THE PRODUCTIVITY OF NILE TILAPIA, *OREOCHROMIS NILOTICUS* (L.) REARED UNDER DIFFERENT BROODSTOCK DENSITIES AND PHOTOPERIODS IN A RECYCLING WATER SYSTEM

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ABSTRACT

The effect of three brood fish stocking densities (4, 8 and 12 fish / m^2) combined with three photoperiods (12, 15 and 18 hours/day) on the fry production of the Nile tilapia, *Oreochromis niloticus* (L.), were evaluated in a recycling water system. Treatments were arranged according to a 3×3 factorial design with three replicates giving a total of 27 spawning fiberglass tanks. Males and females with mean body weights of 160.3 and 112.0 g, respectively, were stocked at a male: female ratio of 1:3 in all tanks, and the experiment lasted for 120 days. The results showed that breeders stocked at the lowest stocking density (4 fish / m^2) combined with the longest photoperiod (18 hours/day) had significantly higher ($P<0.05$) mean values for total fry production, fry / kg female /day, fry / female /day, fry / m^2 / day, spawning rate and hatching rate than at 8 and 12 fish/m^2 broodstock densities exposed to the same photoperiod. Moreover, the productivity parameters of tilapia decreased in descending order with the medium and short photoperiods (15 and 12 hours/day, respectively) for all densities. The maximum percentage of yolk-sac and swim-up fry stages were obtained at the lowest stocking density combined with the longest photoperiod. These findings are discussed to achieve optimum reproductive performance of Nile tilapia broodstock for fry production management.

INTRODUCTION

Many exogenous factors involving water temperature and light (intensity and duration) often interact to regulate the onset of gonadal maturation, the spawning season, spawning frequency and the calibration of the endogenous rhythm of tilapia reproduction (Lauenstein, 1978; Jalabert & Zohar, 1982; Philippart & Ruwet, 1982). The effect of water temperature on tilapia spawning is well documented (Brummett, 1995; Macintosh & Little, 1995). However, only little information is available on the possible effects of lighting intensity and photoperiod on tilapia reproduction (e.g. Hyder, 1970; Rothbard & Pruginin, 1975; Jalabert & Zohar, 1982; Philippart & Ruwet, 1982; Brummett, 1995; Marshall & Bielic, 1996; Ridha *et al.*, 1998). It is believed that melatonin is the key hormone involved in the regulation of endogenous rhythms by photoperiod cues. During the hours of darkness, synthesis of melatonin by photoreceptors of the pineal gland is increased. Melatonin action is linked to other reproductive endocrine glands, which is responsible for advancing mollification in salmonids (Porter *et al.*, 1998). The low fecundity and asynchronous breeding habit of the maternal mouth-brooding tilapia of the genus *Oreochromis*, represents one of the major constraints that hinder expansion in tilapia reproduction. Therefore, some techniques have been developed to counteract this problem, such as optimum stocking rate of broodstock per unit area (Bautista, *et al.*, 1988; Little, 1989; Ridha *et al.*, 1998), broodstock exchange and conditioning at regular intervals (Little, 1989; Little *et al.*, 1993), frequency of periodic seed removal from the brooding females (Verdegem & McGinty, 1987; Little, 1989; Little *et al.*, 1993) and temperature manipulation (Behrends & Smitherman, 1983). Broodstock density is one of the important biological factors that has considerable influence on fry production in tilapia (Silvera, 1978; Lee, 1979; Hughes & Behrends, 1983; Guerrero & Guerrero, 1985; Bautista *et al.*, 1988; Obi & Shelton, 1988). Moreover, the manipulation of broodstock density is one of several techniques applied to improve mass production of tilapia fry (Abella & Batao, 1989). In general, low broodstock densities gave better fry production than higher densities (Bautista *et al.*, 1988; Ridha *et al.*, 1998). In ponds, the low production of tilapia fry has been attributed to a suboptimal broodstock density (Mires, 1982). On the other hand, under intensive hatchery systems, broodstocks are often stocked at high densities in small and confined breeding units such as aquaria, tanks and net enclosures (hapas), resulting in aggression and fighting between males, and thus, affecting fry production (Behrends *et al.*, 1993). The aforementioned studies on the effect of broodstock density on fry production were conducted in aquaria, plastic pools, ponds and hapas. However, scarce studies have been conducted in water recirculating systems using biological filters. In Saudi Arabia, fry production has been done by using the recirculating system because of the limited freshwater resources. Several workers indicated that lower stocking densities (≤ 4 fish / m^2) give better fry production. However, a study conducted by little (1989) showed that the maximum daily fry production was obtained at 8 fish/m^2. While lower fry production has been reported for higher densities, it is still worthwhile to reconfirm such findings using the recirculating tank system. Therefore, the present study was performed to determine the optimum brood-stock density and the photoperiod for the fry production of the Nile tilapia, *Oreochromis niloticus* (L.), under an intensive recycling hatchery system.

MATERIALS AND METHODS

Three broodstock densities (4, 8 and 12 fish/m^2) of Nile tilapia, *Oreochromis niloticus* (L.), combined with three photoperiods (12, 15 and 18 hours/day[1]) were assigned according to a 3×3 factorial design. Each combination represented a treatment and each was conducted in three replicates giving a total of 27 spawning fiberglass tanks, each measuring 1.0×1.0×0.5 m (L×W×H). The spawning tanks were illuminated at light intensity of 2500 Lux using fluorescent tubes fixed above the tanks. A biological filter recycled the effluent water from spawning tanks, water was partially (10%) replaced with fresh water daily after siphoning the wastes at about 7:30 am. All tanks were aerated with compressed air and the water temperature was maintained at 27°C ±1 by using thermostatically controlled titanium immersion heaters installed in the header tanks. Males and females with mean body weights of 160.3 and 112.0 g, respectively, were stocked at a sex ratio of 1 male to 3 females in all tanks throughout the experimental period of 120 days. The upper maxillary bone of the males was removed to minimize injury as a result of aggressive behaviour (Lee, 1979). All fish were sampled every two weeks for weight measurements. Eggs, yolk-sac fry and swim-up fry were collected during sampling of broodstock. Both eggs and yolk-sac fry were further incubated as described by Ridha *et al.* (1998). In the present experiment, hatching rates were determined as percentage of swim-up fry produced from the total spawned eggs. Breeders were fed three times daily at 2.0 % body weight per day with 3 mm sinking fish pellets (40% crude protein, Arasco, Saudi Arabia). The amount of feed was adjusted every two weeks after broodstock weighing. Dissolved oxygen and water temperature were measured twice daily using a dissolved oxygen (DO) meter (Orion, Boston, MA, USA). Total ammonia (NH_3-N), unionized ammonia (NH_3), nitrites (NO2-N), nitrates (NO3-N) and pH were measured weekly, using a Hach kit (Loveland, CO, USA). The present work was achieved through the research project number 7063 (1427-1429H) financial supporting from Deanship of scientific research, King Faisal University.

Data obtained on mean growth, fecundity (expressed as total fry production / tank, fry / kg^1 female day, fry / female / day and fry / m^2 / day), mean spawning rate, fry composition and hatching rates were statistically analyzed using SPSS (1996) Computer Program, as two-way analysis of variance (ANOVA) to determine separately the possible effect of different brood stocking densities and photoperiods and their possible interactions on fry production. Duncan's multiple range tested the mean values at a 5% level of significance (Duncan, 1955).

RESULTS

Water quality

The mean, minimum and maximum values of the water temperature, dissolved oxygen, pH, salinity, total ammonia, unionized ammonia, nitrite and nitrate are shown in Table (1). The mean values for these water quality parameters were as follows: temperature 27.4 °C, DO 7.0 mg / L, pH 7.1, salinity 2.0 ‰, NH_3-N 0.97 mg / L^1, NH_3 0.013 mg / L^1, NO_2-N 0.25 mg / L and NO_3-N 8.0 mg / L, respectively. The above measurements of water quality parameters were within the safe ranges for the spawning and growth of tilapia.

Broodstock growth performance

Throughout the experiment, an increase in broodstock biomass and mean body weights was observed in all broodstock densities combined with the different photoperiods. At the end of the experiment, Figure (1) shows that the total biomass increased to the highest values in the high broodstock density (12 fish / m^2), then it was significantly decreased ($P>0.05$) in the medium and low broodstock densities (8 & 4 fish / m^2, respectively). However, males and females in low stocking density showed significantly higher ($P<0.05$) mean harvested weight, mean daily growth rate (g fish / day) and specific growth rate (SGR) than fishes stocked at medium and high densities (Fig. 2). On the other hand, a positive relationship was found between the length of photoperiods within the three stocking densities and the increment of the above mentioned growth parameters were significantly higher ($P<0.05$) in the longest photoperiod (18 hours daily) than in the medium and short photoperiods for the low stocking density and insignificant ($P>0.05$) within medium and higher stocking densities. Moreover, females had a significantly higher ($P<0.05$) specific growth rate than males in all broodstock densities.

Reproductive performance and fry production:

The reproductive performance and total fry production are graphically represented in Figures (3, 4 and 5). Adversely, the number of produced fry increased as density decreased. Broodstock at a density of 4 fish m^{-2} had significantly higher ($P<0.05$) total fry production rates than at the two higher densities (8 & 12 fish / m^2). The lowest stocking density combined with the longest photoperiod (18 hours daily), had significantly highest total fry production (6563 fry) among all treatments. It was found that the mean fry production displayed a pattern of high flattened peak from 2-8 weeks of the experimental time followed by medium and low fluctuated peaks as fry production gradually declined for all trials, but the low broodstock density had higher peaks of production than the other two densities. In the medium and high broodstock densities, spawning was quickly declined and stopped gradually with time, respectively, while, at the lowest density, it continued till the end of the experiment. The reproductive performance and total fry production records were higher significantly in the longest photoperiod (18 hours daily) than in the medium and short photoperiods (15 & 12 hours daily) within the three stocking densities tested.

Spawning rate and fry composition

The mean spawning rate of females at the 4 fish / m^2 density (19.1, 26.2 & 45.4%) was significantly higher ($P<0.05$) than at the 8 fish / m^2 (11.2, 16.7 & 26.5%) and 12 fish m^{-2} (7.3, 12.1 & 15.4%) densities for short, medium and longest photoperiods, respectively (Fig.5). It can be noticed from Table (2) that the mean hatching rate of produced eggs from brooding females stocked at 4 fish / m^2 (90.4%) was significantly higher ($P<0.05$) than those obtained from brooding females stocked at 8 fish / m^2 (79.5%) and 12 fish / m^2 (58.4%) for the longest photoperiod. Regardless of stocking density, the longest photoperiod (18 hours daily) had significantly a positive effect on the hatching percentage than medium and short photoperiods.

Fecundity, expressed as fry / kg female / day and fry / female /day, was significantly ($P<0.05$) affected by broodstock density (Fig. 4). The lowest density had the highest mean fry / kg female / day (118.4, 121.2 & 128.0) and mean fry / female / day (16.0, 16.6 & 18.2) for the photoperiods of 12, 15 and 18 hours per day, respectively. However, the higher broodstock densities (8 and 12 fish / m^2) had significantly lower values for mean fry / kg female / day and mean fry / female / day. On the other hand, fry production per unit area calculated as fry / m^2 / day was decreased with the increase in brood-stock density. Broodstock at the lowest density (4 fish / m^2) produced significantly higher ($P<0.05$) fry / m^2 day than at the other two densities (Fig. 3).

Regardless photoperiod, the mean percentages of fry in the sac- and swim-up fry stages were significantly higher ($P<0.05$) at the lowest density (4 fish / m^2) than at the medium and highest densities (8 & 12 fish / m^2, respectively). Also, it was found that the percentage of collected fry in all broodstock densities was relatively increased with expanding the photoperiod (Table 2). However, significant difference in the mean percentage of eggs was observed among the three densities; the highest percentage (61.4%) was reported at the highest density (12 fish / m^2) while the lowest percentage (20.1%) was at the lowest density (4 fish / m^2).

DISCUSSION

Water quality

All water quality parameters throughout the present work were within safe ranges and acceptable limits for the spawning and growth of tilapia under recycling systems, and were comparable with those reported by Lin & Lui (1989) and Hassan (1992), with a maximum loading rate of 4.45 kg / m^3 and pH of 7.5. Papoutsoglou & Tziha (1996) obtained maximum values of 1.28 mg / L for NH_4, 0.021 mg / L for NH_3 and 0.28 mg / L for NO_2 for *O. aureus* stocked at a density of 7.9 kg / m^3 in 100-L aquaria under a recycling system at a temperature of 23.6 °C, a DO content of 6.5 and a pH of 7.5 with 5% mortality. Ernst *et al.* (1991) reported maximum total ammonia of 0.69 mg / L under a recycling system. However, Siddiqui *et al.* (1997) obtained a range of 0.2-0.6 mg / L for total ammonia in an open system.

Broodstock growth performance

Throughout the present study, an increase in broodstock biomass and mean individual body weights of males and females was observed in all treatments (Fig. 1), indicating favourable conditions for growth. At the end of the experiment, mean total fish biomass differed significantly between treatments ($P<0.05$) as it increased with each increase in stocking density and vice versa. The mean harvested body weight of males was higher ($P<0.05$) than females in all treatments. Both growth rate and specific growth rate of males and females in the lowest density was significantly higher than their growth performance at medium and higher stocking densities (Fig. 2).

However, the significantly higher SGR of the females over the males in the same treatment was probably a result of higher breeding activities of males during spawning, also it may be related to the heavy weight of ripe ovaries occupied with eggs than the weight of testes. Maluwa & Costa-Pierce (1993) considered the poor SGR of breeders at densities 0.7, 1.0 and 1.7 fish / m^2 as an indication of a shift from growth to spawning activity. In the present study, the slow growth of females stocked at 12 fish m^{-2} was probably caused by high stocking rates rather than shifting from growth phase to spawning phase, since breeders at this density had poor spawning performance. These results indicate that there is enough energy for both somatic growth and spawning activity at a low stocking density. Also, the high broodstock density had a depressing effect on growth as a result of competition between individuals for space and food (Obi & Shelton, 1988).

Effect of stocking density on reproductive performance and fry production

Generally, the lowest broodstock density (4 fish / m^2) resulted in the maximum fry production among all treatments (Figs. 3 and 4). These results are in agreement with those reported for many tilapia species in different aquaculture systems. Hughes & Behrends (1983) indicated that a breeder's density of 5 fish / m^2 *O. niloticus* stocked in hapas at a male: female ratio of 1:2 produced a fry yield of 150 fry / kg female / day. However, Behrends & Smitherman (1983) found that the interspecific spawning of *O. mossambicus* females with *O. hornorum* males in hapas with broodstock density of 3.6 fish / m^2 at a male: female sex ratio of 1:1 to be the optimum density for fry production (338 fry / kg female / day). On the other hand, an inverse relationship was reported by Allison *et al.* (1976) between the broodstocking density of *O. aureus* and the average number of fry produced. The higher peaks of fry production at a density of 4 fish / m^2 in the present results compared with the other densities indicated a more synchronous spawning. however, increasing stocking density beyond 4 fish m^{-2} was not effective in improving fry production, that conclusion was in close agreement with the findings of Bautista *et al.* (1988). Moreover, Little (1989) obtained a maximum daily fry production at the broodstock density of 8 fish / m^2 and the lowest fry / kg female / day (119) from high density such as 4.7 females / m^2 (9.5 fish / m^2). A general trend of declining fry production per unit area as the density increased was observed in the present work and the above mentioned studies. Inversely, Obi & Shelton (1988) reported that the fry production per unit area (m^2) in *O. hornorum* (Trewavas) increased with the increase of the broodstock density. Similar observations for *O. shiranus*

(Boulenger) were reported by Maluwa & Costa-Pierce (1993). These contrasting results might have been partly caused by differences in stocking densities used. It must be noted that the maximum stocking densities used by the above authors were 4 and 1.7 fish / m^2, respectively, and that both these numbers were below the density used by most researchers. Therefore, the conclusion of the above authors that a higher number of fry stocks could be produced at a higher stocking density might be true as long as broodstock density did not exceed the optimum density. The significantly low production of fry at higher densities in the mouth-brooding tilapia is contributed to several factors, such as competition between individuals for space, which may interfere with the spawning behaviour, and therefore, disrupt and depress breeding. Silvera (1978) showed that the minimum area for individual fish was 0.12 m^2 / fish and that spawning would be affected at higher broodstock densities. In the present study, smaller areas were available for individual fish at the higher densities of 8 and 12 fish / m^2 (0.13 and 0.08 m^2 / fish, respectively). The lowest density had more (0.25 m^2 / fish) space for the individual spawner. The male breeders may chase non-spawning females out of their territory to charm spawning females. This could be a negative feedback mechanism to prevent overpopulation. Fishelson (1966) indicated that the minimum size of territory in ponds for males is 0.7-1.0 m^2. In the present study, at the lowest density (4 fish / m^2), individual males had a spawning area of 1.0 m^2 / male, which lies within the maximum range, whereas at the higher broodstock densities (8 and 12 fish / m^2), the available area of 0.5 and 0.3 m^2 / male, respectively, was below the minimum range. Brummett (1995) stated that competition for spawning site was one of the factors that regulated final gonadal maturation and spawning, and high density might result in gonadal regression and ultimately a general failure in spawning. The species and strain factors represent another factor that affects fry production in tilapia. In the present study, the fecundity of 128 fry / kg female / day obtained at a density of 4 fish / m^2 was comparable to that obtained by Smitherman *et al.* (1988) for the same species (110 fry / kg female / day) kept in suspended hapas at the same stocking density and sex ratio. However, it was lower than those obtained by Little (1989) and Little *et al.* (1993) using *O. niloticus*. This is attributed to the differences in the spawning potential among strains of the same species (Lee, 1979; Smitherman *et al.*, 1988; Eguia, 1996). Moreover, differences in spawning frequency and fecundity among individual fish can be related to variability in fry production (Chang *et al.*, 1988). The present results indicate that the fry production of Nile tilapia reared in recirculation system was similar to those obtained by other workers using aquaria, ponds, hapas and pools. Thus, the present findings reconfirm earlier results that increasing stocking density above 4 fish m^{-2} led to a reduction in fry production.

Effect of photoperiod on reproductive performance and fry production

A general trend of higher fry production associated with an increase in photoperiod length was observed. For example, Behrends & Smitherman (1983) simulated the ambient photoperiod and found that gonadal development and spawning frequency increased when the photoperiod was increased from 10.30h / day to about 12h / day. Ernst *et al.* (1991) observed that an increase in photoperiod from 12.00h / day to 14.30h / day and in temperature from 23 °C to 29.0 °C resulted in a significant increase in fry production in Florida red tilapia, and despite continued high temperature, fry production decreased with a decrease in day length. They concluded that either prolonged high temperature inhibited spawning or photoperiod had a dominant influence on fry production. In this study, data pooled across photoperiods showed that increasing the photoperiod up to 18h / day had a positive effect on the different spawning parameters (Table 2 and Figs. 3, 4 and 5). The lower spawning parameters encountered in the short photoperiod (12h / day) can be explained in terms of a stronger social hierarchical structure of this group of fish, which resulted in lower spawning activity. Little (1989) and Little *et al.* (1993) attributed the main difference in the spawning characteristics of fish in the spawning unit to the relative strength of the hierarchy and found that a weaker hierarchy resulted in improved spawning synchrony. Galman *et al.* (1988) succeeded in obtaining year-round fry production in Philippine red tilapia by supplying artificial light to give an additional 2h duration during the winter months (December-February). Ridha *et al.* (1998) found that *O. spilurus* broodstock maintained year-round under a 14h / day photoperiod had significantly better spawning performance than at a 13h / day photoperiod. The higher fry production and spawning synchrony with an 18h / day photoperiod at light intensity of 2500 lux is probably suggested in this study, since the photoperiod played a more important role in fry production.

Spawning rate and fry composition

The spawning rate was increased in the lowest broodstock density 4 fish / m^2 to indicate that more synchronous than at the medium and higher brood-stock densities (Fig. 5). Similar observations for *O. niloticus* in concrete tanks and hapas were reported by Little (1989). However, the reduced fry production at a higher stocking density indicates a lower fertilization success of eggs and those females were less successful in incubating the fry (Little, 1989; Ernst *et al.,* 1991), and this was attributed to the increased interference during spawning and the stress during incubation (Balarin & Haller, 1982; Little, 1989). Moreover, the released fry might be eaten by non-spawning fish in crowded spawning tanks (Balarin & Haller, 1982). The reduced fry production at higher stocking densities may also a results of the fewer eggs released due to depressed ovulation. Concerning the fry composition, the sac-fry and swim-up fry stages represent another indicator for spawning synchrony. Little (1989) and Little *et al.,* (1993) revealed that the higher percentage of sac-fry and spawning frequency would be the more synchronous spawning. In the present study, the lowest broodstock density with the longest photoperiod (4 fish / m^2/ photo18h / day) exhibited highest percentage of sac-fry, swim-up fry, hatching rate and spawning rate among all treatments. This indicates that spawning at the lowest density was more synchronous than at the higher densities with a tendency towards decreased synchrony as the broodstock density increased and the photoperiod decreased. Little (1989), working with *O. niloticus*, reported similar results and found the highest percentage of fry in the lowest density treatment, and the highest percentage of eggs and lowest spawning frequency in the higher density treatments.

Based on the present work, it can be recommended to use broodstock densities of 4 fish / m^2 exposed to 18h / day photoperiod at light intensity of 2500 lux for improving the reproductive performance and maximize the fry production of *O. niloticus*. It would reduce the amount of feed and leads to efficient utilization of the limited hatchery space and also collect more fry in the non-egg stage that reduces effort in eggs incubation and yields better survival rates.

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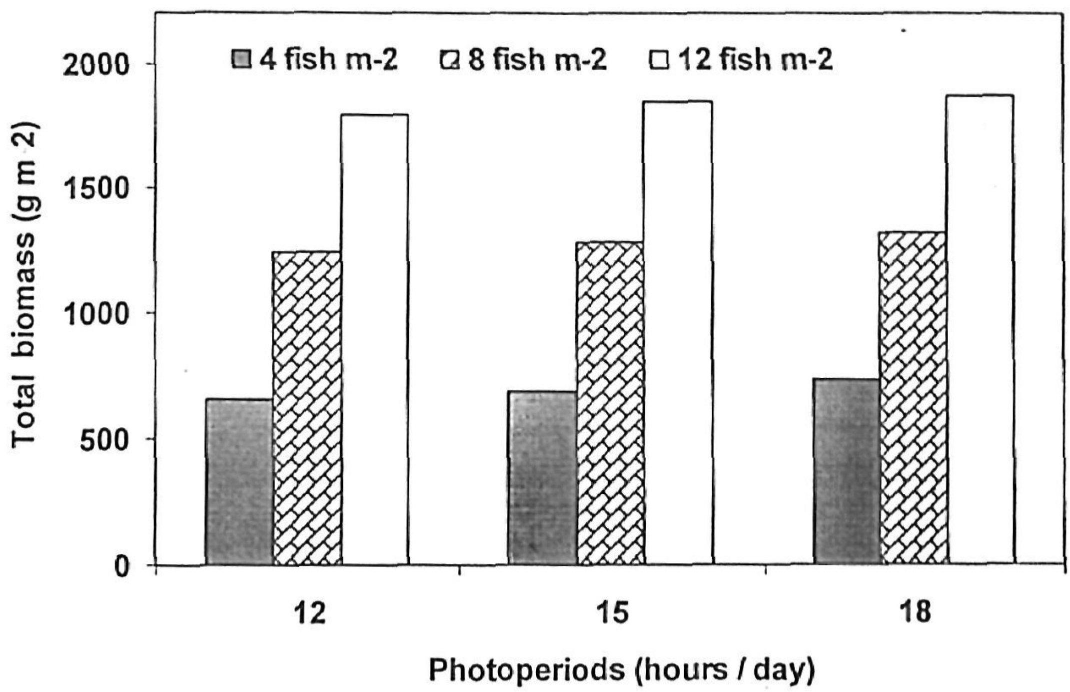
Table 1: Water quality parameters in spawning tanks stocked at three broodstock densities of *O. niloticus* in a recycling water system.

Parameter	Minimum	Maximum	Means ± SD
Water temperature (°C)	25.0	29.2	27.4 ± 1.12
Dissolved oxygen (mg / L)	6.3	7.6	7.0 ± 0.29
pH	6.5	7.5	7.1 ± 0.40
Salinity (‰)	0.6	4.0	2.0 ± 0.93
Total ammonia (NH_3-N) (mg / L)	0.35	1.79	0.97 ± 0.23
Unionized ammonia (NH_3) (mg / L)	0.004	0.022	0.013 ± 0.02
Nitrite (NO_2-N) (mg / L)	0.12	0.49	0.25 ± 0.11
Nitrate (NO_3-N) (mg / L)	4.0	11.0	8.0 ± 1.76

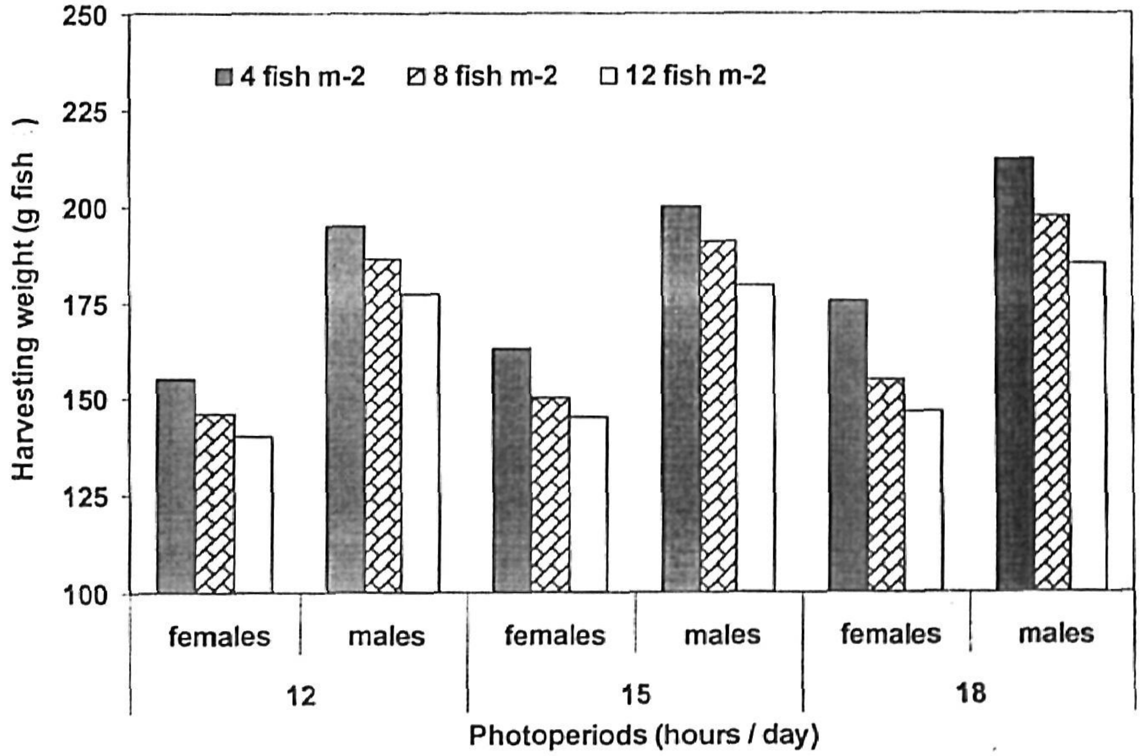
Table 2: Fry composition and hatching rate of *Oreochromis niloticus* at three broodstock ensities (Data include the means ± SD of three replicates*).

Broodstock density (fish / m^2) / Photoperiods (hours / day)	Eggs	Sac-fry (a)	Swim-up fry (b)	Sac-and swim-up fry (a + b)	Hatching rate (%)
4 fish / m^2 / photo 12 h / d	39.5 ± 6.2c	40.3 ±10.1a	20.2 ±4.8a	60.5 ±11.3c	71.2 ± 3.9c
4 fish / m^2 / photo 15 h / d	30.2 ± 5.7c	45.8 ±10.3a	24.0 ±5.2a	69.8 ±12.1b	82.3 ± 5.7b
4 fish / m^2 / photo 18 h / d	20.1 ± 5.0c	52.7 ±11.0a	27.2 ±5.9a	79.9 ±12.0a	90.4 ± 6.1a
8 fish / m^2 / photo 12 h / d	52.1 ± 9.3b	38.3±12.7 b	09.6 ±3.6b	47.9±13.1d	54.1 ± 2.3e
8 fish / m^2 / photo 15 h / d	46.8 ±11.1b	45.0±13.6b	08.2 ±3.3b	53.2 ±13.5c	63.0 ± 4.1d
8 fish / m^2 / photo 18 h / d	41.4 ±10.4b	47.6±13.9b	11.0 ±3.9b	58.6 ±14.2c	79.5 ± 5.9c
12 fish / m^2 / photo 12 h / d	61.4 ±15.4a	34.6±12.0c	4.0 ±0.5c	38.6 ±13.3e	43.0 ± 2.1f
12 fish / m^2 / photo 15 h / d	57.1 ±14.3a	37.6±12.6c	5.3 ±0.9c	42.9 ±14.6d	50.2 ± 3.4e
12 fish / m^2 / photo 18 h / d	53.6 ±13.5a	39.5±13.7c	6.9 ±1.0c	46.4 ±15.4d	58.4 ± 3.9e

*In each column, means followed by different superscript letters are significantly different ($P<0.05$).

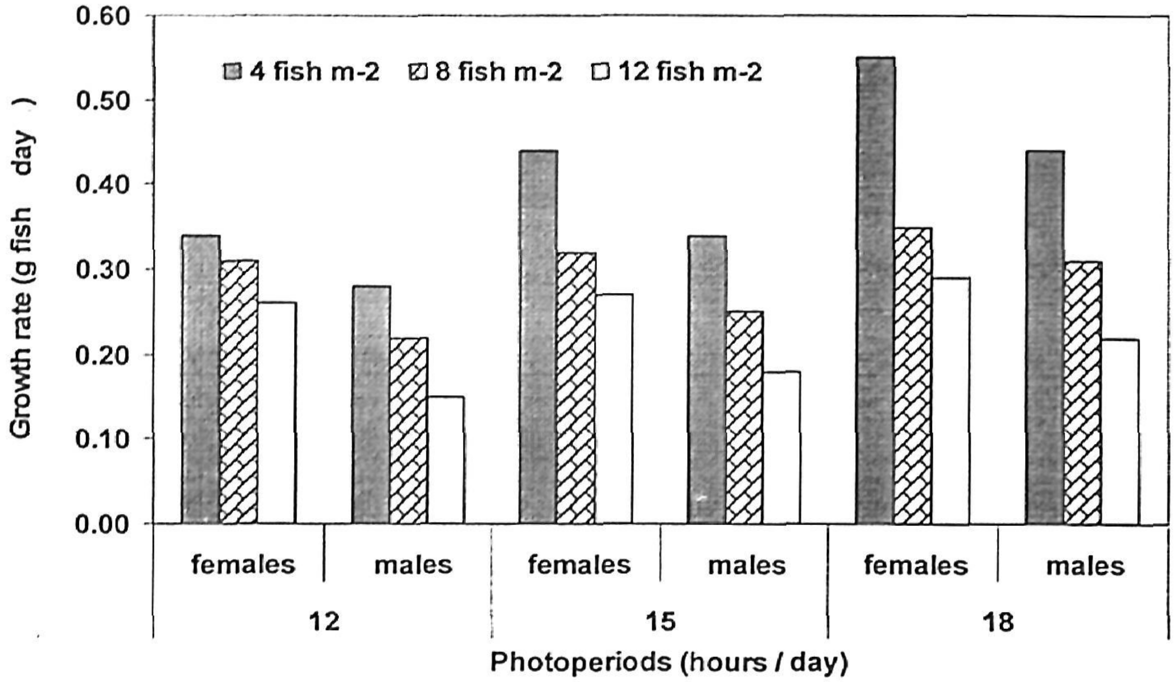


a) Total biomass (g fish m^{-2})

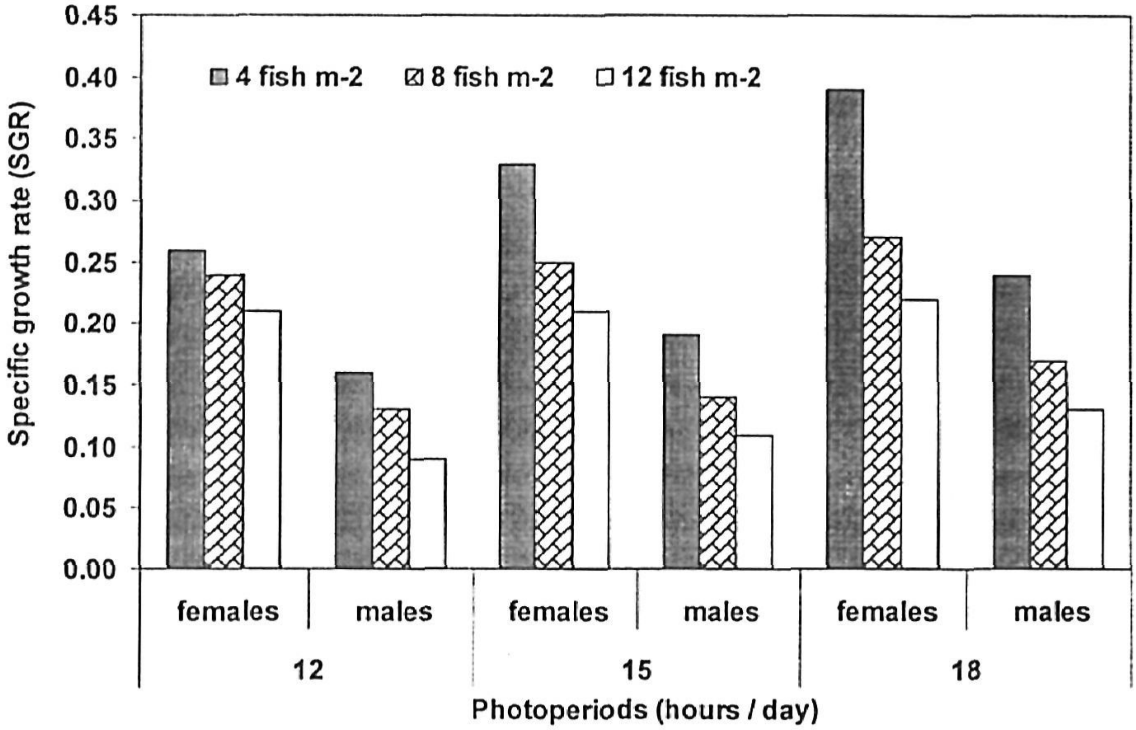


b) Harvesting weight (g / fish)

Fig 1. The total biomass and harvesting weight of *O. niloticus* broodstock reared at three stocking densities (4, 8 & 12 fish / m^2) and three photoperiods (12, 15 & 18 hours / day).

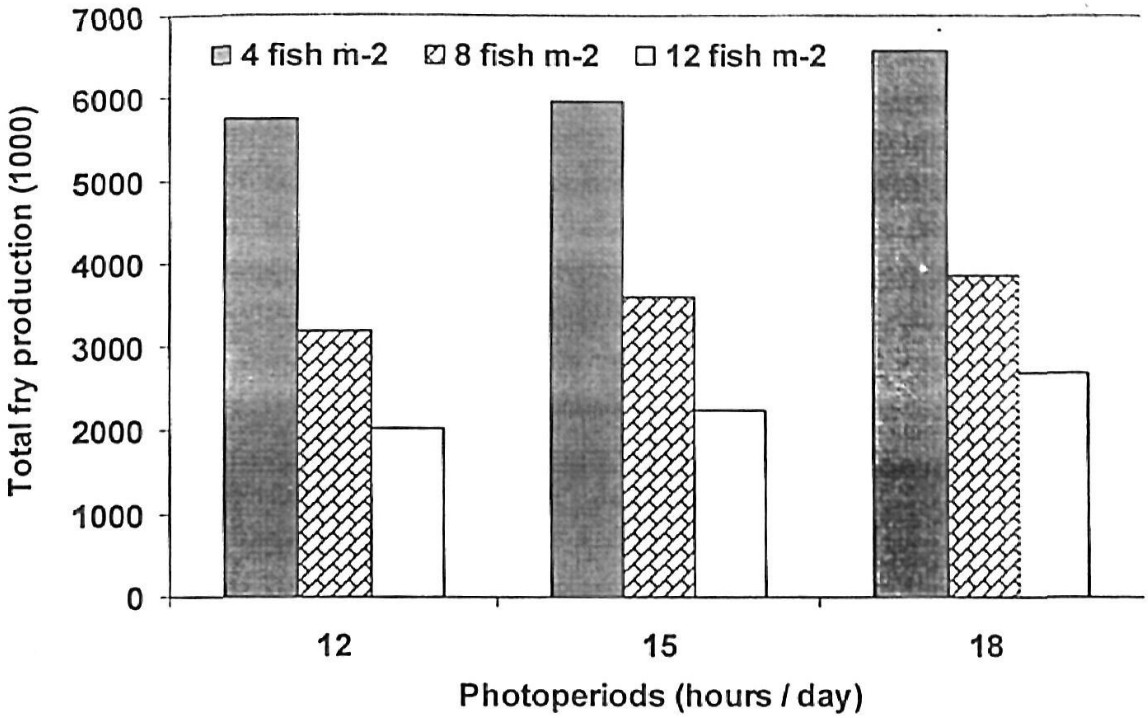


a) Growth rate (g / fish / day)

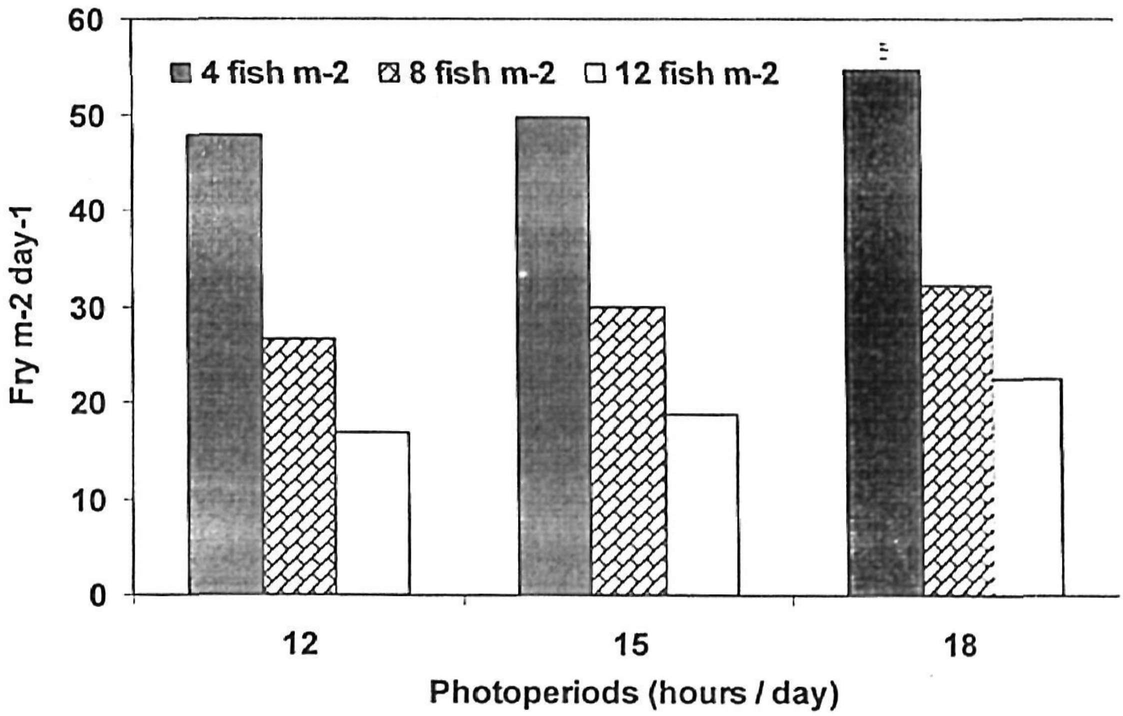


b) Specific growth rate (SGR)

Fig 2. The growth performances of *O. niloticus* broodstock reared at three stocking densities (4, 8 & 12 fish / m^2) and three photoperiods (12, 15 & 18 hours / day).

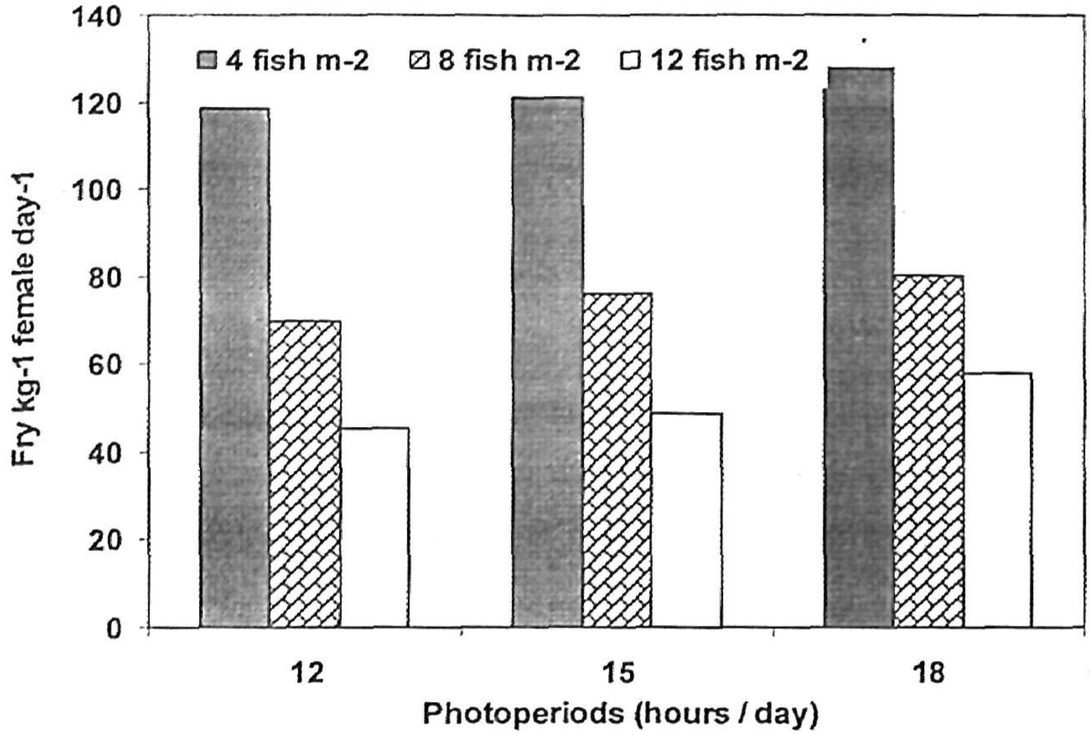


a) Total fry production (1000)

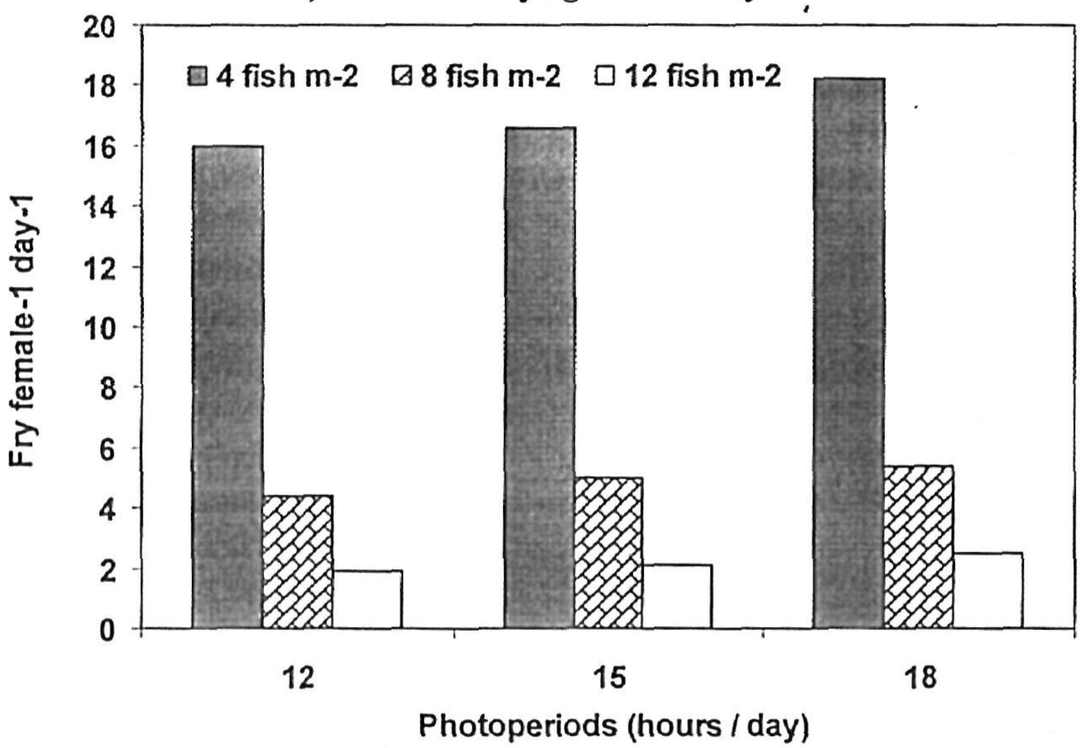


b) Average fry production (fry m^{-2} day^{-1})

Fig 3. Total and average fry production of *O. niloticus* broodstock at three stocking densities (4, 8 & 12 fish / m^2) and three photoperiods (12, 15 & 18 hours / day).

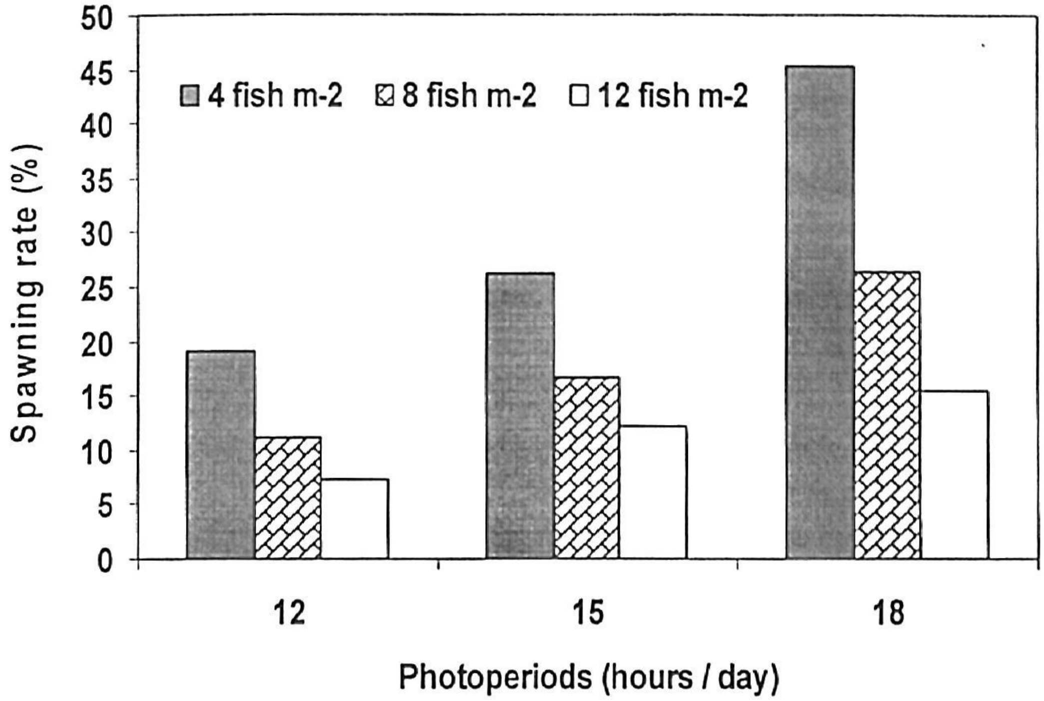


a) Number of fry kg^{-1} female day^{-1}

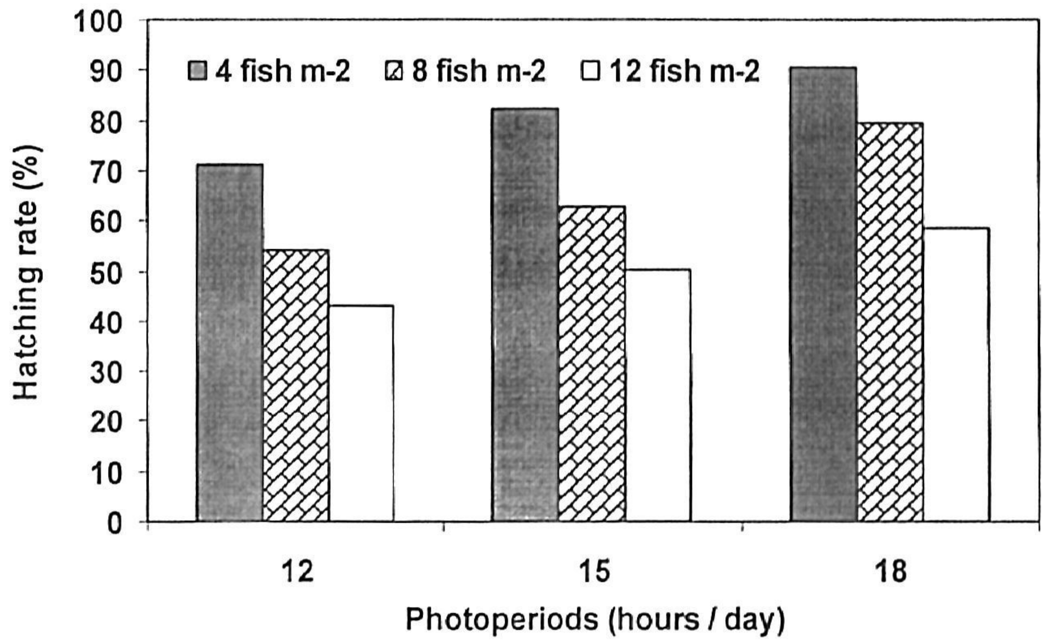


b) Number of fry $female^{-1}$ day^{-1}

Fig 4. The relative fry production of *O. niloticus* broodstock at three stocking densities (4, 8 & 12 fish / m^2) and three photoperiods (12, 15 & 18 hours / day).



a) The spawning rate (%)



b) The hatching rate (%)

Fig 5. The spawning and hatching rates of *O. niloticus* broodstock at three stocking densities (4, 8 & 12 fish / m^2) and three photoperiods (12, 15 & 18 hours / day).