39.76% and 51.26% lower than those of monoculture sediments, respectively. These results indicate that tilapia are useful in improving water quality in shrimp ponds. Tian *et al.* (2001b) also reported that the best stocking rates were 7.2 shrimp/m^2, 0.08 tilapia/m^2 and 14 tagelus/m^2 in the polyculture of Chinese penaeid shrimp, Taiwanese red tilapia and constricted tagelus. Wang *et al.* (1998) also found that the optimum stocking density of Chinese shrimp and Taiwanese red tilapia was 6 shrimp/m^2 and 0.32 tilapia/m^2 (126.3 g in size). Compared to the above results, Thai farmers stock shrimps at much higher densities. Overstocking makes management more difficult and is not sustainable in the long run. In comparison, the farmers stocked tilapia with average size of 3-6 cm in length, which might be too small to effect any improvement in the pond environment. The farmers were reluctant to stock large fish since they thought that large fish might eat shrimps. Guo-Chang (1989) found that tilapia fry and fingerlings (1-9 cm) are strong predators on other fish and are known to be cannibalistic if food is in short supply, however, no evidence of shrimps preyed by tilapias was found. Akiyama and Anggawati (1999) reported that yields of shrimp increased when tilapia were stocked into existing shrimp ponds. The suggested stocking rate was 20-25 g fish/m^2 with the size of 50-100 g. The use of all-male fish was needed to control reproduction. Fish were stocked when the shrimp biomass was at least 80 g/m2 (for 3-4 g shrimp) or 150 g/m2 (for 5-6 g shrimp). Tilapia harvest biomass was 40-50 g/m^2 and shrimp survival was 70%. These results seem to indicate that tilapia and shrimp can cohabit the same pond peacefully, without predator-prey relationship established.

The shrimp production and survival in the simultaneous and sequential polyculture was higher than that in monoculture in the present survey. Gonzales-Corre (1988) found that total yield from polyculture was better than that from monoculture in the polyculture of *P. monodon* with Nile tilapia in brackish water. Similarly, Tian *et al*. (2001b) reported that survival and net yield of shrimp in a polyculture system was higher by 3-16 % and 5-17% than that in the monoculture, respectively, due probably to the better water quality in the polyculture system.

Gonzales-Corre (1988) reported that tilapia were found to compete with shrimp for food. Saelee (2002) conducted studies on the polyculture of shrimp and Nile tilapia in low salinity water. He found that FCR of shrimp from polyculture was approximately equal to 2 and was higher than that in the monoculture (about 1.6). He concluded that tilapia-shrimp polyculture is feasible technically, but may not be attractive economically. One way of circumventing the problem of tilapia competing with shrimp for expensive pelleted feed is by culturing the tilapia in a cage. In the present survey, however, FCR of shrimp in the polyculture was found to be lower than that in the monoculture.

Red tilapia and Mozambique tilapia were the favored species in the southern Thailand. The most favorite tilapia strain among the surveyed shrimp farmers was red tilapia. The farmers observed that red tilapia grew faster and could command a high price in the market. However, some farmers in the central provinces stocked solely Nile tilapia because they cultured their shrimp in low salinity waters (0-5 ppt). Another reason given for choosing Nile tilapia was that it was easier for them to find seed of this species in hatcheries compared to red tilapia.

One farmer in Petchaburi province polycultured milkfish with shrimp, with the purpose of using milkfish in improving water quality in shrimp ponds and in cleaning up waste from the pond bottom. However, Baylon (1996) reported that polyculture of shrimp with milkfish resulted to significantly higher phytoplankton content compared to monoculture, but no significant differences in biological oxygen demand, total suspended solids, phosphate, nitrate and ammonia contents of pond water between polyculture and monoculture. Baylon (1996) also undertook a crop rotation experiment to determine the effect on sediment quality of shrimp ponds by culturing milkfish immediately after shrimp harvest. The results showed that sediment sampled from the ponds where milkfish had been cultured had shown a decrease in organic matter for three ponds only, while the phosphorus content decreased in only two ponds. Tian *et al*. (2001a) reported that most varieties of tilapia are omnivorous in feeding habit and are filter feeders in the main, thus they are capable of improving water quality in ponds (Diana *et al*., 1991; Ruan *et al*., 1992, 1993; Zhang *et al*., 1999).

The present survey showed that the use of chemicals for shrimp culture was reduced in the polyculture, compared to monoculture. If such polyculture systems could be optimized to eliminate the use of chemicals in the tilapia-shrimp polyculture, the resultant tilapias and

Table 6. Partial budget analysis to compare increased profit from shrimp ponds alone between direct and currently used cage-cum-pond style of simultaneous tilapia-shrimp polyculture, sequential tilapia-shrimp polyculture and crop rotation tilapia-shrimp polyculture and their respective previous monoculture (unit: US$/ha/crop).

Item	Farmers using direct polyculture		Farmers using cage-cum-pond polyculture		Farmers using sequential polyculture	
	Previous Monoculture (n=8)	Current Polyculture (n=18)	Previous Monoculture (n=2)	Current Polyculture (n=4)	Previous Monoculture (n=5)	Current Polyculture (n=18)
Income from shrimp	19,553	25,213	19,543	23,178	17,109	21,255
Income from fish	----	1,209	----	2,768	----	----
Added income (A)	----	6,869	----	6,403	----	4,146
Cost for feed	4,597	6,311	5,920	7,024	3,563	4,429
Cost for fish seed	----	104	----	112	----	----
Added cost (B)	----	1,818	----	1,216	----	866
Increased profit (A-B)	----	5,051	----	5,187	----	3,280

Table 7. Partial budget analysis to compare increased profit from shrimp ponds alone between different tilapia-shrimp polyculture systems and monoculture system found in the current survey (unit: US$/ha/crop).

Item	Current Monoculture (n=4)	Direct Polyculture (n=18)	Cage-cum-pond Polyculture (n=4)	Sequential Polyculture (n=18)	Crop rotation Polyculture (n=3)
Income from shrimp	16,523	25,213	23,178	21,255	15,754
Income from fish	----	1,209	2,768	----	----
Added income (A)	----	9,899	9,423	4,732	-769
Cost for feed	6,270	6,311	7,024	4,429	5,048
Cost for shrimp seed	1,632	1,628	1,352	1,632	1,888
Cost for fish seed	----	104	112	----	----
Added cost (B)	----	141	586	-1,841	-966
Increased profit (A-B)	----	9,758	8,837	6,573	197

shrimps then could be marketed as "green" products, giving benefit to both producers and consumers.

Therefore, polyculture of shrimp with tilapias may provide an alternative approach for shrimp farming, which could ultimately lead to a more sustainable shrimp industry. However, further research is needed on merits of converting from monoculture to polyculture of shrimp.

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