Asian Fisheries Science
The Journal of the Asian Fisheries Society

Asian Fisheries Science **24** (2011):88-95

ISSN 0116-6514
E-ISSN: 2073-3720
https://doi.org/10.33997/j.afs.2011.24.1.008

Experimental Partitioned Co-culture of Channel Catfish *Ictalurus punctatus* and Blue Tilapia *Oreochromis aureus*

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Abstract

Blue tilapia, *Oreochromis aureus* were experimentally co-cultured with channel catfish, *Ictalurus punctatus* in floating cages, without supplemental feeding. Tilapia were stocked on April 20, 1995 at the equivalent of 5000 ha^{-1} and channel catfish fingerlings were stocked on Mar. 20, 1995 at 27500 ha^{-1}. After harvest on Oct. 23, 1995 (185 d), tilapia averaged 437.7$\pm$ 4.26 g each. From a stocking size of 24.9 $\pm$ 5.16 g, the daily growth was 2.2 $\pm$ 0.23 $g.d^{-1}$. Improvements in water quality in co-culture were reduced levels of pH, TAN (total ammonia-nitrogen) and UIA (un-ionized ammonia). Aeration in co-culture ponds was significantly higher in August. Chlorophyll *a* was not significantly different. Mean net combined yield in co-culture ponds, with the addition of 2118.55 $\pm$ 367.15 $kg.ha^{-1}$ tilapia, was significantly higher, 12001.64 $\pm$ 767.43 vs. 10,055.74 $\pm$ 734.70 $kg.ha^{-1}$, than in monoculture. FCR (food conversion ratios) for catfish were not significantly different; however, with tilapia included they were significantly lower, 1.58 $\pm$ 0.11 vs. 1.85 $\pm$ 0.85. Blue tilapia were beneficial to production and outperformed Nile tilapia in a similar system by reaching marketable size (0.4 kg) with no additional feed.

Introduction

Co-culture is the raising of more than one species in the same rearing unit or system in a compatible manner. It has also been termed polyculture, and is a key component of sustainable aquaculture, or aquecology (after agroecology, Gliessman, 2000). The species co-cultured is secondary to the main culture species and is added to improve water quality, reduce disease incidence, add a food source and/or improve economics of the overall system. Co-culture systems are typically used in outdoor ponds, tanks or raceways, but also in recirculation systems and other grow-out units (Perschbacher and Freeman, 2004). A beneficial tilapia commercial co-culture system is with penaeied shrimp in seawater ponds (Fitzimmons, 2001).

Low-intensity systems have traditionally utilized polyculture to further efficiency where resources are scarce. In these systems, the species are mixed and may be said to form a mixed co-culture or ecological aquaculture (Costa-Pierce, 2002). A partitioned co-culture system with the secondary species (Nile tilapia, *Oreochromis niloticus*) separated from the primary species (channel catfish, *Ictalurus punctatus*) has been examined to optimize the water quality benefits (Perschbacher, 1995, 2003a). A ratio of 1:4 tilapia:channel catfish by number to attain a weight ratio of 1:8 or 5,000 $tilapia.ha^{-1}$ to 20000 channel $catfish.ha^{-1}$ was used based on Perschbacher and Lorio (1993). Tilapia were placed in floating cages, thus benefiting water quality and tilapia growth by consumption of channel catfish direct and indirect wastes (phytoplankton,

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zooplankton, bacteria), while avoiding feed competition and tilapia reproduction and facilitating tilapia harvest. The latter have been identified as major impediments to tilapia culture in the southern U.S. (Hargreaves, 2000).

A partitioned co-culture system, termed cage-cum-pond, has successfully evaluated fed caged *Clarias spp.* and unfed, sex-reversed, free-roaming Nile tilapia, in Thailand (Lin, 1990; Lin and Diana, 1995). Unfed, partitioned Nile tilapia are an essential component of a high density partitioned aquaculture system (PAS) with channel catfish (Brune et al. 2003).

During trials, evaluating the partitioned co-culture system of Nile tilapia with channel catfish substantial improvement in water quality (reduced off-flavor algae, stabilized phytoplankton populations, and improved oxygen and ammonia levels) and catfish production was found. However, without supplemental feed and with the need to harvest in the fall before lethal temperatures for tilapia, the Nile tilapia averaged less than 0.2 kg (Perschbacher, 2003a). In this system, the tilapia were not raised to provide an additional crop, but rather to improve water quality, primarily by reducing off-flavor-causing cyanobacteria. Feeding tilapia would have reduced their effectiveness in cropping algae and suspended organic matter and likely added to overall system costs. With the value of tilapia increasing and market size growing, an additional objective in tilapia co-culture would be producing a marketable product of 0.45 kg (Morrison et al. 1995).

Another major tilapia species that effectively filter-feeds and has been examined in co-culture with catfish is blue tilapia, *Oreochromis aureus* (Williamson and Smitherman, 1975; Torrans and Lowell, 1987; Morrison et al. 1995). Stanley and Jones (1976) found blue tilapia grew 36% in 36 d on a 2.8% bw.d^{-1} dried *Spirulina* diet with a food conversion ratio (FCR) of 2.0. Blue tilapia, however, have also been found to consume large amounts of zooplankton (Spataru and Zorn, 1978). In a mixed co-culture study to maximize blue tilapia growth, 2500 ha^{-1} 0.5-g blue tilapia fry attained an average of 0.327 kg with 10000 fed channel catfish and blue catfish, *Ictalurus furcatus* fingerlings.ha^{-1} after 167 d (Morrison et al. 1995). Another study also utilized mixed co-culture of blue tilapia and catfish to provide forage and improve water quality (Torrans and Lowell, 1987). At 5000, 6.1-g blue tilapia fry.ha^{-1} with 10000 fed channel catfish.ha^{-1} the average size attained after 140 d was 0.258 and 0.208 kg for male and female blue tilapia, respectively (Torrans and Lowell, 1987). In these mixed co-culture studies, tilapia had access to supplemental feed.

This study designed and tested a partitioned co-culture system of blue tilapia and channel catfish, similar to a Nile tilapia co-culture system evaluated earlier (Perschbacher, 2003a). Although channel catfish stocking was increased from 20000 to 27500 ha^{-1} and no bighead carp, *Hypophthalmichthys nobilis* were added, other aspects were the same.

Materials and Methods

Experimental earthen ponds at the University of Arkansas at Pine Bluff (UAPB) Aquaculture Research Station were utilized. Ponds were filled with well water with alkalinity and hardness of approximately 150 mg.l^{-1} as calcium carbonate. Mixed blue tilapia averaging 24.9 $\pm$ 5.16g were stocked on April 20, 1995 into four, 1m^3 floating cages (1.27 cm by 2.54 cm mesh) at 50 per cage or 5000 ha^{-1} in each of four, 0.04-ha ponds. These were 1-year old fish that had been held over the winter in hatchery tanks. Catfish fingerlings had been stocked on March 20, 1995 at 27500 ha^{-1}. Four additional ponds were controls without caged tilapia, but with free-roaming channel catfish. Catfish were fed 32% protein floating pellets 5 d.$week^{-1}$ to satiation, with amount fed recorded. Tilapia were not fed. A selective harvest of 730 g marketable catfish by size-selective seining was made on July 14, 1995. All ponds were harvested on Oct. 23, 1995 and tilapia counted, while catfish subsamples were weighed and fish counted. Reproduction of channel catfish and tilapia was estimated at harvest, and included in gross and net yield calculations. The reproduction data were not included in size, gain, or survival calculations.

Daily dissolved oxygen (DO) readings were made in the morning and late afternoon in each pond with a multiprobe meter (OI Analytical, College Station, TX). Aeration was supplied when morning DO values were at or below 3.0 mg.l^{-1} or afternoon values at or below 5.0 mg.l^{-1}. Water quality and plankton were sampled weekly in each pond. A PVC water column sampler was employed at 0800-0900 h to obtain a sample that was taken to the nearby laboratory for determination of total ammonia-nitrogen (TAN) and nitrite-nitrogen by nessler and diazotization methods, respectively (HACH, Loveland, CO.), and water temperature and pH with the Aquacheck meter. Un-ionized ammonia (UIA) was calculated. FCR (food conversion ratio) was calculated by weight of feed divided by weight of fish produced. Production and monthly water quality data were compared between treatments using Student's t-test for paired samples with 3 df. The alpha level was set at 0.05.

Results

Production results are presented in Table 1. At harvest on October 23 1995, tilapia averaged 437.7 $\pm$ 42.6g and catfish averaged 511.0 $\pm$ 26.2g and 493.2 $\pm$ 41.2g without and with tilapia, respectively. The selective harvest for catfish yielded 154.50 $\pm$ 9.80 and 150.59 $\pm$ 6.08 kg without and with tilapia, respectively. Catfish net yield, with the selective harvest, averaged 10055.74 $\pm$ 734.70 and 9883.09 $\pm$ 1101.36 kg.ha^{-1} without and with tilapia, respectively. Tilapia net yield was 2118.55 $\pm$ 367.15 kg.ha^{-1}. Total net yield averaged 10048.35 $\pm$ 734.70 and 12001.80 $\pm$ 767.43 kg.ha^{-1} without and with tilapia, respectively. Gross yields averaged 12520.25 $\pm$ 734.75 and 14596.56 $\pm$ 773.51 kg.ha^{-1} without and with tilapia, respectively. Highest gross yield was 15622 kg.ha^{-1}. Mean daily weight gain for fed catfish was 1.94 $\pm$ 0.12 and 1.84 $\pm$ 0.19 g.d^{-1} without and with tilapia, respectively. Mean daily weight gain for unfed blue tilapia was 2.23 $\pm$ 0.023 g.d^{-1}. Food conversion ratios for catfish were 1.85 $\pm$ 0.05 and 2.00 $\pm$ 0.23 without and with tilapia, respectively. With tilapia included, the combined FCR was 1.58 $\pm$ 0.11.

Aerators were needed in non tilapia ponds beginning in June, 1995 at an average 8.25 $\pm$ 1.7 instances.pond^{-1} and increasing to 8.75 $\pm$ 2.9 instances in September, 1995. In tilapia ponds, usage also began in June, 1995 with 5.75 $\pm$ 3.0 instances required per pond, increasing to 12.5 $\pm$ 1.9 in August, 1995. August was the only month when significant differences were found, Aeration needs declined in October, with cooler weather and lower feeding.

Water quality results are presented in Table 2. Morning dissolved oxygen levels were significantly higher in ponds without tilapia during the months of September and October, but average levels were quite high for all months. Monthly pH levels were only significantly different in March, with tilapia ponds lower. The TAN was significantly higher in ponds without tilapia in June and July, and combined with the higher pH for those months resulted in significantly higher UIAs. Nitrite-nitrogen levels were low and significantly higher in ponds without tilapia in July and August. Chlorophyll *a* levels did not significantly differ and were below 100 ug.l^{-1}, with the exception of August in ponds without tilapia. Pheophytin *a* concentration was lower in ponds without tilapia during each month and significantly so in April and May.

Table 1. Production parameters, mean ($\pm$ Standard Deviation), in 0.04-ha channel catfish ponds with and without co-cultured blue tilapia. Tilapia were stocked April 20, 1995 and catfish March 20, 1995 and harvested October 23, 1995 (after 185 and 215 d, respectively). A selective harvest of marketable catfish was performed July 13, 1995.

Parameter	Without Tilapia	With Tilapia
Stocking-catfish		
Density (fish ha^{-1})	27,500	27,500
Mean weight (g fish^{-1})	89.9 (136.2)	89.9 (136.2)
Total weight (kg)	247.2	247.2
Stocking-tilapia		
Density (fish ha^{-1})		5,000
Mean weight (g fish^{-1})		24.9 (5.16)
Total weight (kg)		12.45
Harvest-selective catfish		
Mean weight (g fish^{-1})	739.02 (46.95)^{a}	727.35 (38.90)^{a}
Total weight (kg)	154.50 (9.80)^{a}	150.59 (6.08)^{a}
Harvest-final catfish		
Mean weight (g fish^{-1})	511.0 (26.2)^{a}	493.2 (41.2)^{a}
Total weight (kg)	341.47 (42.14)^{a}	329.63 (55.57)^{a}
Survival-combined (%)	88.4 (3.9)^{a}	88.5 (2.9)^{a}
Harvest-final tilapia		
Mean weight (g fish^{-1})		437.7 (42.6)
Total weight (kg)		80.29 (7.76)
Survival (%)		91.7 (2.8)
Reproduction-catfish		
Total weight (kg)	2.18 (3.52)^{a}	13.95 (13.67)^{a}
Reproduction-tilapia		
Total weight (kg)		9.41 (7.71)
FCR		
Catfish	1.85 (0.05)^{a}	2.00 (0.23)^{a}
Catfish and tilapia	1.85 (0.05)^{a}	1.58 (0.11)^{b}

Gain-catfish		
Mean gain (g fish^{-1})	421.1 (26.2)^{a}	403.3 (41.2)^{a}
Daily weight gain (g fish^{-1} d^{-1})	1.94	1.84
Total weight gain (kg)	282.5 (42.14)^{a}	275.4 (55.57)^{a}
Gain-tilapia		
Mean gain (g fish^{-1})		412.8 (42.6)
Daily weight gain (g fish^{-1} d^{-1})		2.23
Total weight gain (kg)		75.75 (7.76)
Yield-catfish		
Gross yield (kg ha^{-1})	12,520.25 (734.75)^{a}	2,355.25 (1101.25)^{a}
Net yield (kg ha^{-1})	10,055.74 (734.70)^{a}	9,883.09 (1101.36)^{a}
Yield-tilapia		
Gross yield (kg ha^{-1})		2,243.05 (365.14)
Net yield (kg ha^{-1})		2,118.55 (367.15)
Yield-combined		
Gross yield (kg ha^{-1})	12,520.25 (734.75)^{a}	14,596.56 (773.51)^{b}
Net yield (kg ha^{-1})	10,048.25 (734.70)^{a}	12,001.80 (767.43)^{b}

Mean values with different superscript letters in the same row were significantly different ($P \leq 0.05$).

Discussion

The positive benefits from partitioned co-culture of channel catfish and blue tilapia were substantial. In comparison to previous research with Nile tilapia co-culture in cages with channel catfish, blue tilapia in co-culture also improved water quality through reduced levels of unionized ammonia. However, while Nile tilapia averaged 0.21 $\pm$ 0.02 kg (Perschbacher, 2003a), blue tilapia averaged twice their size, 0.44 $\pm$ 0.04 kg.

Blue tilapia are assumed to have attained greater size and faster growth rate compared to Nile tilapia by consuming zooplankton (and perhaps other organic matter) as suggested by significantly reduced nauplii, cladocerans and copepods in the co-culture ponds (White and Perschbacher, 1996). In mesocosm comparisons with other microorganism filter-feeders, blue tilapia reduced rotifers, copepods, nauplius and cladocerans by 88, 87, 72 and 100% respectively, which was a greater percentage reduction than by Nile tilapia, silver carp, *Hypothalmichthys molitrix*, threadfin shad, *Dorosoma petenese* (with the exception of nauplii) and 2 local unionid clams (Perschbacher, 2003b). Apparently, blue tilapia converted this rich source of food, with approximately 50% protein and high in lipids (Grabner et al. 1981), into fish flesh. Caprellid amphipods have also been proposed to provide marine carnivorous fish with adequate nutrition without fish meal (Woods, 2009). As feed is the most costly production input and issues of sustainability concerning fish meal are growing, utilizing this rich source of neglected production is promising.

Table 2. Mean (± Standard Deviation) days of aerator use (Aer.) and morning water quality indices by month and treatment: no tilapia (NT), tilapia (T).

Month/Treatment	Aer. (#)	DO (mg l^{-1})	pH	TAN (mg l^{-1})	UIA-N (mg l^{-1})	N02-N (mg l^{-1})	Chl. *a.* (ug l^{-1})	Pheo. *a.* (ug l^{-1})
March								
NT	0.0	7.78^{a}	8.24^{a}	0.36^{a}	0.014^{a}	0.02^{a}	11.2^{a}	6.8^{a}
		(0.34)	(0.05)	(0.03)	(0.002)	(0.005)	(6.7)	(3.6)
T	0.0	7.43^{a}	8.15^{b}	0.42^{a}	0.02^{a}	0.005^{a}	11.6^{a}	7.4^{a}
		(0.25)	(0.04)	(0.05)	(0.001)	(0.01)	(4.9)	(7.2)
April								
NT	0.0	6.42	8.27^{a}	0.47^{a}	0.03^{a}	0.007^{a}	52.1^{a}	17.0^{a}
		(0.77)	(0.19)	(0.03)	(0.02)	(0.003)	(19.1)	(5.22)
T	0.0	6.27^{a}	8.16^{a}	0.53^{a}	0.02^{a}	0.005^{a}	40.0^{a}	29.9^{b}
		(0.69)	(0.10)	(0.05)	(0.01)	(0.004)	(1.0)	(3.4)
May								
NT	0.0	5.50^{a}	8.12^{a}	1.23^{a}	0.081^{a}	0.11^{a}	27.9^{a}	28.9^{a}
		(0.66)	(0.31)	(0.54)	(0.085)	(0.11)	(17.3)	(8.4)
T	0.0	5.67^{a}	8.10^{a}	1.01^{a}	0.054^{a}	0.13^{a}	32.2^{a}	34.2^{b}
		(0.89)	(0.28)	(0.34)	(0.043)	(0.12)	(18.1)	(8.1)
June								
NT	8.25^{a}	5.67^{a}	8.11^{a}	2.11^{a}	0.12^{a}	0.21^{a}	33.5^{a}	10.7^{a}
	(1.7)	(0.37)	(0.28)	(0.51)	(0.04)	(0.05)	(20.4)	(6.3)
T	5.75^{a}	5.81^{a}	8.03^{a}	1.53^{b}	0.07^{b}	0.16^{a}	43.7^{a}	13.3^{a}
	(3.0)	(0.60)	(0.24)	(0.56)	(0.01)	(0.02)	(6.8)	(3.3)
July								
NT	8.5^{a}	5.38^{a}	7.66^{a}	3.43^{a}	0.14^{a}	0.27^{a}	60.1^{a}	15.4^{a}
	(2.6)	(0.70)	(0.40)	(1.01)	(0.04)	(0.08)	(14.1)	(4.5)
T	8.0^{a}	4.73^{a}	7.70^{a}	2.16^{b}	0.07^{b}	0.16^{b}	53.5^{a}	21.2^{a}
	(3.7)	(0.52)	(0.17)	(0.72)	(0.04)	(0.03)	(39.6)	(4.3)
August								
NT	6.0^{a}	5.04^{a}	7.65^{a}	1.90^{a}	0.05^{a}	0.14^{a}	110.0^{a}	16.9^{a}
	(2.6)	(0.35)	(0.16)	(0.31)	(0.01)	(0.02)	(41.04)	(4.9)
T	12.5^{b}	4.96^{a}	7.58^{a}	1.61^{a}	0.04^{a}	0.07^{b}	87.3^{a}	21.2^{a}
	(1.9)	(0.60)	(0.23)	(0.36)	(0.02)	(0.02)	(29.6)	(8.9)
September								
NT	8.75^{a}	5.74^{a}	7.71^{a}	2.86^{a}	0.07^{a}	0.23^{a}	89.7^{a}	26.5^{a}
	(2.9)	(0.66)	(0.25)	(0.32)	(0.02)	(0.10)	(68.3)	(11.3)
T	6.25^{a}	5.21^{b}	7.65^{a}	2.71^{a}	0.06^{a}	0.17^{a}	79.0^{a}	34.8^{a}
	(1.26)	(0.70)	(0.26)	(0.35)	(0.03)	(0.06)	(17.3)	(13.9)
October								
NT	5.75^{a}	8.69^{a}	7.75^{a}	1.85^{a}	0.04^{a}	0.22^{a}	35.7^{a}	14.7^{a}
	(2.6)	(2.60)	(0.03)	(0.37)	(0.01)	(0.1)	(6.7)	(4.7)
T	3.5^{a}	7.79^{b}	7.62^{a}	1.37^{a}	0.02^{b}	0.17^{a}	44.0^{a}	17.2^{a}
	(1.7)	(2.22)	(0.05)	(0.06)	(0.00)	(0.05)	(13.0)	(10.1)

Mean values with different superscript letters in the same column within the same month were significantly different ($P \leq 0.05$).

Although not analyzed in this study, the nutrient profile of tilapia has been enhanced by a doubling of the ratio of *n*-3 to *n*-6 fatty acids through utilizing natural food sources compared to commercial diets (Karapanagiotdis et al. 2002; Zenebe et al. 2003). The *n*-3 to *n*-6 ratio in natural populations of Nile tilapia in Ethiopia has varied to even greater degree from 1.61 to 6.67, attributed to different natural food types (especially zooplankton) (Zenebe et al. 1998). An experimental diet fed to Nile tilapia of half *Spirulina* and half 32% protein catfish commercial feed has reduced the need for supplemental feed, with a resulting better nutritional profile (Perschbacher et al. 2009).

Marketing, cage installation, hatchery availability, and state-by-state regulation of blue tilapia are issues to be addressed on a commercial application level.

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Received:25/01/2011; Accepted: 23/03/2011(MS10-59)