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Reproductive biology of the invasive *Coptodon zillii* in the Shadegan International Wetland, Iran

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Abstract

This study explores the reproductive biology of the redbelly tilapia (*Coptodon zillii*, Gervais, 1848) in the Shadegan International Wetland, southwest Iran. An acceptable number of samples were examined, revealing significant differences, with males averaging 156.17 mm in total length and 78.19 g in weight, compared to females' 144.23 mm and 63.66 g. The sex ratio was skewed in favor of males. The highest Gonadosomatic Index (GSI) values were recorded in April (4.35) and June (2.76), correlating with the reproductive peak and water temperatures of 25.87°C and 34.06°C, respectively. The absolute fecundity ranged from 1,274 to 8,299 eggs per female, with an average of 3,091.25 eggs in the spring and summer months. This study provides essential baseline data for managing and controlling *C. zillii*, an invasive species threatening the biodiversity of the Shadegan Wetland.
Keywords: Fecundity, Gonadal Maturity, Gonadosomatic Index, Invasive species

Introduction

Tilapia, which includes nearly a hundred species within the cichlid tribe, has been widely introduced around the world and is now present in many countries as either a native or introduced species (Bonham, 2022); however, the Nile tilapia, *Oreochromis niloticus* (Linnaeus, 1758) is, by far, the most widely cultured tilapia species (FAO, 2024). Multiple species of tilapia, including the redbelly tilapia, *Coptodon zillii* (Gervais, 1848), have been identified in the natural waters of Khuzestan Province in southwest Iran; their presence is likely accidental, stemming from water connections with Iraq (Khaefi et al., 2014; Roozbhfar et al., 2014; Mousavi-Sabet & Eagderi, 2016; Valikhani et al., 2016; Rafiee et al., 2017). This species, originating from Africa and the Jordan River system, is essential for artisanal fishing and aquaculture within its native range (Froese & Pauly, 2024).

Coptodon zillii has established a breeding population in the Shadegan International Wetland in southwest Iran. This ecologically significant area, designated as a UNESCO Natural Heritage site and the 34th Ramsar site (Kholfenilsaz et al., 2009), hosts a wide variety of species (Hashemi et al., 2015), including the invasive *C. zillii*, which was first recorded in 2012 (Khaefi et al., 2014). As Iran's largest wetland, it is noted for its cultural significance and tourism potential (Rafei & Danehkar, 2021), highlighting the importance of studying and managing invasive species like *C. zillii* to protect its biodiversity.

Due to the limited biological data available on *C. zillii* in Iran, particularly regarding its reproductive characteristics and population dynamics, this study seeks to elucidate the reproductive biology of the species in the Shadegan Wetland. Specifically, the research focused on understanding the length and weight measurements, sex ratio, Gonadosomatic Index (GSI), gonadal maturity stages, and fecundity of *C. zillii*. By exploring these parameters, the study aims to establish a fundamental knowledge base that is crucial for effectively managing invasive species and preserving native ecosystems in the area, as emphasized by Pasko and Goldberg (2014).

Material and methods

Sampling Site

Samples were collected throughout the four seasons of 2014–2015 near Sarrakhieh village, a prominent fishing area in the middle of the Shadegan Wetland (Fig. 1). Access to sampling sites, which were randomly selected within productive fishing zones, was facilitated by local fishing boats. Gill nets with mesh sizes ranging from 23 to 42 mm were utilized in varying numbers, heights, and lengths, deployed in the afternoon, and retrieved the following morning. *C. zillii* specimens were initially preserved in a 10% formalin solution (Sotola et al., 2019) before being transported to the laboratory for further analysis.

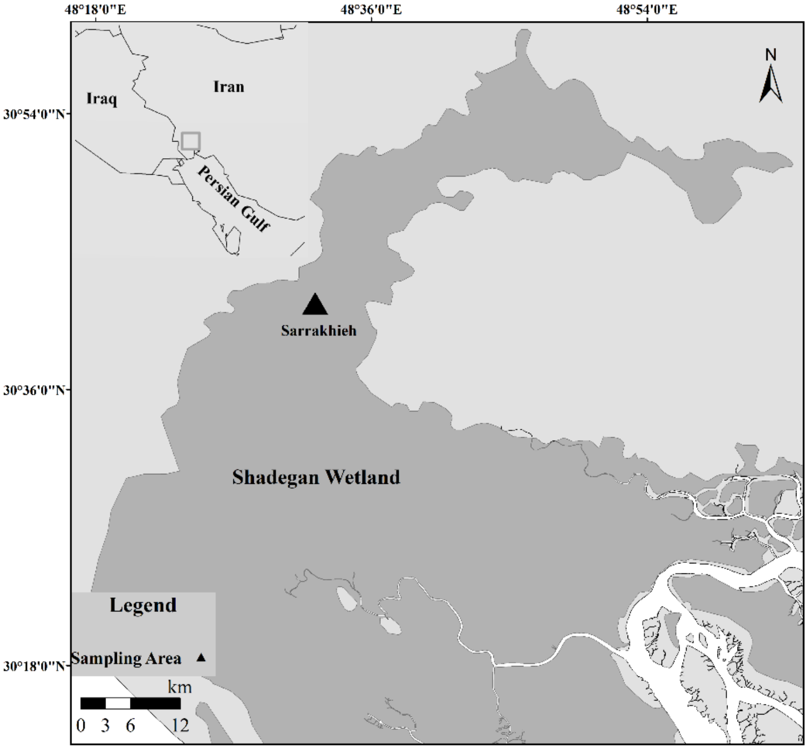

Figure 1. The sampling area in the Shadegan Wetland, SW Iran, showing the location where samples were collected during the four seasons of 2014–2015

Reproductive Analysis

The specimens ' total length and wet body weight were precisely recorded to the nearest 0.1 mm and 0.01 g using a measuring board and an electronic balance, respectively. The gonad mass of female specimens was measured with a precision of 0.01 g, allowing for calculating the Gonadosomatic Index (GSI) (Ishikawa & Tachihara, 2008). Fecundity was assessed using the gravimetric method (Hunter et al., 1985). Given that *C. zillii* is an asynchronous breeder, a five-stage maturity scale, as described by Holden and Raitt (1974), was used to identify the stages of gonad development macroscopically.

The GSI and water temperature data are depicted in the accompanying graphs, while the fecundity data are represented using the median and interquartile range (IQR). This choice of summary statistics was made because the data distribution significantly deviated from normality, and there was unequal variance among the samples. The statistical analyses were conducted using the RStudio software, specifically version 2023.09.1+494, with the graphical representations created using the "ggplot2" package (version 3.4.4). Additionally, the sampling locations were mapped and visualized using ArcMap 10.2.

Results

Length and Weight Measurements

In the central region of the Shadegan Wetland, male individuals exhibited an average total length (TL) of 156.17 mm [median (IQR) = 158 (146–166), with a maximum of 191 mm and a minimum of 86 mm, N = 250], and an average weight of 78.19 g [median (IQR) = 77.49 (59.94–93.49), with a maximum of 211.94 g and a minimum of 12.94 g, N = 250]. Female individuals had a lower average TL of 144.23 mm [median (IQR) = 146 (134–155), with a maximum of 183 mm and a minimum of 91 mm, N = 203], and an average weight of 63.66 g [median (IQR) = 63.94 (48.21–76.42), with a maximum of 136 g and a minimum of 11.16 g]. Statistical analysis using the Mann-Whitney U Test revealed that males were significantly larger and heavier than females ($P < 0.01$).

Reproductive Measurements

Out of the 466 individuals assessed for reproductive characteristics, the overall sex ratio was 1 male to 0.78 females. When excluding samples from March, where macroscopic sex identification is challenging, the ratio adjusted to 1 male to 0.84 females. Female mean GSI values were relatively low in November (0.41) and March (0.62), with an increase during the spring, reaching a peak of 4.35 in April. Following this peak, GSI values gradually declined to 1.37 by August, with a minor increase noted in September (1.98), which coincided with surface water temperature changes (Fig. 2). The average surface water temperature was recorded at 18.78°C in November and 18.13°C in March, rising to 25.87°C in April and peaking at 34.06°C in June, before decreasing to 30.03°C in September.

The assessment of gonadal maturity stages revealed that a significant portion of the female specimens were actively engaged in the reproductive process during different times of the year. Specifically, in the spring months of April and June, 84.13% of the female fish were found to be in advanced reproductive stages (stage III, IV, or V). This percentage decreased during the summer months of July, August, and September, where 58.33% of the females were at these reproductive stages. In contrast, during the non-reproductive periods, only 4.54% of the female fish were in the reproductive process in November, which increased slightly to 33.33% in March.

The species' absolute fecundity (oocytes/female) ranged from 1,274 to 8,299 eggs during the reproductive period, encompassing the spring and summer months. The average number of eggs produced was 3,091.25, with a median of 2,865 eggs and an interquartile range (IQR) of 2,203 to 3,596 eggs. Additionally, the mean relative fecundity (oocytes/g female), was calculated to be 48.77 eggs/g, based on a sample size of 65 fish.

At the onset of the reproductive period in April, the absolute fecundity ranged from 1,933 to 8,299 eggs. During this time, the average fecundity increased to 3,563.60 eggs, with a median of 3,348 eggs and an IQR of 2,708 to 3,828 eggs. The mean relative fecundity also rose to 53.16 eggs/g, based on a sample size of 38 fish. This data suggests an increase in fecundity metrics as the reproductive season progressed.

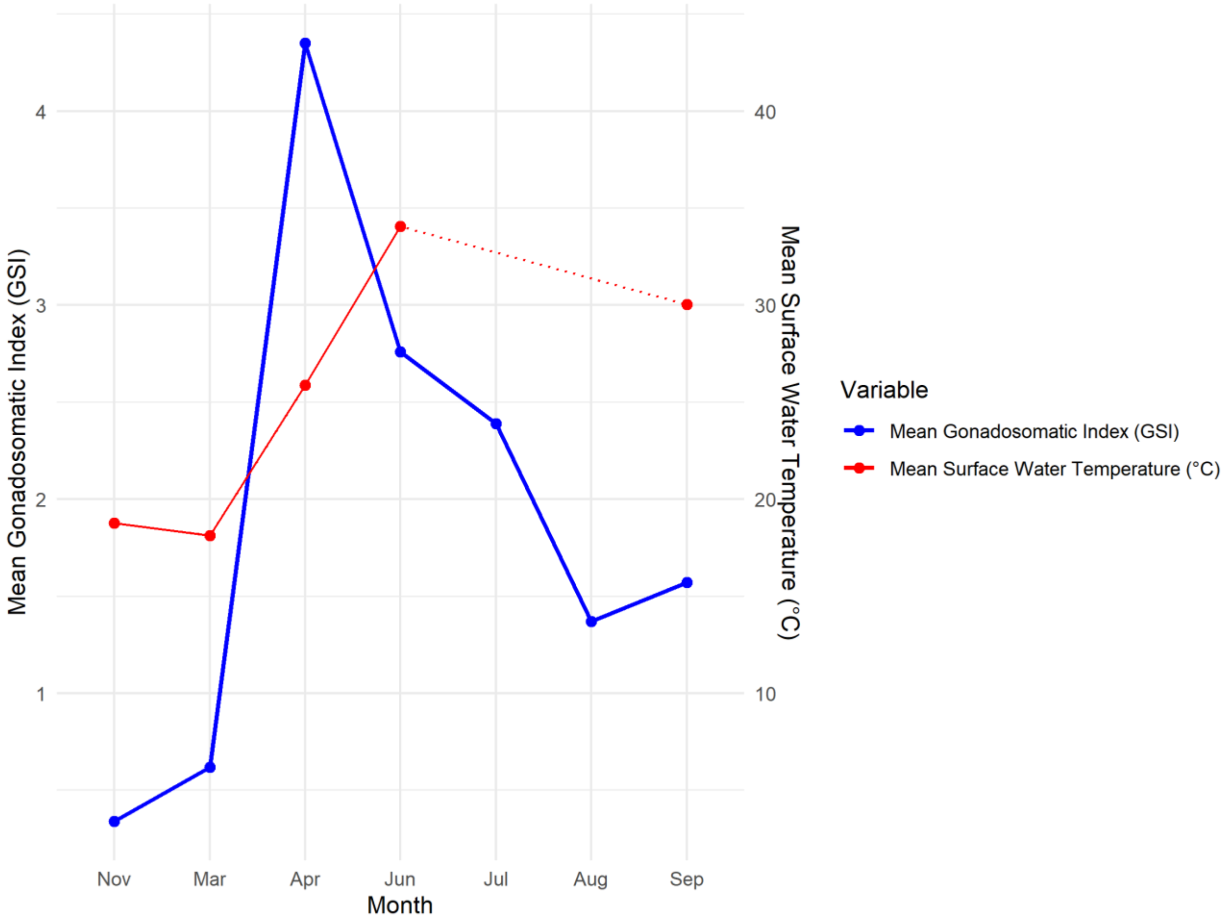

Figure 2. The changes in mean gonadosomatic index for the female of *Coptodon zillii* and mean surface water temperature (°C) in the Shadegan Wetland, SW Iran (2014–2015)

Discussion

The highest GSI values for *C. zillii* were observed during the spring and summer seasons, with a notable peak occurring in April. This finding is consistent with the results reported by Negassa and Padanillay (2008), as well as Ishikawa and Tachihara (2008), who also documented similar seasonal reproductive patterns. The mean absolute fecundity in this study was comparable to previous estimates, such as the 3,045 eggs reported for populations in the Nile River (El-Kasheif et al., 2013) and 3,606 eggs under laboratory conditions (Coward & Bromage, 2000). In this context, fecundity was defined as the number of mature oocytes in the ovaries before spawning.

However, it is important to note that *C. zillii* is a multiple-spawning species (Rana, 1988), meaning it spawns several times within a breeding season. This could have led to an overestimation of fecundity since the counts were based on maturing oocytes rather than the actual number of eggs laid (Rana, 1988; Coward & Bromage, 2000). Consequently, the fecundity estimates provided in this study may only represent a portion of the species' reproductive capacity.

Armas-Rosales (2006), citing Fukusho (1968) and Platt and Hauser (1978), noted that the optimal water temperature for *C. zillii* is close to 30°C. At temperatures higher or lower than this, feeding, growth, and swimming endurance decrease, and 20°C or below, feeding and growth nearly stop. *C. zillii* spawns year-round in warm tropical regions and during the warmer seasons at higher latitudes (Siddiqui, 1979). It has also been reported that this species spawns in water temperatures ranging from 22.5°C to 31.5°C (Hauser, 1977). However, Philippart and Ruwet (1982) note that other environmental factors such as day length, light intensity, and water level can also influence spawning in addition to water temperature.

The minimum and maximum temperatures at which tilapia were caught were 17.4°C during winter (March) and 34°C in spring (June) in the Shadegan Wetland. The sensitivity of tilapia to temperature can be used to control their population. As a management measure, since this species is highly vulnerable at low water temperatures and becomes lethargic during winter, a warm water flow can be used to guide them to a location where they can be caught, reducing the breeding population for the next season (Ishikawa & Tachihara, 2008). This strategy appears to be potentially effective and beneficial. According to the fishermen, tilapia move to the bottom during cold days and to the reeds and aquatic plants during warm days, making them less likely to be caught in fishing nets.

The reproductive biology of *C. zillii* in the Shadegan Wetland demonstrates significant seasonal variability, with peak reproductive activity occurring in spring. The study found that males are generally larger and heavier than females, with a sex ratio slightly favoring males. The GSI and fecundity data indicate that the species is multiple-spawning, with reproductive activity closely linked to water temperature. These findings are crucial for developing effective management strategies to control this invasive species' population and protect the Shadegan Wetland's ecological integrity. The study underscores the importance of continued monitoring and research on *C. zillii* to mitigate its impact on native biodiversity.

Acknowledgment

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