Mitigating the Effects of High Temperature and Turbidity on Seed Production of Nile Tilapia from Hapa-In-Pond Systems

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Yang Yi and Potjanee Clayden
Aquaculture and Aquatic Resources Management
Asian Institute of Technology
Pathumthani, Thailand

James E. Rakocy
Agricultural Experiment Station
University of the Virgin Islands
Kingshill St. Croix, Virgin Islands

James S. Diana
School of Natural Resources and Environment
University of Michigan
Ann Arbor, Michigan

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Abstract

A study, consisting of two experiments, was conducted at the Asian Institute of Technology (AIT), Thailand, for 95 days for Experiment A and 113 days for Experiment B during May 2003–March 2004 to investigate effects of high temperature and turbidity on seed production of Nile tilapia. Experiment A was conducted using a randomized complete block design in a 300-m^2 earthen pond of 1.6 m deep, and had three treatments with three replicates each: (A) 70-cm water depth in hapas (control); (B) 100-cm water depth in hapas; and (C) 140-cm water depth in hapas. Experiment B was conducted using a complete randomized design in six 200-m^2 earthen ponds of 1.2 m deep, and had two treatments with three replicates each: (A) without underwater walkways (control); (B) with underwater walkways.

Egg production was increased by about 72% and 96% in the 100- and 140-cm treatments, compared to the control. There was no significant difference in mean individual egg weight among all three treatments ($P > 0.05$). Fertilization rates in the two deeper treatments (37.49% and 42.05% in the 100- and 140-cm deep treatments, respectively) were significantly higher than that (21.06%) in the control ($P < 0.05$), however, hatching rates were not significantly different among all three treatments ($P > 0.05$). Lowering water temperature by using deep ponds is an effective way to increase reproductive performance of Nile tilapia during the hot season.

The turbidity at the end of the experiment and its change throughout the experiment was significantly lower in the treatment with walkways than in the treatment without walkways ($P < 0.05$), however, there was no significant difference in egg production, fertilization rate and hatching rates between the two treatments ($P > 0.05$). Lowering turbidity and fouling caused by egg collection through underwater walkways may not be effective in improving reproductive performance. However, further research is needed on the effects of fouling on reproductive performance of Nile tilapia.

Introduction

Among several methods used for mass seed production of Nile tilapia (*Oreochromis niloticus*), hapa-in-pond spawning is perhaps the most efficient and widely adopted by commercial hatcheries in Southeast Asia (Little, 1989; Little et al., 1997). The hapa-in-pond hatchery method developed by the Asian Institute of Technology involves broodfish spawning, egg incubation, and fry collection in net cages (hapas) suspended in earthen ponds. Using this technology, a large number of quality tilapia fry can be produced continuously throughout the year in the tropics (Bhujel, 1999). In Thailand, more than 50 million fry are produced monthly with this method.

Reproduction of Nile tilapia can begin at water temperature as low as 20°C (Popma and Lovshin 1996) with optimum water temperature ranging from 25 to 32°C (Philippart and Ruwet, 1982, Little and Hulata, 2000). The egg production and hatching are adversely affected by high water temperature in ponds (Bevis, 1994). It has been reported that drastic drops (> 50%) in seed output occur in most tilapia hatcheries in Thailand when water temperature is above 33°C during the hot season (Little et al., 1997; Bhujel, 1999). To facilitate convenient operation for egg/fry collection, hapas are usually suspended 70–80 cm deep in a pond of 1 m or less. This shallowness heats pond water dramatically, resulting in critically high temperatures throughout the water column and causing stress to the fish. Tropical ponds with depths greater than 1.3 m often exhibit vertical temperature differential at midday of 3–5°C between upper and lower water column (Diana et al., 1991). Therefore, suspending hapas below 1 m or so could provide considerably cooler conditions for fish to avoid heat stress.
Another problem of shallow ponds is that water is persistently turbid from resuspension of bottom mud as workers frequently wade through the pond for egg collection. Consequently, muddy water decreases oxygen content by reducing light for photosynthesis by phytoplankton, and also curtails water exchange in mud-fouled hapas. In addition, the re-suspended particles may also contaminate eggs, lowering the hatching rate. One method to eliminate this would be to install walkways under water to facilitate egg/fry harvest in ponds without stirring up mud.

The objectives of this study were to:

1) Increase seed production of Nile tilapia by lowering water temperature by increased pond water depth; and
2) Improve seed production and water quality by reducing mud turbidity and fouling.

METHODS AND MATERIALS

This study, consisting of two experiments, was conducted at the Asian Institute of Technology (AIT), Thailand, for 95 days for Experiment A and 113 days for Experiment B during May 2003–March 2004.

Experiment A was conducted using a randomized complete block design in a 300-m^2 earthen pond of 1.6 m depth to investigate effects of high temperature on seed production of Nile tilapia in a hapa-in-pond system. There were three treatments with three replicates each: (A) 70-cm water depth in hapas (control); (B) 100-cm water depth in hapas; and (C) 140-cm water depth in hapas. Nine hapas, each 17.5 m^2 in surface area (7 x 2.5 m), were suspended as 3 rows and 3 columns in the pond. Brood tilapias were stocked at 2.5 fish m^{-2} (18 males and 26 females) in each hapa on 2 May 2003, and harvested on 5 August 2003. Underwater wooden walkways were constructed in the pond to facilitate the egg collecting operation.

Experiment B was conducted using a complete randomized design in six 200-m^2 earthen ponds of 1.2 m deep to investigate effects of turbidity on seed production of Nile tilapia in a hapa-in-pond system. There were two treatments with three replicates each: (A) without underwater walkway (control); (B) with underwater walkway. Three hapas of 20 m^2 in surface area (8 x 2.5 m) were suspended in each pond. Brood tilapias were stocked at 2.5 fish m^{-2} (20 males and 30 females) in each hapa on 3 December 2003, and harvested on 25 March 2004.

Brood tilapias in both experiments were fed with commercial pelleted feed (27% crude protein) twice daily at 1% body weight per day. Prior to the start of the experiments, all ponds were drained completely, dried for 2 weeks, and filled with water from a nearby canal. Pond water level was maintained at 1.6 m in Experiment A and 1.0 m in Experiment B by adding water weekly to replace water loss due to seepage and evaporation. All ponds were fertilized twice before stocking fish by using urea at a rate of 28 kg N ha^{-1} week^{-1} and triple superphosphate (TSP) at a rate of 7 kg P ha^{-1} week^{-1}.

In Experiment A, diurnal dissolved oxygen (DO) and temperature were measured twice a week at 0600, 1000, 1400, 1800, and 2200 h at 10, 40, 70, 100, 120, and 140 cm deep in the water both inside and outside of hapas. In Experiment B, DO was measured monthly at 0600 h at 25 cm above the bottom, 25 cm below the water surface, and the midpoint between these levels. Water samples were taken biweekly at 1000 h for analyses of total Kjeldahl nitrogen (TKN), total ammonia nitrogen (TAN), nitrate nitrogen (nitrate-N), nitrite nitrogen (nitrite-N), total phosphorus (TP), soluble reactive phosphate (SRP), total alkalinity, chlorophyll *a*, total suspended solids (TSS) and total volatile solids (TVS) following standard methods (Egna et al., 1987; APHA et al., 1985). Prior to water sampling, DO, temperature, pH, and Secchi disk visibility was measured in situ. In Experiment B, turbidity was determined from the water sampled from both hapas and ponds before and after seed harvests. Fouling material on each hapa was collected by washing at the end of each experiment, and dry weight of the fouling material was determined.

Tilapia seeds were collected from mouths of females at 5-day intervals, and their bulk weight and number were recorded immediately after collection. Collected eggs were observed and classified as: Stage I – un-eyed eggs (fertilized eggs are yellow, yellowish green, or white without any spots); Stage II – un-eyed eggs (fertilized eggs are dark yellow or brownish yellow with very thin black color spots, while unfertilized eggs are yellowish white color); Stage III – eyed eggs (fertilized eggs are dark yellow or brownish yellow color with clear eyes and spots, while unfertilized eggs are white color); Stage IV – hatched or yolk sac fry; and Stage V – swim-up fry (Juntana, 1990). Collected eggs of Stages I-IV were transferred into aluminum trays for incubation. At each seed harvest, five samples of 40–50 eggs were taken from each hapa. These eggs were examined under microscope to determine viability and fouling. Stage I eggs were incubated in down-welling incubators for about 8–10 hours, then the eggs were examined microscopically to observe egg development. Embryos with well-developed, double-layered cell walls and a nucleus were considered as viable whereas opaque (without layer) embryos were considered not viable. Stage III eggs (5 days after fertilization) were examined at egg harvest by a direct count of live (viable) and dead (not viable) eggs.

Data from each experiment were analyzed statistically by analysis of variance (ANOVA) and *t*-test using the SPSS 10.0 statistical software package (SPSS Inc., USA). Differences were considered significant at an alpha level of 0.05. All means were given with ± 1 standard error (SE).

RESULTS

Experiment A – Effects of Temperature

Survival of both male and female fish was 100% in all three treatments (Table 1). Mean weight of females at harvest, ranging from 135 to 138 g fish^{-1}, was not significantly different among the three treatments ($P > 0.05$), and was slightly greater than at stocking (112–127 g fish^{-1}). Average spawning percentages, ranging from 8.45% to 17.12%, were lowest in 70-cm treatment (control), intermediate in the 100-cm treatment, and highest in the 140-cm treatment ($P < 0.05$). The average spawning percentage in the 140-cm treatment was significantly higher than that in the 70-cm treatment ($P < 0.05$), while the average spawning percentage in the 100-cm treatment was not significantly different from the 70- or 140-cm treatments ($P > 0.05$). Total egg production (eggs hapa^{-1}), average egg productivity (eggs m^{-2} d^{-1}) and average egg production (eggs female^{-1}) increased with increasing hapa depth from 70 cm to 140 cm ($P < 0.05$). In terms of spawned females, however, both absolute and relative fecundity was not significantly different among all three treatments ($P > 0.05$). Egg production was increased by 72% and 96% in the 100- and 140-cm treatments, compared to the control. There was no significant difference in mean individual egg weight among all three treatments ($P > 0.05$). Fertilization rates in the two deeper treatments (37.49% and 42.05% in the 100- and 140-cm treatments, respectively) were significantly higher than in the control (21.06%; $P < 0.05$). However, hatching rates, ranging from 59.63% to 69.28%, were not significantly different among all three treatments.

Temperature ranged from 29.8 to 38.2°C during the experimental period. Overall mean values of water temperature were not significantly different at the same depth. Mean water temperature was also not significantly different at the same time inside or outside of hapas from each treatment. However, water temperature decreased significantly with increasing water depth from 10 to 140 cm both inside and outside hapas ($P < 0.05$; Table 2). On one of the hottest days during the experimental period, water temperature was not significantly different among depths at early morning ($P > 0.05$) and showed significant differences at all measurement depths at 1000, 1400 and 1800 h ($P < 0.05$; Table 3). During the nighttime, water temperature became isothermal with depth (Table 3). Water temperature at the lowest two depths changed slightly from 31.00 to 31.87°C during the daytime, while water temperature at the surface reached 36.70°C at 1400 h, giving the difference of more than 5°C between surface and bottom temperatures (Table 3).

DO concentrations in early morning were not significantly different among depths, inside hapas of the same treatment, or in open water ($P > 0.05$), but were significantly different at the same depth between hapas and open water ($P < 0.05$; Table 4). DO concentrations at early morning were highest in open water, intermediate in the two shallow hapa treatments, and lowest in the 140-cm treatment ($P < 0.05$; Table 4). DO concentrations showed significant differences among depths within the same treatment or between different treatments at the same depth for most measurements (Table 4). DO concentrations at the bottom of the 140-cm treatment were lowest, but were maintained within the optimal range for tilapia growth throughout the experimental period (Table 4).

For all other water quality parameters (Table 5), there were no significant differences between the three depth treatments and open water ($P > 0.05$). Dry weight of fouling material, ranging from 0.16 to 0.25 kg hapa^{-1}, varied largely within treatments, and was not significantly different among the three treatments ($P > 0.05$; Table 5).

Experiment B – Effects of Turbidity

There were no significant differences in growth or reproductive performance between ponds with or without walkways in Experiment B. Survival of male and female tilapia was 100% in both treatments (Table 6). Mean weight of female tilapia at stocking and harvest was 57 and 89 g fish^{-1} in ponds with walkways and 62 and 96 g fish^{-1} in control ponds. Average spawning percentages were 13.39% without walkways and 16.07% with walkways. In terms of both total females and spawned females, egg production performance was not significantly different between treatments. There was no significant difference in mean individual egg weight between treatments. Both fertilization rates and hatching rates were not significantly different between treatments.

Average turbidity in hapas and open water increased steadily towards the end of the experiment (Figure 1). Average turbidity in hapas and open water before egg collection ranged from 25 to 55 NTU and was not significantly different between treatments ($P > 0.05$; Table 7). Average turbidity in open water after egg collection was significantly higher without walkways than with walkways ($P < 0.05$), while average turbidity in hapas after egg collection was not significantly different between the two treatments ($P > 0.05$). Consequently, the increased turbidity in open water due to egg collection was significantly higher without walkways, while there was no significant difference in turbidity increase inside hapas of the two treatments ($P > 0.05$). However, percentage of turbidity change, ranging from 34.82% to 242.73%, was not significantly different between the two treatments in both hapas and open water ($P > 0.05$; Table 7). Dry weight of fouling material was 7.53 and 9.20 kg hapa^{-1} in treatments with and without walkways, respectively, but was not significantly different between the treatments ($P > 0.05$; Table 7). Turbidity was significantly higher in the treatment with walkways than in the treatment without walkways at the beginning of the experiment ($P < 0.05$), however, the turbidity at the end of the experiment and its change throughout the experiment was significantly lower in the treatment with walkways than in the treatment without walkways ($P < 0.05$; Table 7).

All other water quality parameters except TVS were within the optimal range for tilapia, and were not significantly different between treatments with and without walkways ($P > 0.05$; Table 8). TVS concentrations inside hapas were not significantly different between treatments ($P > 0.05$), however, they were significantly higher in open water for the treatment with walkways ($P < 0.05$; Table 8). Temperature ranged from 21.3 to 34.0°C during the experiment.

DISCUSSION

The results of the present study indicate that high temperature had significant effects on total egg production. Little et al. (1997) and Bhugel (1999) reported that drastic drops (> 50%) in seed output occurred in most tilapia hatcheries in Thailand when water temperature was above 33°C during the dry season, and this was supported by the results of the present study. Average water temperature in the afternoon reached 35°C at 10 cm deep, 33°C at 70 cm deep, and was below 33°C at both 100 and 140 cm deep. The high temperature resulted in poorer reproductive performance of Nile tilapia in shallower hapas. The results of the present study also indicate that high temperature significantly reduced fertilization rate, but had no significant effect on the hatching rate of fertilized eggs.

High temperature stress may be reduced by using deep ponds, pond shading, water sprinkling, and circulating during daytime, however, no research has been done so far on the effectiveness and applicability of these techniques (Bhugel, 2000). In preliminary trials in both tanks and ponds, Bhugel (1999) attempted to decrease temperature and reduce heat stress on brood Nile tilapia in tanks and hapa-in-pond system using sprinkling, shading, aeration and their combinations. While sprinkling and shading increased the number of eggs produced in hapas, shading, sprinkling, and aeration had no significant effects on tilapia reproductive performance in tanks. Furthermore, the combination of shade and aeration in tanks and the combination of shading and sprinkling in hapas actually had negative effects on seed output in that experiment.
Fouling has been identified as a major problem in net cages, due to reducing water quality inside hapas (Lovshin and Ibrahim, 1988; Claereboudt et al., 1994; Dubost et al., 1996). Fouling can be caused by many factors such as high feeding rate and turbidity from re-suspension of bottom mud due to egg collection activity. In the present study, underwater walkways were constructed in an attempt to reduce turbidity due to egg collecting activity. While significantly higher turbidity in water, and fouling on hapas, was caused by the egg collection activity without walkways, the increased turbidity did not cause lower egg quantity or quality.

This study demonstrated that lowering water temperature using deep ponds is an effective way to increase reproductive performance of Nile tilapia during hot season, while lowering turbidity and fouling caused by egg collection may not be effective. However, further research is needed on the effects of fouling on reproductive performance of Nile tilapia.

ANTICIPATED BENEFITS

The improved deep pond approach has significantly increased efficiency for tilapia seed production by the hapa-in-pond method. This will benefit both small-scale farmers and commercial producers in Asia and other countries. As the hapa-in-pond method continues to be used by farmers, these innovations can easily be extended as well by AIT or country extension agents.

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Table 1. Reproductive performance of Nile tilapia stocked in hapas suspended at different depths in Experiment A.

Parameters	Treatments		
	70-cm deep	*100-cm deep*	*140-cm deep*
Survival (%)	100±0	100±0	100±0
Mean weight of stocked females (g fish^{-1})	127±5	123±9	112±1
Mean weight of harvested females (g fish^{-1})	136±6	138±14	135±6
Spawning percentage (%)	8.45±1.28^{a}	14.63±2.68^{ab}	17.12±1.09^{b}
Total egg production (eggs hapa^{-1})	34,902±6,901^{a}	59,923±10,761^{ab}	68,493±6,333^{b}
Average egg productivity (eggs m^{-2} day^{-1})	21±4^{a}	36±6^{ab}	41±4^{b}
Average egg production (eggs female^{-1})	1,342±265^{a}	2,305±414^{ab}	2,634±244^{b}
Absolute fecundity (eggs spawned female^{-1})	933±98	927±23	903±38
Relative fecundity (eggs kg^{-1} of spawned female)	7,084±743	7,186±583	7,324±426
Mean egg weight (g egg^{-1})	0.005±0.001	0.005±0.001	0.006±0.001
Fertilization rate (%)	21.06±2.95^{a}	37.49±4.28^{b}	42.05±4.94^{b}
Hatching rate (%)	69.28±2.20	60.40±2.18	59.63±6.24

[ab] Mean values in the same row with different superscripts were significantly different ($P < 0.05$).

Table 2. Profile of overall mean temperature in hapas suspended at different depths in Experiment A.

Time/Treatment	Water Depths					
	10 cm	*40 cm*	*70 cm*	*100 cm*	*120 cm*	*140 cm*
0600 h[1]	a	ab	b	c	c	d
70-cm treatment	31.05±0.01	31.07±0.01	31.07±0.01			
100-cm treatment	31.05±0.02	31.07±0.01	31.08±0.01	31.09±0.01		
140-cm treatment	31.10±0.00	31.11±0.01	31.13±0.00	31.05±0.00	31.05±0.00	30.96±0.00
Open water	31.09±0.01	31.10±0.01	31.11±0.01	31.12±0.01	31.04±0.01	30.95±0.01
1000 h	a	b	c	d	e	f
70-cm treatment	32.00±0.01	31.81±0.01	31.57±0.00			
100-cm treatment	32.04±0.03	31.79±0.01	31.54±0.00	31.39±0.01		
140-cm treatment	32.11±0.04	31.81±0.02	31.58±0.01	31.39±0.01	31.20±0.01	31.03±0.01
Open water	32.16±0.01	31.86±0.03	31.60±0.00	31.37±0.01	31.23±0.02	30.92±0.03
1400 h	a	b	c	d	e	f
70-cm treatment	34.69±0.03	33.65±0.03	32.78±0.02			
100-cm treatment	34.74±0.03	33.66±0.03	32.82±0.04	32.30±0.03		
140-cm treatment	34.67±0.06	33.75±0.04	32.85±0.03	32.27±0.03	31.86±0.01	31.55±0.01
Open water	34.80±0.05	33.66±0.02	32.83±0.03	32.14±0.02	31.65±0.01	31.30±0.01
1800 h	a	b	c	d	e	f
70-cm treatment	33.62±0.02	33.50±0.00	33.08±0.3			
100-cm treatment	33.65±0.02	33.49±0.03	33.11±0.02	32.67±0.01		
140-cm treatment	33.62±0.04	33.48±0.04	33.12±0.02	32.60±0.03	32.18±0.02	31.85±0.03
Open water	33.73±0.01	33.55±0.01	33.18±0.02	32.58±0.04	32.09±0.02	31.65±0.02
2200 h	ab	a	a	b	c	d
70-cm treatment	32.79±0.01	32.81±0.00	32.81±0.00			
100-cm treatment	32.78±0.02	32.83±0.01	32.83±0.01	32.79±0.02		
140-cm treatment	32.78±0.02	32.84±0.01	32.85±0.00	32.75±0.02	32.39±0.01	32.02±0.05
Open water	32.83±0.01	32.87±0.01	32.88±0.00	32.77±0.03	32.40±0.02	31.95±0.05

[1] Mean values measured at the same time indicated by different letters were significantly different ($P < 0.05$).

Table 3. Daily temperature fluctuation during one of the hottest days (22 May 2003) during the experimental period.

Water depth (cm)	Time (h)				
	0600	*1000*	*1400*	*1800*	*2200*
10	30.98 ± 0.02	32.59 ± 0.07^{a}	36.70 ± 0.07^{a}	35.28 ± 0.04^{a}	33.37 ± 0.02^{a}
40	30.99 ± 0.01	31.81 ± 0.03^{b}	33.58 ± 0.10^{b}	33.96 ± 0.08^{b}	33.41 ± 0.01^{a}
70	30.99 ± 0.01	31.42 ± 0.02^{c}	32.45 ± 0.05^{c}	32.89 ± 0.03^{c}	33.41 ± 0.01^{a}
100	30.99 ± 0.01	31.23 ± 0.02^{d}	31.97 ± 0.07^{d}	32.46 ± 0.04^{d}	33.40 ± 0.00^{a}
120	30.98 ± 0.02	31.15 ± 0.02^{de}	31.60 ± 0.12^{e}	32.07 ± 0.03^{e}	32.35 ± 0.02^{b}
140	31.00 ± 0.00	31.08 ± 0.03^{e}	31.48 ± 0.08^{e}	31.87 ± 0.08^{e}	32.23 ± 0.08^{b}

Mean values with different superscript letters in the same column were significantly different ($P < 0.05$).

Table 4. Profile of overall mean DO concentrations (mg/L) in hapas suspended at different depths in Experiment A.

Time/Treatment	Water Depths					
	10 cm	*40 cm*	*70 cm*	*100 cm*	*120 cm*	*140 cm*
0600 h						
70-cm treatment	$3.27\pm0.03_{x}$	$3.24\pm0.02_{x}$	$3.22\pm0.03_{x}$			
100-cm treatment	$3.16\pm0.04_{x}$	$3.10\pm0.05_{x}$	$3.07\pm0.05_{y}$	$3.03\pm0.06_{xy}$		
140-cm treatment	$2.96\pm0.04_{y}$	$2.89\pm0.04_{y}$	$2.85\pm0.03_{z}$	$2.87\pm0.03_{y}$	$2.83\pm0.05_{x}$	$2.91\pm0.06_{x}$
Open water	$3.19\pm0.09_{x}$	$3.14\pm0.07_{x}$	$3.11\pm0.05_{xy}$	$3.08\pm0.05_{x}$	$3.12\pm0.04_{y}$	$3.24\pm0.06_{y}$
1000 h						
70-cm treatment	4.51 ± 0.10^{a}	$4.36\pm0.09_{xy}^{ab}$	$4.08\pm0.05_{x}^{b}$			
100-cm treatment	4.37 ± 0.19^{a}	$4.14\pm0.16_{y}^{a}$	$3.91\pm0.13_{xy}^{ab}$	$3.54\pm0.11_{xy}^{b}$		
140-cm treatment	4.37 ± 0.04^{a}	$4.11\pm0.03_{y}^{b}$	$3.78\pm0.01_{y}^{c}$	$3.33\pm0.04_{y}^{d}$	3.12 ± 0.04^{e}	2.97 ± 0.06^{f}
Open water	4.80 ± 0.08^{a}	$4.54\pm0.06_{x}^{b}$	$4.12\pm0.03_{x}^{c}$	$3.65\pm0.03_{x}^{d}$	3.22 ± 0.04^{d}	3.11 ± 0.02^{f}
1400 h						
70-cm treatment	6.84 ± 0.09^{a}	$6.05\pm0.07_{y}^{b}$	$5.15\pm0.10_{y}^{c}$			
100-cm treatment	6.91 ± 0.26^{a}	$6.06\pm0.19_{y}^{ab}$	$5.07\pm0.17_{y}^{c}$	$4.07\pm0.10_{y}^{d}$		
140-cm treatment	6.89 ± 0.10^{a}	$6.07\pm0.08_{y}^{b}$	$4.99\pm0.10_{y}^{c}$	$4.00\pm0.06_{y}^{d}$	3.42 ± 0.06^{e}	3.01 ± 0.01^{f}
Open water	7.50 ± 0.17^{a}	$6.64\pm0.10_{x}^{b}$	$5.59\pm0.06_{x}^{c}$	$4.50\pm0.08_{x}^{d}$	3.65 ± 0.06^{e}	2.95 ± 0.11^{f}
1800 h						
70-cm treatment	$7.10\pm0.04_{x}^{a}$	$6.80\pm0.09_{xy}^{b}$	$5.65\pm0.04_{x}^{c}$			
100-cm treatment	$7.17\pm0.14_{x}^{a}$	$6.70\pm0.12_{y}^{b}$	$5.56\pm0.07_{x}^{c}$	$4.48\pm0.06_{y}^{d}$		
140-cm treatment	$7.01\pm0.08_{x}^{a}$	$6.52\pm0.08_{y}^{b}$	$5.54\pm0.07_{x}^{c}$	$4.23\pm0.05_{z}^{d}$	3.58 ± 0.08^{e}	3.08 ± 0.03^{f}
Open water	$7.67\pm0.22_{y}^{a}$	$7.16\pm0.17_{x}^{b}$	$6.02\pm0.08_{y}^{c}$	$4.72\pm0.07_{x}^{d}$	3.97 ± 0.16^{e}	3.09 ± 0.14^{f}
2200 h						
70-cm treatment	$5.53\pm0.06_{xy}$	$5.49\pm0.06_{xy}$	5.33 ± 0.08			
100-cm treatment	$5.43\pm0.08_{xy}^{a}$	$5.41\pm0.10_{xy}^{a}$	5.24 ± 0.11^{a}	$4.54\pm0.07_{xy}^{b}$		
140-cm treatment	$5.24\pm0.04_{y}^{a}$	$5.25\pm0.03_{y}^{a}$	5.13 ± 0.03^{a}	$4.30\pm0.08_{y}^{b}$	$3.61\pm0.10_{x}^{c}$	2.99 ± 0.07^{d}
Open water	$5.72\pm0.15_{x}^{a}$	$5.67\pm0.11_{x}^{a}$	5.46 ± 0.12^{a}	$4.69\pm0.03_{x}^{b}$	$4.03\pm0.07_{y}^{c}$	3.19 ± 0.18^{d}

Mean values with different superscript letters in the same row were significantly different ($P < 0.05$); and values with different subscript letters in the same column under each time were significantly different ($P < 0.05$).

Table 5. Overall means of water quality parameters measured at 1000 h during Experiment A and dry weight of fouling material on hapas determined at the end of the experiment.

Parameter	Treatments			Open water
	70-cm deep	*100-cm deep*	*140-cm deep*	
pH	7.62±0.06	7.61±0.06	7.58±0.06	7.59±0.11
Alkalinity (mg L^{-1} as $CaCO_3$)	51±2	52±2	52±2	52±4
Secchi Disk Depth (cm)	47±2	45±2	45±3	41±3
TAN (mg L^{-1})	0.71±0.15	0.69±0.14	0.61±0.12	0.57±0.20
Nitrite-N (mg L^{-1})	0.08±0.03	0.08±0.03	0.08±0.03	0.08±0.06
Nitrate-N (mg L^{-1})	0.42±0.08	0.47±0.08	0.47±0.08	0.48±0.16
TKN (mg L^{-1})	1.54±0.26	1.30±0.23	1.51±0.27	1.23±0.34
SRP (mg L^{-1})	0.01±0.01	0.01±0.00	0.01±0.00	0.01±0.00
TP (mg L^{-1})	0.30±0.06	0.27±0.06	0.25±0.05	0.27±0.09
Chl *a* (μg L^{-1})	21±4	22±5	19±3	16±6
TSS (mg L^{-1})	18±3	18±3	19±3	19±6
TVS (mg L^{-1})	6±1	6±2	6±2	6±3
Fouling Material (kg $hapa^{-1}$)	0.25±0.02	0.18±0.02	0.16±0.04	----

Table 6. Reproductive performance of Nile tilapia stocked in hapas in ponds with or without underwater walkways in Experiment B.

Parameter	Treatments	
	Without Underwater Walkway	*With Underwater Walkway*
Survival (%)	100±0	100±0
Mean Weight Of Stocked Females (g $fish^{-1}$)	62±5	57±2
Mean Weight Of Harvested Females (g $fish^{-1}$)	96±6	89±8
Spawning Percentage (%)	13.39±1.13	16.07±1.83
Total Egg Production (egg no. $hapa^{-1}$)	31,971±182	37,113±6,389
Average Egg Productivity (egg no. m^{-2} day^{-1})	14±0	16±2
Average Egg Production (egg no. $female^{-1}$)	1,065±6	1,237±213
Absolute Fecundity (egg no. spawned $female^{-1}$)	625±42	563±37
Relative Fecundity (egg no. kg^{-1} of spawned female)	7,103±250	7,444±265
Mean Egg Weight (g egg^{-1})	0.005±0.000	0.005±0.000
Fertilization Rate (%)	78.28±2.55	80.90±2.03
Hatching Rate (%)	72.20±4.7	72.20±3.7

Table 7. Mean values of turbidity under different circumstances in treatments with and without walkways in Experiment B.

Parameter	Open Water		Inside Hapas	
	With Walkway	*Without Walkway*	*With Walkway*	*Without Walkway*
Turbidity Before Egg Collection (NTU)	40±8	34±5	37±6	32±4
Turbidity After Egg Collection (NTU)	69±3[a]	85±0[b]	71±6	81±3
Turbidity Change by Egg Collection (NTU)	29±6[a]	50±5[b]	34±4	49±6
Turbidity Change by Egg Collection (NTU man-hour^{-1})	19±4[a]	33±3[b]	22±3	32±4
Percentage of Turbidity Change by Egg Collection (%)	84.78±30.77	158.51±42.39	98.28±24.36	161.13±40.03
Fouling Material (kg hapa^{-1})	----	----	9.20±0.57	7.53±0.73
Turbidity at Stocking (NTU)	13±2[a]	4±1[b]	14±4[x]	3±1[y]
Turbidity at Harvest (NTU)	121±8[a]	140±4[b]	131±10[y]	140±7[y]
Turbidity Change Throughout the Experiment (NTU)	108±6[a]	136±3[b]	117±7[x]	136±6[y]
Percentage of Turbidity Change (%)	892±117[a]	4388±1708[b]	1060±378[x]	5314±2194[y]
Turbidity Increased (NTUman-hour^{-1})	54±3[a]	68±2[b]	58±4[x]	68±3[y]

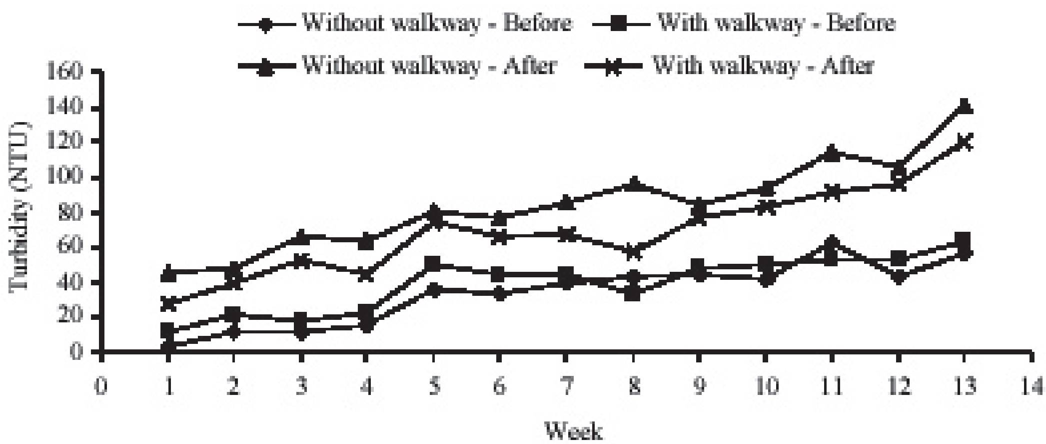
Mean values in the same row and category with different superscript letters were significantly different ($P < 0.05$).

Table 8. Overall means of water quality parameters measured inside hapas and open water in Experiment B.

Parameter	Inside Hapas		Open Water	
	With Walkway	*Without Walkway*	*With Walkway*	*Without Walkway*
Temperature (C)	27.9±0.04	28.0±0.04	27.2±0.06	27.2±0.07
DO at Drawn (mg L^{-1})	2.82±0.04	2.92±0.04	2.96±0.09	3.02±0.07
Secchi Disk Depth (cm)	41±4	46±2	39±5	53±2
Alkalinity (mg L^{-1} as $CaCO_3$)	135±7	131±4	134±7	131±4
TAN (mg L^{-1})	0.15±0.01	0.16±0.03	0.19±0.07	0.15±0.03
Nitrate-N (mg L^{-1})	0.05±0.01	0.07±0.02	0.08±0.01	0.06±0.01
Nitrate-N (mg L^{-1})	0.01±0.00	0.01±0.00	0.01±0.00	0.01±0.00
TKN (mg L^{-1})	1.00±0.12	0.94±0.01	0.97±0.07	1.00±0.05
SRP (mg L^{-1})	0.01±0.00	0.01±0.00	0.01±0.00	0.01±0.00
TP (mg L^{-1})	0.71±0.01	0.71±0.01	0.73±0.01	0.69±0.02
Chl *a* (mg m^{-3})	15±5	5±1	18±6	6±2
TSS (mg L^{-1})	41±4	37±2	49±4	39±3
TVS (mg L^{-1})	14±1	12±0	19±5[a]	12±0[b]

Mean values in the same row and category with different superscript letters were significantly different ($P < 0.05$).

Figure 1. Weekly values for turbidity before and after egg collection in the treatments with and without walkways in Experiment B.



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