# Semi-Intensive Culture of Red Tilapia in Brackishwater Ponds

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*Final Report*

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## Abstract

An experiment was conducted at the Asian Institute of Technology, Thailand, to investigate effects of fertilization rates and salinity levels on the growth of sex-reversed Thai red tilapia (*Oreochromis* sp.). The experiment was designed to test two fertilization rates (28 kg nitrogen and 7 kg phosphorus $ha^{-1}$ $wk^{-1}$, N:P = 4:1; and 14 kg N and 7 kg P $ha^{-1}$ $wk^{-1}$, N:P = 2:1) and three salinity levels (10, 20, and 30‰). An additional treatment using optimized fertilization rates (28 kg N and 7 kg P $ha^{-1}$ $wk^{-1}$, N:P = 4:1) in freshwater ponds served as a control. Red tilapia fingerlings (20.2 to 23.7 g size) were stocked at 2.4 fish $m^{-2}$ in 5-$m^2$ cement tanks with soil bottoms. They were cultured for 160 days.

Growth performance of red tilapia was better in brackish water than in fresh water. Growth of red tilapia in brackish water was inversely related to the salinity levels ($r = -0.63$, $P < 0.05$), decreasing significantly with increasing salinity. Best growth performance was achieved in the treatment with N:P ratio of 4:1 at 10‰ salinity. The highest net economic return was achieved in the treatment with N:P ratio of 2:1 at 10‰ salinity, and all treatments had positive returns.

Preliminary trials using a single species of marine phytoplankton showed that growth of red tilapia fed with *Chaetoceros* sp. and *Thalassiosira* sp. was significantly better than those fed with *Tetraselmis* sp. and *Chlorella* sp., and the former two resulted in a significantly higher protein utilization efficiency than the latter two. The prey ingestion rate of red tilapia for *Chaetoceros* sp. and *Thalassiosira* sp. was significantly higher than that for *Tetraselmis* sp. and *Chlorella* sp.

## Introduction

Many tilapia species are euryhaline and can grow in saline water after proper acclimation (Suresh and Lin, 1992). Varieties of red tilapia have been successfully cultured in saline waters (Watanabe, 1991). However, most of those tilapia culture trials were conducted in intensive systems with pelleted feeds, requiring frequent water exchanges or cages. Compared to the voluminous literature available for semi-intensive culture of tilapia in freshwater ponds, literature on semi-intensive culture in saline ponds is almost nonexistent. The species composition, feeding, and nutritional value of phytoplankton for tilapia growth in freshwater are relatively well understood, notably in work by Moriarty and Moriarty (1973), Bowen (1982), Hepher and Pruginin (1982), and recently the Pond Dynamics/ Aquaculture Collaborative Research Support Program (PD/A CRSP) (Egna and Boyd, 1997). The PD/A CRSP project did conduct a brief experiment on Nile tilapia grow-out in fertilized brackishwater ponds in the Philippines in the early 1980s (Woessner et al., 1991). In that experiment fish production was extremely low, resulting from high mortality due to uncontrolled high salinity. We are assuming that fertilization rates for brackishwater ponds are similar to those for freshwater ponds. Common PD/A CRSP fertilization guidelines are 28 kg nitrogen (N) and 7 kg phosphorus (P) $ha^{-1}$ $wk^{-1}$, giving a N:P ratio of 4:1 (Knud-Hansen et al., 1991).

During the last few years, there has been a strong desire to culture tilapia in brackishwater ponds in Southeast Asia, as well as in Central and South America (Green, 1997). The major reason for this need is that there are a large number of shrimp ponds available, resulting from either failure in shrimp farming or desires to diversify shrimp culture. Tilapias appear to be the most appropriate choice for such a culture system because there are few domesticated finfish species that feed on low-cost natural foods such as detritus and plankton. This interest in brackishwater culture is particularly strong in Thailand and Vietnam where shrimp culture is now commonly reduced to one crop per year, leaving the ponds empty for half a year. Tilapia culture is also attractive to shrimp farmers as a by-product to utilize abundant phytoplankton in either shrimp ponds or their effluents. Thai strain red tilapia (*Oreochromis* sp.) has been becoming more and more popular in Thailand, and there is a great potential to culture this species in brackishwater ponds.

The purposes of this study were to determine an appropriate fertilization regime in brackish water for culture of Thai red tilapia and to investigate the nutritional value and prey consumption of specific marine phytoplankton as food organisms for Thai red tilapia.

## METHODS AND MATERIALS

This experiment was carried out at the Asian Institute of Technology (AIT), Thailand, from June through November 2000 to determine an appropriate fertilization regime and salinity level for culture of Thai red tilapia in brackish water. The experiments were conducted in a randomized complete block design with a 2 × 3 factorial arrangement to test effects of two fertilization regimes (28 kg N and 7 kg P $ha^{-1}$ $wk^{-1}$, N:P = 4:1; and 14 kg N and 7 kg P $ha^{-1}$ $wk^{-1}$, N:P = 2:1) and three salinity levels (10, 20, and 30‰) on growth of Thai red tilapia. There were six combinations (treatments) and an additional treatment using the PD/A CRSP standard fertilization regime (28 kg N and 7 kg P $ha^{-1}$ $wk^{-1}$, N:P = 4:1) in fresh water (0‰) that served as a control. Three replicates were used per treatment. The experiment was conducted in twenty-one 5-$m^2$ (2 × 2.5 m) cement tanks filled with 10 cm of soil on the bottom. The tanks were grouped into three blocks, and treatments were allocated randomly to tanks in each block.

Thai strain red tilapia was used in the experiment. Sex-reversed all-male Thai red tilapia fingerlings (20.2 to 23.7 g size) were purchased from a local hatchery and acclimated to appropriate salinity levels in acclimation tanks by raising the salinity level 5‰ every two days until the target salinity was reached. The acclimated Thai red tilapia fingerlings were stocked at 2.4 fish $m^{-2}$ in all experimental tanks on 8 June 2000. During the experiment 50% of the initial tilapia stock was seined, counted, and weighed en masse biweekly for each tank. All fish were harvested on 15 November 2000, after 160 days of culture. Daily weight gain (g $fish^{-1}$ $d^{-1}$), yield (kg $pond^{-1}$), and extrapolated yield (kg $ha^{-1}$ $yr^{-1}$) were calculated.

All tanks were fertilized weekly with urea and triple superphosphate (TSP) to achieve the treatment dosage. Initial pond fertilization took place one week prior to fish stocking. Sodium bicarbonate was applied at 250 kg $ha^{-1}$ in the third week. Salinity was regulated by trucking hypersaline water (150‰) to AIT and diluting to the appropriate concentrations. Salinity levels in all tanks were monitored weekly. Water depth in all tanks was maintained at 1 m throughout the experiment by adding water of appropriate salinity levels weekly to replace evaporation and seepage losses. All tanks were aerated for 24 hours daily using one airstone in each tank.

Water samples integrated from the entire water column were taken biweekly near the center of each tank at approximately 0900 h for analysis of pH, alkalinity, total ammonium nitrogen (TAN), nitrite-nitrogen, nitrate-nitrogen, total Kjeldahl nitrogen (TKN), soluble reactive phosphorus (SRP), total phosphorus (TP), chlorophyll *a*, total suspended solids (TSS), total volatile solids (TVS), and plankton composition (Parsons et al., 1984; APHA, 1985; Egna et al., 1989). At the time of collecting water samples, Secchi disk visibility was measured using a Secchi disk, while temperature and dissolved oxygen (DO) were measured at the time of collecting water samples with a YSI model 54 oxygen meter (Yellow Springs Instruments, Yellow Springs, Ohio, USA). Diel measurements for temperature, DO and pH were conducted in each pond at 0600, 1000, 1400, 1600, 1800, and 0600 h once a month.

Preliminary trials were also carried out to investigate the nutritional value and prey consumption of specific marine phytoplankton species, *Tetraselmis* sp., *Chlorella* sp., *Thalassiosira* sp., and *Chaetoceros* sp., for Thai red tilapia. The first trial on nutritional value was conducted over 15 days in twelve glass jars of 15-l volume with three replicates for each species. Each jar was filled with 15‰ salinity water and continuously aerated using an airstone throughout the experimental period. Thai red tilapia (1.42 to 1.61 g size) were stocked at 0.4 fish $l^{-1}$ and fed twice daily with the same quantity (dry matter, DM) of each phytoplankton species, which were cultured in the AIT laboratory and were approximately three to four days old. Red tilapia growth was determined by bulk-weight at the beginning and end of the culture period. Water in jars was changed

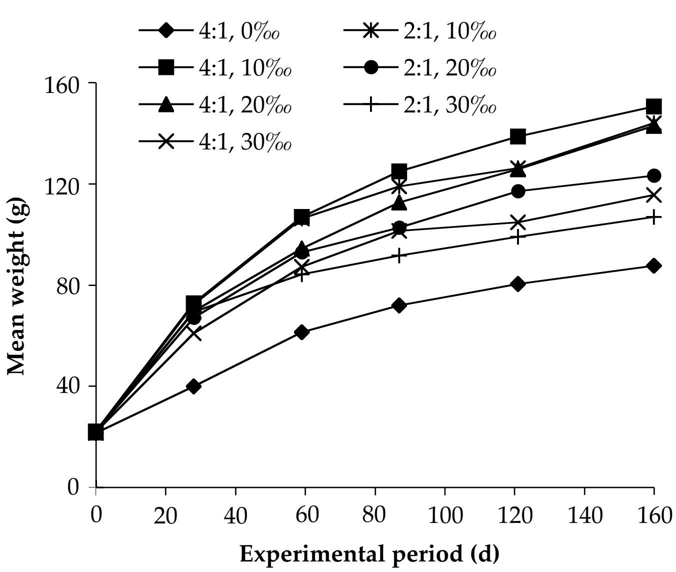


Figure 1. Mean weight of Thai red tilapia in all treatments over the 160-day experimental period.

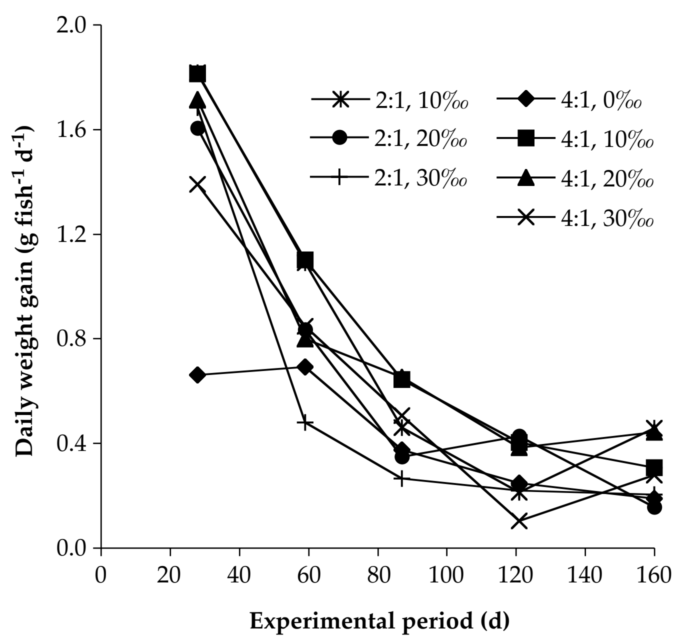


Figure 2. Daily weight gain of Thai red tilapia in all treatments over the 160-day experimental period.

by half each morning. Water temperature, DO, salinity, and pH were measured at 0800 h daily prior to changing water. Proximate analysis of red tilapia and the four phytoplankton species was done at the beginning and end of the culture period using methods described by Lowry et al. (1951), Yoshida et al. (1976), Buddington (1980), and Tecator (1983, 1987). The second trial on prey consumption was conducted twice, at the beginning and end of the first trial, in twelve glass jars of 4-l water volume with three replicates for each species for approximately two hours. Red tilapia were stocked at 1.5 fish $l^{-1}$ with mean weights of 1.50 and 2.20 g for the prey consumption trials conducted at the beginning and end of the first trial, respectively. The same quantity (DM) of each phytoplankton species was put into each jar, and the dry weight of phytoplankton was determined immediately after the two-hour feeding period.

Data were analyzed statistically using analysis of variance and linear regression (Steel and Torrie, 1980) with SPSS (version 7.0) statistical software package (SPSS Inc., Chicago, USA). Differences were considered significant at an alpha of 0.05. Statistical analyses for survival rates (%) were performed on data after arcsine transformation. Mean values of survival rates in this text are listed in normal scale followed by their confidence limits. All other means are given with ± 1 standard error (SE).

A partial budget analysis was conducted to determine economic returns of red tilapia cultured at different salinity levels and different fertilization regimes (Shang, 1990). The analysis was based on farm-gate prices in Thailand for harvested fish and current local market prices for all other items expressed in US dollars (US$1 = 40 baht). Farm-gate price of red tilapia was fixed at \$0.50 $kg^{-1}$. Market prices of sex-reversed all-male red tilapia fingerlings (\$0.0125 $piece^{-1}$), electricity (\$0.05 $kWh^{-1}$), sodium bicarbonate (\$0.775 $kg^{-1}$), urea (\$0.1875 $kg^{-1}$), and TSP (\$0.3125 $kg^{-1}$) were applied to the analysis. The calculation for cost of working capital was based on an annual interest rate of 8%.

## RESULTS

There was no mortality of red tilapia in any treatment. Red tilapia grew fast in the first two months, and then growth declined towards the end of the experiment period (Figures 1 and 2). Growth performance of red tilapia (Table 1) was inversely related to salinity levels ($r = -0.63$, $P < 0.05$), and size at harvest decreased with increased salinity (Figure 3). For a given salinity level, there was no significant difference in size at harvest for the two fertilization regimes ($P > 0.05$, Table 1 and Figure 3). All growth performance parameters were best in the treatment with high N:P ratio at 10‰ salinity and were significantly better than those in the treatment with low N:P ratio at 30‰ salinity and those in the freshwater treatment ($P < 0.05$) but were not significantly different from other

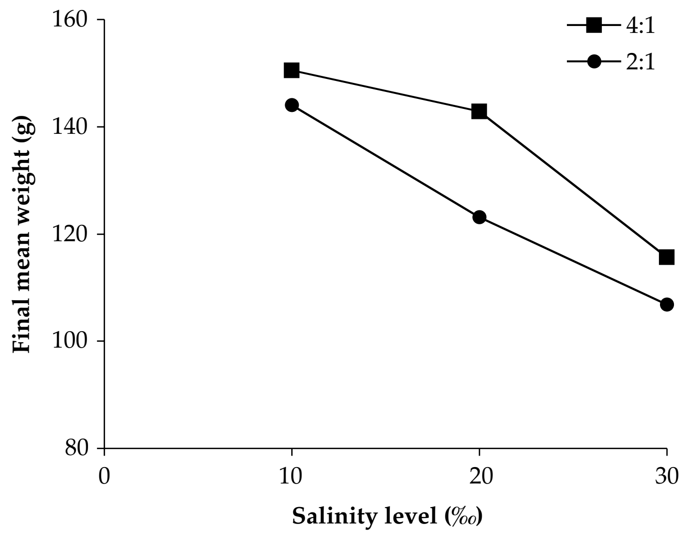


Figure 3. Comparison of final mean weight of Thai red tilapia cultured at different salinity levels under low and high fertilization rates after the 160-day experiment period.

Table 1. Performance values (mean ± SE) of Thai red tilapia in cement tanks at different fertilization regimes and salinity levels at stocking and harvest (160 d later). Data with superscripts showed significant differences among treatments, and treatments with the same superscript are not significantly different.

| Parameters | Salinity and Fertilization Rate | | | | | | |
|---|---|---|---|---|---|---|---|
| | *N:P = 4:1* | | | | *N:P = 2:1* | | |
| | 0‰ | 10‰ | 20‰ | 30‰ | 10‰ | 20‰ | 30‰ |
| STOCKING | | | | | | | |
| Density (fish $m^{-2}$) | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 |
| Total Number (fish $tank^{-1}$) | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Mean Weight (g $fish^{-1}$) | 21.4 ± 0.3 | 22.0 ± 0.4 | 21.6 ± 0.3 | 21.9 ± 0.9 | 21.5 ± 0.6 | 22.0 ± 0.2 | 22.1 ± 1.0 |
| Total Weight (kg $tank^{-1}$) | 0.26 ± 0.00 | 0.26 ± 0.00 | 0.26 ± 0.00 | 0.26 ± 0.01 | 0.26 ± 0.01 | 0.26 ± 0.00 | 0.26 ± 0.01 |
| HARVEST | | | | | | | |
| Total Number (fish $tank^{-1}$) | 12 ± 0 | 12 ± 0 | 12 ± 0 | 12 ± 0 | 12 ± 0 | 12 ± 0 | 12 ± 0 |
| Mean Weight (g $fish^{-1}$) | 87.5 ± 11.7 $^{a}$ | 150.5 ± 9.2 $^{c}$ | 142.8 ± 17.0 $^{bc}$ | 115.6 ± 11.0 $^{abc}$ | 144.0 ± 14.3 $^{bc}$ | 123.1 ± 6.1 $^{abc}$ | 106.8 ± 10.0 $^{ab}$ |
| Total Weight (kg $tank^{-1}$) | 1.05 ± 0.14 $^{a}$ | 1.81 ± 0.11 $^{c}$ | 1.71 ± 0.20 $^{bc}$ | 1.39 ± 0.13 $^{abc}$ | 1.73 ± 0.17 $^{bc}$ | 1.48 ± 0.07 $^{abc}$ | 1.28 ± 0.12 $^{ab}$ |
| Survival Rate (%) | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Daily Weight Gain (g $fish^{-1}$ $d^{-1}$) | 0.41 ± 0.07 $^{a}$ | 0.80 ± 0.06 $^{c}$ | 0.76 ± 0.11 $^{bc}$ | 0.59 ± 0.06 $^{abc}$ | 0.77 ± 0.09 $^{bc}$ | 0.63 ± 0.04 $^{abc}$ | 0.53 ± 0.07 $^{ab}$ |
| Total Weight Gain (kg $tank^{-1}$) | 0.79 ± 0.14 $^{a}$ | 1.54 ± 0.11 $^{c}$ | 1.45 ± 0.21 $^{bc}$ | 1.12 ± 0.12 $^{abc}$ | 1.47 ± 0.17 $^{bc}$ | 1.21 ± 0.07 $^{abc}$ | 1.02 ± 0.13 $^{ab}$ |
| Net Yield (t $ha^{-1}$ $yr^{-1}$) | 3.62 ± 0.64 $^{a}$ | 7.04 ± 0.48 $^{c}$ | 6.64 ± 0.95 $^{bc}$ | 5.13 ± 0.56 $^{abc}$ | 6.71 ± 0.76 $^{bc}$ | 5.53 ± 0.33 $^{abc}$ | 4.64 ± 0.58 $^{ab}$ |
| Gross Yield (t $ha^{-1}$ $yr^{-1}$) | 4.79 ± 0.64 $^{a}$ | 8.24 ± 0.50 $^{c}$ | 7.82 ± 0.93 $^{bc}$ | 6.33 ± 0.60 $^{abc}$ | 7.88 ± 0.78 $^{bc}$ | 6.74 ± 0.34 $^{abc}$ | 5.85 ± 0.54 $^{ab}$ |

Table 2. Mean (± SE) values of water quality parameters measured throughout the experiment. Data with superscripts showed significant differences among treatments, and treatments with the same superscript are not significantly different.

| Parameters | Salinity and Fertilization Rate | | | | | | |
|---|---|---|---|---|---|---|---|
| | *N:P = 4:1* | | | | *N:P = 2:1* | | |
| | 0‰ | 10‰ | 20‰ | 30‰ | 10‰ | 20‰ | 30‰ |
| DO at Dawn (mg $l^{-1}$) | 5.40 ± 0.26 | 5.74 ± 0.17 | 5.04 ± 0.19 | 4.77 ± 0.16 | 5.63 ± 0.20 | 5.07 ± 0.20 | 5.00 ± 0.17 |
| Temperature (°C) | 28.2–32.7 | 28.1–32.7 | 28.2–32.7 | 28.2–32.7 | 28.2–32.7 | 28.3–32.7 | 28.1–32.7 |
| pH | 7.1–11.1 | 6.4–10.2 | 6.3–10.0 | 6.1–9.6 | 5.7–11.0 | 6.7–10.2 | 6.4–9.8 |
| Alkalinity (mg $l^{-1}$ as $CaCO_3$) | 46.5 ± 1.4 $^{a}$ | 27.6 ± 2.9 $^{b}$ | 29.7 ± 1.6 $^{b}$ | 22.9 ± 1.2 $^{b}$ | 29.3 ± 2.7 $^{b}$ | 27.8 ± 2.9 $^{b}$ | 27.8 ± 6.8 $^{b}$ |
| TKN (mg $l^{-1}$) | 1.90 ± 0.17 $^{ab}$ | 2.91 ± 0.34 $^{c}$ | 2.60 ± 0.32 $^{bc}$ | 2.05 ± 0.25 $^{ab}$ | 1.41 ± 0.18 $^{a}$ | 1.75 ± 0.43 $^{a}$ | 1.24 ± 0.08 $^{a}$ |
| TAN (mg $l^{-1}$) | 0.02 ± 0.00 $^{a}$ | 0.05 ± 0.00 $^{a}$ | 0.05 ± 0.00 $^{a}$ | 0.09 ± 0.01 $^{b}$ | 0.04 ± 0.01 $^{a}$ | 0.04 ± 0.01 $^{a}$ | 0.05 ± 0.02 $^{a}$ |
| Nitrite-N (mg $l^{-1}$) | 0.38 ± 0.03 $^{abc}$ | 0.44 ± 0.01 $^{c}$ | 0.42 ± 0.02 $^{bc}$ | 0.39 ± 0.04 $^{abc}$ | 0.35 ± 0.03 $^{ab}$ | 0.31 ± 0.02 $^{a}$ | 0.31 ± 0.04 $^{a}$ |
| Nitrate-N (mg $l^{-1}$) | 0.43 ± 0.06 $^{ab}$ | 0.87 ± 0.03 $^{d}$ | 0.85 ± 0.10 $^{d}$ | 0.70 ± 0.08 $^{cd}$ | 0.36 ± 0.04 $^{a}$ | 0.63 ± 0.07 $^{bc}$ | 0.56 ± 0.02 $^{bc}$ |
| TP (mg $l^{-1}$) | 0.83 ± 0.13 | 0.52 ± 0.07 | 0.56 ± 0.02 | 0.41 ± 0.07 | 0.47 ± 0.05 | 0.53 ± 0.09 | 0.61 ± 0.17 |
| SRP (mg $l^{-1}$) | 0.56 ± 0.16 | 0.30 ± 0.07 | 0.35 ± 0.03 | 0.20 ± 0.06 | 0.26 ± 0.05 | 0.30 ± 0.08 | 0.44 ± 0.19 |
| Chlorophyll *a* (mg $m^{-3}$) | 62 ± 15.0 | 53 ± 3.4 | 57 ± 7.5 | 72 ± 1.4 | 58 ± 3.7 | 68 ± 9.0 | 69 ± 7.1 |
| TSS (mg $l^{-1}$) | 119 ± 8.6 $^{a}$ | 132 ± 4.0 $^{a}$ | 172 ± 6.9 $^{b}$ | 232 ± 9.1 $^{c}$ | 121 ± 6.4 $^{a}$ | 163 ± 4.7 $^{b}$ | 228 ± 15.6 $^{c}$ |
| TVS (mg $l^{-1}$) | 32 ± 3.4 $^{a}$ | 38 ± 1.3 $^{a}$ | 50 ± 4.0 $^{b}$ | 71 ± 2.8 $^{c}$ | 38 ± 3.0 $^{a}$ | 51 ± 2.8 $^{b}$ | 70 ± 4.4 $^{c}$ |

Table 3. The most abundant phytoplankton genera (from high to low) in different treatments measured throughout the experiment.

| Salinity and Fertilization Rate | | | | | | |
|---|---|---|---|---|---|---|
| *N:P=4:1* | | | | *N:P=2:1* | | |
| 0‰ | 10‰ | 20‰ | 30‰ | 10‰ | 20‰ | 30‰ |
| *Scenedesmus* | *Entomoneis* | *Entomoneis* | *Chaetoceros* | *Entomoneis* | *Entomoneis* | *Chaetoceros* |
| *Golenkinia* | *Chaetoceros* | *Chaetoceros* | *Entomoneis* | *Chaetoceros* | *Chaetoceros* | *Entomoneis* |
| *Euglena* | *Coscinodiscus* | *Coscinodiscus* | *Coscinodiscus* | *Coscinodiscus* | *Chroomonas* | *Chroomonas* |
| *Ankistrodesmus* | *Navicula* | *Chroomonas* | *Oscillatoria* | *Chlorella* | *Coscinodiscus* | *Nitzschia* |
| *Coelastrum* | *Oscillatoria* | *Lyngbya* | *Lyngbya* | *Lyngbya* | *Lyngbya* | *Coscinodiscus* |

Table 4. Partial budget analysis for red tilapia cultured in different salinity levels under different fertilization regimes (based on a 1-ha tank per year).

| Parameters | Salinity and Fertilization Rate | | | | | | |
|---|---|---|---|---|---|---|---|
| | *N:P = 4:1* | | | | *N:P = 2:1* | | |
| | 0‰ | 10‰ | 20‰ | 30‰ | 10‰ | 20‰ | 30‰ |
| GROSS REVENUE | | | | | | | |
| Red Tilapia (US$) | 2,395 | 3,520 | 3,320 | 2,565 | 3,355 | 2,765 | 2,320 |
| Total (US$) | 2,395 | 3,520 | 3,320 | 2,565 | 3,355 | 2,765 | 2,320 |
| VARIABLE COST | | | | | | | |
| Red Tilapia Fingerlings (US$) | 300 | 300 | 300 | 300 | 300 | 300 | 300 |
| Urea (US$) | 594 | 594 | 594 | 594 | 297 | 297 | 297 |
| TSP (US$) | 578 | 578 | 578 | 578 | 578 | 578 | 578 |
| Sodium Bicarbonate (US$) | 194 | 194 | 194 | 194 | 194 | 194 | 194 |
| Electricity (US$) | 329 | 329 | 329 | 329 | 329 | 329 | 329 |
| Cost of Working Capital (US$) | 160 | 160 | 160 | 160 | 136 | 136 | 136 |
| Total (US$) | 2,154 | 2,154 | 2,154 | 2,154 | 1,834 | 1,834 | 1,834 |
| NET RETURN (US$) | 241 | 1,366 | 1,166 | 411 | 1,521 | 931 | 486 |

Table 5. Average proximate compositions of different phytoplankton species and red tilapia fed with these single phytoplankton species. Data with superscripts showed significant differences among treatments, and data with the same superscript are not significantly different.

| Treatment | Moisture (%) | Crude Protein (%) | Lipid (%) | Ash (%) |
|---|---|---|---|---|
| PHYTOPLANKTON | | | | |
| *Tetraselmis* sp. | 91.25 ± 1.26 [a] | 10.56 ± 0.85 [b] | 7.86 ± 0.29 [a] | 52.12 ± 2.05 [a] |
| *Chlorella* sp. | 91.94 ± 1.54 [a] | 12.14 ± 1.03 [b] | 12.56 ± 1.22 [b] | 52.36 ± 1.14 [a] |
| *Thalassiosira* sp. | 91.13 ± 0.99 [a] | 13.25 ± 0.82 [b] | 8.63 ± 0.86 [a] | 53.44 ± 1.05 [a] |
| *Chaetoceros* sp. | 90.66 ± 1.47 [a] | 8.53 ± 0.41 [a] | 10.12 ± 0.92 [b] | 51.32 ± 2.02 [a] |
| RED TILAPIA | | | | |
| *Tetraselmis* sp. | 83.02 ± 0.96 [a] | 68.12 ± 0.39 [a] | 17.60 ± 0.20 [a] | 25.40 ± 0.42 [b] |
| *Chlorella* sp. | 82.57 ± 0.29 [a] | 67.14 ± 0.51 [a] | 17.59 ± 0.09 [a] | 25.94 ± 0.38 [b] |
| *Thalassiosira* sp. | 82.68 ± 0.41 [a] | 69.85 ± 0.87 [a] | 17.64 ± 0.06 [a] | 22.29 ± 0.19 [a] |
| *Chaetoceros* sp. | 82.91 ± 1.57 [a] | 69.89 ± 0.97 [a] | 17.54 ± 0.16 [a] | 22.93 ± 0.53 [a] |

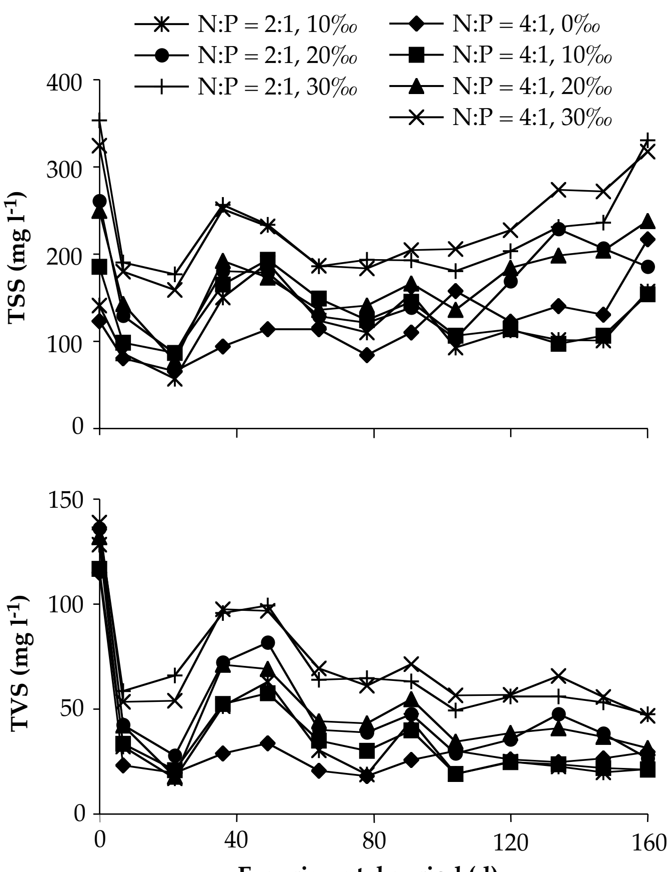


Figure 4. Fluctuations of TSS and TVS (0900 h) in all treatments over the 160-day experimental period.

brackishwater treatments ($P > 0.05$, Table 1). Growth performance in fresh water was lowest and significantly lower than that in the treatments with high N:P ratio at 10 and 20‰ salinity and with low N:P ratio at 10‰ salinity. Growth of red tilapia in brackish water was 22 to 72% faster than that in fresh water. There was no significant interaction between N:P ratio and salinity level on the growth of red tilapia ($P > 0.05$).

Mean values of water quality parameters measured throughout the experimental period are summarized in Table 2. Concentrations of DO at dawn were above 4 mg $l^{-1}$ on average.

Table 6. Growth (mean ± SE) of Thai red tilapia fed with different phytoplankton species at initial and final (15 d later) times. Data with superscripts showed significant differences among treatments, and treatments with the same superscript are not significantly different.

| Treatment | Initial Mean Weight (g $fish^{-1}$) | Final Mean Weight (g $fish^{-1}$) | Mean Weight Gain (g $fish^{-1}$) |
|---|---|---|---|
| *Tetraselmis* sp. | 1.42 ± 0.13 [a] | 1.97 ± 0.05 [b] | 0.54 ± 0.17 [b] |
| *Chlorella* sp. | 1.47 ± 0.05 [a] | 1.57 ± 0.06 [a] | 0.11 ± 0.01 [a] |
| *Thalassiosira* sp. | 1.42 ± 0.07 [a] | 2.49 ± 0.06 [c] | 1.07 ± 0.03 [c] |
| *Chaetoceros* sp. | 1.61 ± 0.10 [a] | 2.47 ± 0.12 [c] | 0.87 ± 0.04 [c] |

Water temperature and pH values ranged from 28.1 to 32.7°C and 5.7 to 11.1, respectively; both did not differ among treatments. Alkalinity was generally low in all treatments throughout the experimental period except for an increase after applying sodium bicarbonate in the third week. Alkalinity in the freshwater treatment was significantly higher than in the brackishwater treatments ($P < 0.05$), among which there were no significant differences. Concentrations of TKN, nitrite-N, and nitrate-N were higher in the treatments with high N:P ratio than in the treatments with low N:P ratio, and the highest values were obtained in the treatment with high N:P ratio at 10‰ salinity ($P < 0.05$). Concentrations of TAN were significantly higher in the treatment with high N:P ratio at 30‰ salinity than other treatments ($P < 0.05$), among which there were no significant differences ($P > 0.05$). However, concentrations of both TP and SRP were not significantly different in any treatment ($P > 0.05$). Chlorophyll *a* concentrations fluctuated throughout the experimental period without significant differences among treatments ($P > 0.05$). Nitrogen: phosphorus ratios did not result in significant differences in either TSS or TVS ($P > 0.05$); however, both increased significantly with increasing salinity levels ($P < 0.05$, Figure 4). The qualitative analysis of plankton composition showed that the most abundant phytoplankton genera were completely different between freshwater and brackishwater treatments (Table 3). In brackishwater treatments it seemed that phytoplankton composition was affected by salinity levels but not by fertilization rates, and the composition was similar in the 10 and 20‰ treatments. These two treatments were different from phytoplankton in the 30‰ treatment. In the 10 and 20‰ treatments, the most abundant phytoplankton genus was *Entomoneis*, followed by *Chaetoceros* and *Coscinodiscus*, while in the 30‰ treatment the most abundant genus was *Chaetoceros*, followed by *Entomoneis* and *Coscinodiscus* (Table 3).

The partial budget analysis for our data indicated that red tilapia culture in fertilized ponds was profitable (Table 4). The net return from freshwater ponds was lower than that from brackishwater ponds, while the net return decreased with increased salinity levels. The highest net return was achieved in the treatment with N:P ratio of 2:1 at 10‰ salinity, followed by the treatment with N:P ratio of 4:1 at 10‰ salinity, in which the best fish growth was achieved. At 10 and 30‰ salinity, the net return was higher in the ponds with N:P ratio of 2:1 than those with N:P ratio of 4:1, while at 20‰ salinity, the net return was higher in the ponds with N:P ratio of 4:1 than those with N:P ratio of 2:1.

The proximate analysis indicated that there was no significant difference in moisture and ash content of the four tested phytoplankton species ($P > 0.05$, Table 5). *Chaetoceros* sp. had the significantly lowest crude protein content, while *Chaetoceros* sp. and *Chlorella* sp. had significantly higher lipid content compared to other species ($P < 0.05$, Table 5). Red tilapia fed with different phytoplankton species did not show significant differences in moisture, crude protein, or lipid contents ($P > 0.05$), but ash content was significantly higher in red tilapia fed with *Tetraselmis* sp. and *Chlorella* sp. than in those fed with *Thalassiosira* sp. and *Chaetoceros* sp. ($P < 0.05$, Table 5). The best growth performance of red tilapia was achieved by feeding with *Thalassiosira* sp. and *Chaetoceros* sp., intermediate with *Tetraselmis* sp., and poorest with *Chlorella* sp. ($P < 0.05$, Table 6). *Chaetoceros* sp. had the lowest crude protein content but gave the highest protein utilization efficiency, which was not significantly different from that of *Thalassiosira* sp. but was significantly higher than that of *Tetraselmis* sp. and *Chlorella* sp. by more than two and ten times, respectively ($P < 0.05$, Table 7). The two-hour prey consumption trials showed that the prey ingestion rates of red tilapia for *Chaetoceros* sp. and *Thalassiosira* sp. were significantly higher than those for *Tetraselmis* sp. and *Chlorella* sp. ($P < 0.05$, Table 8).

## DISCUSSION

Thai red tilapia grew faster in brackish water than in fresh water in this experiment, which is consistent with the results obtained by Hoa (1996). Similar results were also reported in monosex Florida red tilapia (Watanabe et al., 1988a, 1993), *O. mossambicus* (Canagaratnam, 1966; Juerss et al., 1984; Villegas, 1990), *O. mossambicus* × *O. hornorum* hybrid (Garcia and Sedjro, 1987, cited in Watanabe et al., 1993), mixed-sex Taiwanese red tilapia (*O. mossambicus* × *O. niloticus* hybrid) (Liao and Chang, 1983), and $F_1$ hybrid of *O. mossambicus* × *O. niloticus* (Villegas, 1990). The better growth performance in saline water might be attributed to higher osmoregulation energy costs in fresh water than in brackish water or seawater found in *O. mossambicus* × *O. hornorum* hybrid (Febry and Lutz,

Table 7. Protein utilization efficiency of red tilapia fed with different phytoplankton species in glass 15-l jars for 15 days. Data with superscripts showed significant differences among treatments, and data with the same superscript are not significantly different.

| Treatment | Phytoplankton | | Red Tilapia | | Protein Utilization Efficiency (%) |
|---|---|---|---|---|---|
| | *Fed Amount* (g DM jar$^{-1}$) | *Crude Protein* (g jar$^{-1}$) | *Biomass Gain* (g jar$^{-1}$) | *Crude Protein* (g jar$^{-1}$) | |
| *Tetraselmis* sp. | 26.06 ± 0.00 | 2.75 ± 0.01 | 2.60 ± 1.18 | 0.30 ± 0.14 | 10.91 ± 4.95 [b] |
| *Chlorella* sp. | 26.06 ± 0.00 | 3.16 ± 0.02 | 0.63 ± 0.06 | 0.07 ± 0.01 | 2.33 ± 0.22 [a] |
| *Thalassiosira* sp. | 26.06 ± 0.00 | 3.45 ± 0.01 | 6.39 ± 0.16 | 0.77 ± 0.02 | 22.40 ± 0.56 [c] |
| *Chaetoceros* sp. | 26.06 ± 0.00 | 2.22 ± 0.01 | 5.21 ± 0.24 | 0.62 ± 0.03 | 27.99 ± 1.31 [c] |

Table 8. Consumption of different phytoplankton species by red tilapia with mean weights of 1.50 g and 2.20 g in 4-l glass jars during the two-hour trial period.

| Treatment | Initial Phytoplankton Concentration (mg DM jar$^{-1}$) | Final Phytoplankton Concentration (mg DM jar$^{-1}$) | Phytoplankton Consumed (mg DM jar$^{-1}$) | Prey Ingestion Rate (mg DM g$^{-1}$ fish h$^{-1}$) |
|---|---|---|---|---|
| TILAPIA OF 1.50 G SIZE | | | | |
| *Tetraselmis* sp. | 273 ± 17.2 [a] | 180 ± 20.0 [b] | 93 ± 8.3 [a] | 5 ± 0.5 [a] |
| *Chlorella* sp. | 288 ± 18.2 [a] | 177 ± 14.4 [b] | 110 ± 19.3 [a] | 6 ± 1.1 [a] |
| *Thalassiosira* sp. | 269 ± 9.9 [a] | 48 ± 5.0 [a] | 221 ± 12.5 [b] | 12 ± 0.7 [b] |
| *Chaetoceros* sp. | 251 ± 10.3 [a] | 51 ± 24.3 [a] | 200 ± 18.4 [b] | 11 ± 1.0 [b] |
| TILAPIA OF 2.20 G SIZE | | | | |
| *Tetraselmis* sp. | 306 ± 13.5 [a] | 182 ± 5.0 [b] | 124 ± 9.9 [a] | 7 ± 0.5 [a] |
| *Chlorella* sp. | 306 ± 9.9 [a] | 185 ± 6.2 [b] | 121 ± 15.3 [a] | 7 ± 0.9 [a] |
| *Thalassiosira* sp. | 318 ± 14.0 [a] | 85 ± 5.8 [a] | 233 ± 19.1 [b] | 13 ± 1.1 [b] |
| *Chaetoceros* sp. | 311 ± 21.1 [a] | 76 ± 6.7 [a] | 235 ± 27.7 [b] | 13 ± 1.5 [b] |

1987), suppressed territorial aggression in saline waters (Watanabe et al., 1988b), and inhibitory effects of aggressive behavior which varied among different salinities (Liao and Chang, 1983). In contrast, all-male Taiwanese red tilapia exhibited faster growth in fresh water than in salt water (Liao and Chang, 1983), and similar results were found in *O. niloticus* (Villegas, 1990).

Results of studies on effects of salinity on fish growth are controversial. Under saline water conditions, growth of Thai red tilapia decreased with increased salinity levels from 10 to 30‰ in both low and high fertilization rates in this experiment. The present experiment indicates that the growth of Thai red tilapia may reach a peak at the salinity levels of around 10‰, which is in accordance with the results (12‰) for red tilapia from the UK (Payne et al., 1988). These results support the common assumption that growth of euryhaline teleosts is increased at salinities near isosmotic since osmoregulation costs are minimal under these conditions. Febry and Lutz (1987) found that osmoregulation costs in *O. mossambicus* × *O. hornorum* hybrids were lowest in isosmotic seawater (12‰). However, growth at salinities near isoosmotic was found to be lower than that at higher salinities in Florida red tilapia (Watanabe et al., 1988a) and $F_1$ hybrid of *O. mossambicus* × *O. niloticus* (Villegas, 1990). Febry and Lutz (1987) and Watanabe et al. (1988b) proposed that non-osmoregulatory factors such as aggression might also influence the growth performance of tilapia cultured in saline water. Territorial aggression might account for one-third to one-half of the active metabolic rate in teleosts during intense contesting (Brett and Groves, 1979). Watanabe et al. (1988a) attributed the increased growth they found with increasing salinity for Florida red tilapia to increased food consumption and lowered food conversion ratio.

The fertilization regime with high N:P ratio (28 kg N and 7 kg P $ha^{-1}$ $wk^{-1}$) resulted in good growth performance of Thai red tilapia at all tested salinity levels. The results suggested that the optimized fertilization regime in fresh water can be applied in brackish water. However, the simple partial budget analysis based on the market prices in Thailand indicated that net return from the fertilization regime with low N:P ratio (14 kg N and 7 kg P $ha^{-1}$ $wk^{-1}$) was higher than that from high N:P ratio (28 kg N and 7 kg P $ha^{-1}$ $wk^{-1}$). The fertilization regime in brackishwater ponds may be further fine-tuned based on the local conditions.

One surprising result of this experiment was that the growth of Thai red tilapia in fresh water (0.42 g $d^{-1}$) was far below the growth rate of sex-reversed normal *Oreochromis niloticus* (averaging 1 g $d^{-1}$; Diana, 1997), while growth in brackish water was also poor but approached the normal level. It is generally observed that tilapias exhibit poor growth in cement tanks. The same source of Thai red tilapia grew very well (1.17 g $d^{-1}$) at a density of 62.5 fish $m^{-3}$ in cages suspended in a earthen ponds (Yi et al, 2002). However, it would be useful to compare the two tilapia strains for growth characteristics under different salinity conditions to better understand both economic and biological production.

## ANTICIPATED BENEFITS

This experiment demonstrated that Thai red tilapia grows better in brackishwater ponds, especially at 10 to 20‰, than in freshwater ponds in semi-intensive fertilization culture systems. It also showed that Thai red tilapia culture was profitable in fertilized brackishwater ponds. Best growth performance was achieved in brackishwater ponds fertilized at 28 kg N and 7 kg P $ha^{-1}$ $wk^{-1}$ at 10‰, while the highest net return is achieved in brackishwater ponds fertilized at 14 kg N and 7 kg P $ha^{-1}$ $wk^{-1}$ at 10‰. These data provide farmers with low-risk alternatives to culture red tilapia in semi-intensive fertilization systems using underutilized or abandoned shrimp ponds in the coastal zones of Southeast Asia and of other regions. Culture of red tilapia in low salinity brackish water over time may help reclaim these pond areas to agriculture or to freshwater culture.

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