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Reproductive performance of the Mesa silverside (*Chirostoma jordani* Woolman, 1894) under natural and controlled photoperiods

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Key words: breeding, Atherinopsidae, eggs, juveniles, survival rate

ABSTRACT: *Chirostoma jordani* is a native annual species inhabiting lacustrine waters of the Central Mexico Plateau. It is widely distributed and is currently facing high environmental pressures. Five experiments were performed to study the reproductive performance of this species. Four of the experiments were conducted in 270-L indoor recirculation tanks. Two males and one female at the first stage of reproduction were included in each test. A photoperiod of 14 light hours and 10 dark hours was used. In a fifth experiment, 10 females and 15 males were kept in an outdoor 3,000-L recirculation tank under natural photoperiod. The number of spawns, fertilised eggs and 30-day-old juveniles were counted and the survival rate was calculated. The results indicated significant differences ($P<0.05$) between treatments. Higher spawn numbers and greater egg production were observed under controlled photoperiod, and higher numbers of juveniles and a higher survival rate were observed under natural photoperiod. The trials exhibited different patterns of egg production during the experiment. The egg production in the natural-photoperiod trials followed a polynomial curve model. In contrast, the trials under the controlled photoperiod showed an irregular pattern of increases and decreases in egg production.

Introduction

The Mesa silverside (*Chirostoma jordani*), known as 'charal' in its native Mexico, has a broad distribution in the Central Mexico Plateau. Historically, the 'charal' species group has been considered of high economic, social, cultural and ecological importance (Álvarez del Villar, 1970; Miller *et al*., 2005). Many indigenous groups that settled and are distributed along the Lerma-Chapala-Santiago river system depend almost exclusively on the 'charal' fishery, which represents an important food and economic resource for these human populations. Currently, 'charal' populations are decreasing due to habitat modification, human and industrial contamination, overfishing, and, especially, interactions with introduced, non-native species (Miller *et al*., 2005). As a consequence, the charal requires immediate attention to maintain and preserve its natural populations.

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The Mesa silverside is considered an important fishery in the Xochimilco Lake rural area. It is currently in danger due to the drastic environmental changes occurring in lacustrine ecosystems in the Mexico Basin.

Scientific information about the 'charal' species group is scarce. The most important studies generally include biology, fisheries, breeding and morphological-anatomical descriptions (De Buen, 1945; Barbour, 1973a, b; Gallardo-Cabello, 1977; Navarrete, 1981; Gómez-Márquez and Ramírez de Arellano, 1982; Cházaro-Olvera, 1989; Hernández, 1993; Jiménez-Badillo and Gracia, 1995; Cárdenas and Barrera; 1998; Soria-Barreto and Paulo-Maya, 2005; Rojas-Carrillo, 2006; Ibáñez *et al*., 2008; Olvera-Blanco *et al*., 2009).

Many species of teleost fish react to photoperiod treatments. A long daylength stimulates growth and influences early maturation (Boeuf and Le Bail, 1999). The photoperiod is commonly viewed as the principal environmental determinant of reproductive development and has a primary role in phasing the overall reproductive cycle. It is possible that the photoperiod is also an important driver in warm temperate and tropical systems (Bromage *et al*., 2001). Photoperiod manipulation can induce gonadal development in tropical species (Lam and Munro, 1987). There is strong evidence for the role of photoperiod and temperature in driving the reproductive cycles of teleosts fish living in temperate environments, but only a modest understanding of the environmental drivers in tropical systems is available (Pankhurst and Porter, 2003). It is very advantageous to be able to manipulate reproductive activity of broodstock to improve eggs and sperm production. Photoperiod manipulation in fish has been shown to produce better growth, early maturation and year-round production in several annual and temperate species (Huber and Bengtson, 1999; Bromage *et al*., 2001; Shimizu, 2003; Blancas-Arroyo *et al*., 2004; Bayarri *et al*., 2004). In Mexican silverside fishes, studies of peces blancos, *Chirostoma humboldtianum* and *C. estor estor* have investigated the control of breeding through photoperiod and temperature manipulation (Blancas-Arroyo, *et al*., 2004; Martínez-Palacios *et al*., 2007). In both cases, it was found that if the photoperiod and water temperature are maintained at 14 hours of light and approximately 21ºC, spawning can occur throughout the year.

Previously, the information about the relationship between reproduction and photoperiod in the 'charal' species group was insufficient. Figueroa-Lucero *et al*. (2004) and Hernández (2009) described the effect of food type on the growth and survival rate of *Chirostoma*

TABLE 1.

Experimental conditions for the five *C. jordani* trials.

Parameters	Natural photoperiod	Controlled photoperiod			
Trial dates	September-December 2009	May-September 2008	August-November 2009	July-November 2009	July-November 2009
Light regime (Dark:Light)	Natural photoperiod[1]	10:14	10:14	10:14	10:14
Light intensity (Lux)	Natural daylight[1]	70	70	70	70
Tank volume (L)	3 000	274	274	274	274
Flow rate (L min^{-1})	13	14	14	14	14
Stocking level	15 ♂: 10 ♀	2 ♂: 1 ♀	2 ♂: 1 ♀	2 ♂: 1 ♀	2 ♂: 1 ♀
Mean initial body weight (g).	1.10	1.50	1.12	1.12	1.12
Mean initial total length (cm)	6.2	7.0	6.0	6.0	6.0

[1] Altitude = 2 240 m.

riojai during early development and the induction of reproduction through photoperiod manipulation. However, comparable information does not exist for *C. jordani*. For this reason, this investigation aimed to study the response of *C. jordani* to natural and controlled photoperiods. The number of spawn, egg production, 30-day-old juveniles and survival rate were compared between natural and controlled conditions.

Materials and Methods

Production system

Five experiments were conducted in the facilities of the Experimental Aquaculture Production Plant (EAPP) at the Metropolitan Autonomous University Iztapalapa campus to analyse the effect of photoperiod on the number of spawn, production of eggs and juveniles and survival rate in *C. jordani*. A preliminary test was conducted in 2008 in a 270-L indoor recirculation tank. Two males and one female fish that have just reached reproductive maturity were introduced into the tank. The fish had a mean body mass of 1.10 g and a mean total length of 6.0 cm. A photoperiod of 14 Lh and 10 Dh was used. An average temperature of 20.1 ± 1.6ºC and a dissolved oxygen concentration of 5.0±1.2 mg/L were maintained during this trial according to Blancas-Arroyo *et al*. (2004). In 2009, four additional experiments were conducted. In the first trial, 10 females and 15 males, all six months old with a body mass of 1.1 g and a total length of 6.2 cm, were introduced to a 3,000-L outdoor recirculation tank exposed to the natural photoperiod (september-december). A mean temperature of 22.1±1.06ºC and a dissolved oxygen concentration of 4.4±0.13 mg/L were maintained. The

TABLE 2.

Water quality parameters, number of eggs, juvenile production and survival rates in the five *C. jordani* trials.

Parameters	Natural photoperiod	Controlled photoperiod			
Trial dates	September-December 2009	May-September 2008	August-November 2009	July-November 2009	July-November 2009
Temperature (ºC)	22.1±1.06	20.1±1.6	22.1±1.06	22.1±1.06	22.1±1.06
Dissolved oxygen (mg/l)	4.4±0.13	5.0±1.2	4.4±0.3	4.4±0.3	4.4±0.3
pH	8.3	8.7	8.8	8.8	8.8
TAN (mg/l)	< 0.43	< 0.43	< 0.43	< 0.43	< 0.43
Nitrite (mg/l)	<0.20	< 0.20	< 0.20	< 0.20	< 0.20
Nitrate (mg/l)	< 1.36	< 1.36	< 1.36	< 1.36	< 1.36
Non-ionised ammonia (mg/l)	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Egg number	4 502[c]	8 780[d]	2 112[b]	2 985[b]	1 683[a]
Juveniles	4 035[c]	3 817[b]	1 518[a]	2 183[a]	1 315[a]
Survival rate (%)	90[d]	44[a]	72[b]	73[b]	78[c]
Spawns	25[c]	38[d]	19[b]	21[b]	14[a]

[a.d] Different superscript letters in the same row indicate significant differences (P<0.5).

other three trials were performed in three 270-L indoor recirculation tanks. A photoperiod of 14 Lh and 10 Dh was maintained. Two male and one female, 1.12 g in body mass and 6.0 cm in TL, were introduced into each tank (Table 1). Water temperature was maintained at 22.1±1.06ºC, and the dissolved oxygen concentration at 5.0±1.2 mg/L (Table 2). Two plastic egg collectors were placed in each tank.

Stocking and rearing protocol

Broodstock of the Mesa silverside at six months of age and in the first breeding period were selected from a F1 population obtained from founders captured in Xochimilco Channels in Mexico City and cultured in 3,000-L outdoor recirculation tanks in the EAPP facilities. The silversides were fed with commercially formulated feed (Steelhead rainbow trout, Silver Cup with 47% protein and 16% lipids; Silver Cup, Toluca, Mexico) two times daily (10:00 and 16:00 h). The amount of food was adjusted weekly for each culture tank based on the quantity of uneaten food observed. The fertilised eggs hatched in five days (120 h after fertilisation) and were then fed with rotifers (*Brachionis plicatilis*) *ad libitum* for one week. After that week they were fed with nauplii, juveniles and adults of *Artemia franciscana*, until 30 days of age when they showed the characteristics specified for juveniles by Hernández (2009).

Production parameters

Egg collectors were inspected daily and spawn recorded during the experimental period. Each spawn was removed and placed into a 500-mL plastic container with chloride-free water and strong aeration. The eggs were counted under a stereoscopic microscope. The number of fertilised eggs and the number of 30-day-old juveniles per spawn were counted in each recirculation tank. The survival rate (%) was calculated based on the number of fertilised eggs and the number of juveniles.

Statistical analysis

Differences in the average final production of fertilised eggs, 30-day-old juveniles and survival rate between the treatments were evaluated with a one-way ANOVA. A Welch and Brown-Forsythe robust test of equality of means and a Tamhane multiple comparisons

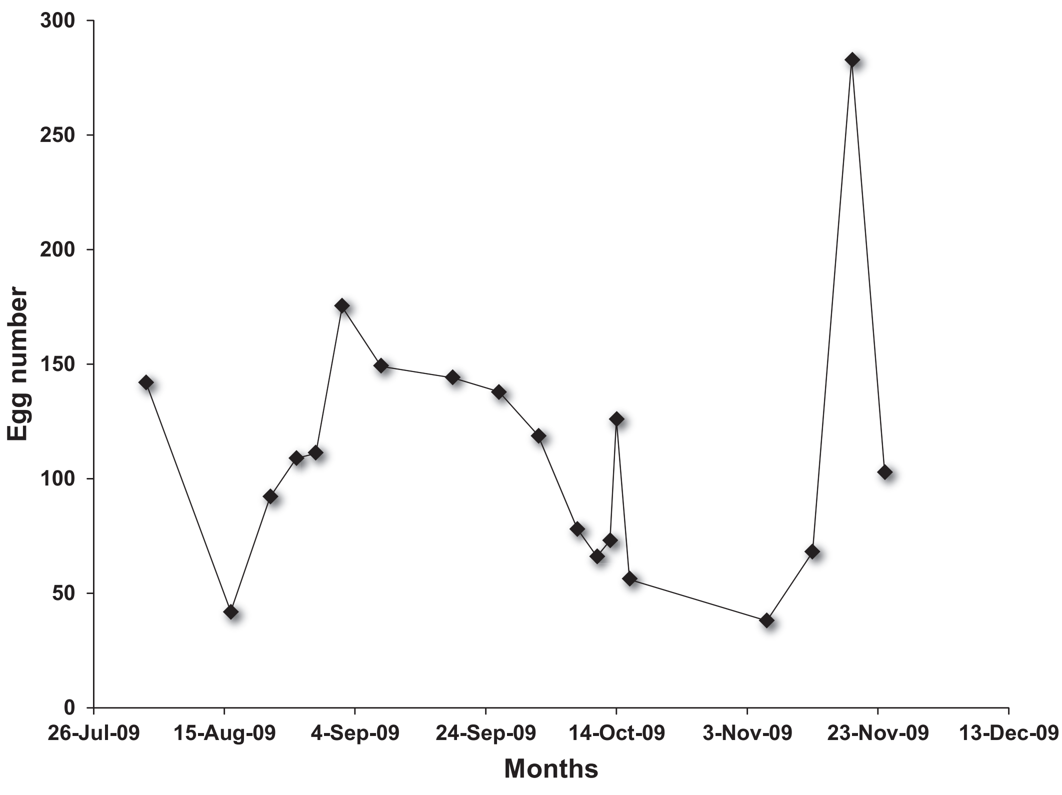

FIGURE 1. Egg production of *C. jordani* (1 ♀: 2 ♂) under a controlled photoperiod (14Lh:10Dh) in an indoor 274-L recirculation-tank from August to November 2009.

procedure was applied (SPSS, version 19). A probability level of P <0.05 was used as the criterion for statistical significance.

Results

The water quality values and parameters of reproductive performance are shown in Table 2.

Physicochemical values did not change over the experimental period, and no negative effects on the breeding behavior of the broodstock were observed. The reproductive performance indicators showed significant differences (P<0.05) between treatments in the number of spawns, eggs, juveniles and survival rate. Higher egg production was observed in the controlled-photoperiod treatment (May-September 2008) than in the natural-photoperiod treatment (September-December 2009). A large number of juveniles and a high survival rate were observed in the natural-photoperiod treatment (September-December 2009), and large spawn numbers were observed in the controlled-photoperiod treatment (May-September 2008).

The pattern of egg production over time differed between experiments. Under the natural photoperiod, egg production followed a polynomial-curve model (polynomial curve fit: $Y = -0.0569x^2 + 4564.5x - 9E+07$; $R^2 = 0.5443$; P<0.05). In contrast, the pattern found in the controlled-photoperiod experiments was irregular, showing increases and decreases in egg production (Figs. 1 and 2).

Discussion

The current results showed high reproductive performance of *C. jordani* under both controlled and natural photoperiods. This species is a multiple spawner and shows a breeding pattern similar to that of other members of the genus *Chirostoma*. Bromage *et al*. (2001) indicated that fish are very sensitive to light, although the thresholds needed for maturation are not yet perfectly known. The reproductive cycle of the Mesa silverside in its natural habitat is primarily determined by water temperature, seasonal fluctuations of day length, rainy season, phytoplankton biomass and water level

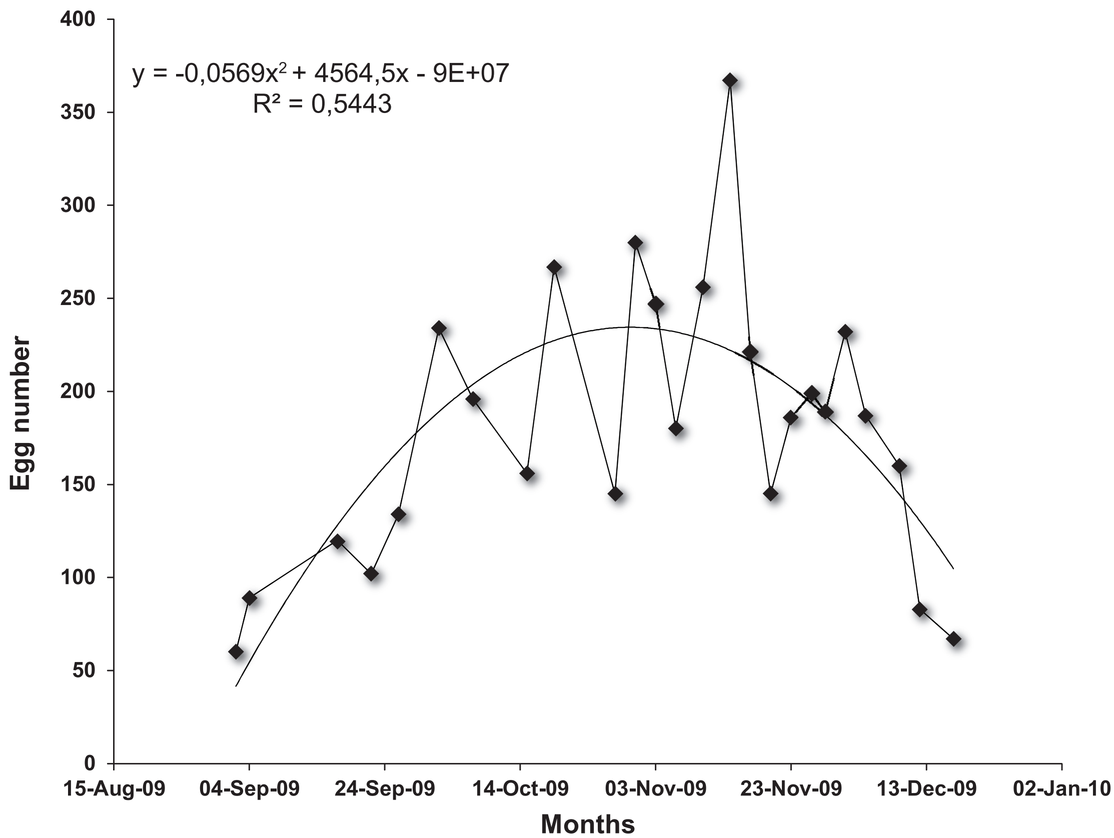

FIGURE 2. Egg production of *C. jordani* (15 ♂: 10 ♀) under a natural photoperiod in an outdoor 3000-L recirculation tank from September to December 2009.

(Olvera-Blanco *et al*., 2009). These factors appear to affect the duration of the spawning season. In general, it has been found that shorter or longer photoperiods are needed to stimulate maturation in fish (Amano *et al*., 2000; Bromage *et al*., 2001; Berril *et al*., 2003). Under regulated conditions of temperature and photoperiod and appropriate feeding procedures, it is possible to control breeding, as shown in the current paper, in which the longer day length and a water temperature of 20ºC efficiently stimulated reproductive activity in *C. jordani*. Similar results have been obtained for the atherinopsid species *Chirostoma estor estor* (Blancas-Arroyo *et al*., 2004) *C. humboldtianum* (Martínez-Palacios *et al*., 2007) and, respectively, and *Menidia beryllina* (Huber and Bengtson, 1999).

Ibañez *et al*. (2008) and Olvera-Blanco *et al*. (2009) have found in wild populations of *C. jordani* in Metztitlán dam (Hidalgo) and Xochimilco Lake (México basin) that this species can reach sexual maturity at relatively small sizes (48 to 55 mm) within the first year of life. The growth of gonads begins in October and continues to April-May. The main peak of reproduction occurs from January to May during the dry season. Also, Rojas-Carrillo (2006) reported that *Chirostoma attenuatum* from Pátzcuaro Lake (Michoacán, Mexico), reproductive activity occurs throughout the year but the maximum intensity occurs from April to May.

Our experiments confirmed that *C. jordani* has a short life cycle and can breed at six months of age. It has been also established that is possible to produce high numbers of eggs and juveniles in recirculation tanks by controlling the water temperature and the photoperiod. The management of one female and two males of *C. jordani* in small recirculating tanks offers several advantages. It is possible to select breeders with outstanding genotypic and phenotypic characteristics, and to perform selective crosses between different cohorts, thus improving the quality and quantity of eggs and juveniles. The high reproductive potential of this species can facilitate the repopulation of lacustrine waters and can be favourable for aquaculture.

This strategy for producing eggs and juveniles of *C. jordani* in substantial numbers may be helpful to preserve the species genome, restocking lacustrine environments in the Mexico Basin and may allow rearing under semi-intensive conditions which are easily implemented, do not require expensive facilities and do not require highly-trained personnel.

Data in this study will be helpful to prevent the extinction of native fishes such as those of the 'charal' group, which exhibit cultural, socio-economical and ecological significance, thus maintaining traditional fisheries and re-establishing the lacustrine environments in the Mexico Basin.

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