



## Original article

Ovarian and spawning reference, size at first maturity and fecundity of *Glossogobius giuris* caught along Vietnamese Mekong DeltaQuang M. Dinh<sup>a,\*</sup>, Ngon T. Truong<sup>b</sup>, Nam S. Tran<sup>c</sup>, Ton H.D. Nguyen<sup>a</sup><sup>a</sup> Department of Biology, School of Education, Can Tho University, Can Tho, Viet Nam<sup>b</sup> Biotechnology Research and Development Institute, Can Tho University, Xuan Khanh Ward, Can Tho, Viet Nam<sup>c</sup> Department of Environmental Sciences, College of Environment and Natural Resources, Can Tho University, Can Tho, Viet Nam

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## ABSTRACT

This study investigates the ovarian development, spawning patterns, maturity size and fecundity of the goby *Glossogobius giuris*—a commercial fish in the Vietnamese Mekong Delta—based on the data analysis of 659 individuals. Specimens were caught using trawl nets from four sites representing freshwater (Cai Rang, Can Tho) to salinized regions in the dry season (Long Phu, Soc Trang), and brackish water regions (Hoa Binh, Bac Lieu and Dam Doi, Ca Mau) over the 12 months of 2020. Histological analysis showed that it was a multi-spawner as different stages of oocytes appeared in mature ovaries. The fish could spawn throughout the year, with a peak in April at the freshwater region and in September at salinized and brackish areas as mature ovaries appeared monthly during the studied period and gonadosomatic index displayed the highest value in April and in September, respectively. This goby's primary egg releasing time tended to be regulated by salinity changes over the four sampling sites. Likewise, size at first maturity of this species could be related to the salinity variation as this value was the longest in freshwater ( $6.14 \pm 0.17$ ) and the shortest in the salinization region ( $4.82 \pm 0.66$ ). Batch fecundity is measured at 5,118–100,003 eggs/female and related to fish length and weight ( $r^2 > 0.76$ ). Findings can be useful for the development of fish conservation strategies and artificial reproducing studies.

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## 1. Introduction

The fish reproductive strategies classified either into semelparity and iteroparity are helpful in fishery management (Miller, 1984; Jakobsen et al., 2016). Many gobies display iteroparous patterns (Miller, 1984; Dinh et al., 2016), for example, *Valenciennea strigata* in French Polynesia (Reavis, 1997) and *Periophthalmus barbarus* in Japan (Etim et al., 2002). Female gobies released five to a thousand eggs on a substrate (e.g., bottom surface or vegetation) during spawning season (Macinnis and Corkum, 2000; Etim et al., 2002; Dinh et al., 2020). The lunar cycle plays a vital role in the spawning and larval recruitment of some estuarine gobies (Thresher, 1984; Berra, 2001). Fish batch fecundity and length at

first maturity are related to fishery management (Fontoura et al., 2009; Teichert et al., 2014; Jakobsen et al., 2016; Tran et al., 2019). Understanding, however, was lacking in the Vietnamese Mekong Delta (VMD), where gobies are overfished (Trinh and Tran, 2012; Diep et al., 2014; Tran et al., 2020a). Consequently, there is a need to understand their recruitment strategies and dynamics.

*Glossogobius* is one of the largest genera of the Gobiidae family, comprising of 29 species in the world, three species of which, *G. giuris*, *G. aureus*, and *G. sparsipapillus*, are relevant in the VMD (Tran et al., 2013; Diep et al., 2014; Tran et al., 2020a). Among these three species, *G. giuris* is widely distributed in brackish to freshwaters in the Indo-Pacific regions (Talwar and Jhingran, 1991; Riede, 2004; Froese and Pauly, 2021), including VMD (Tran et al., 2013; Diep et al., 2014; Nguyen et al., 2020). Its ecology in Bangladesh is reported by Islam (2004), and it spawns two times/year in Mithamoin Haor, Bangladesh (Hossain, 2014), but one/year in Payra River, Bangladesh (Roy et al., 2014) and in Pakistan (Qambrani et al., 2016). In the VMD, its habitat extends typically from estuaries to the upper reaches of the Bassac River basins (Dinh, 2008; Dinh, 2011; Le et al., 2018; Tran et al., 2021), and it shows isometry pattern and plays a commercially important

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role in food supply (Diep et al., 2014; Dinh and Ly, 2014; Phan et al., 2021). However, the fish population is overfishing (Dinh et al., 2017; Tran et al., 2020a). This research, consequently, contributes understanding to its reproductive references (e.g., ovarian development, spawning patterns and seasons, size at first maturity, and batch fecundity) and confirms if its spawning season, size at first maturity and batch fecundity vary with sites. The results will be based for fish conservation efforts and artificial reproduction studies.

## 2. Materials and methods

### 2.1. Studied site description and sample collection

This research was performed for a period of 12 months, from January 2020 to December 2020, in four sites along the Hau River. Sites were selected from freshwater in Cai Rang, Can Tho (CRCT) to salinization in Long Phu, Soc Trang (LPST), and brackish water regions in Hoa Binh, Bac Lieu (HBBL) and Dam Doi, Ca Mau (DDCM) (Fig. 1). These regions are represented by a semi-diurnal tidal range of ~1.2 m, a temperature of ~27 °C, pH of ~8. The salinity in DDCM was the highest with 26.8 ‰, following by HBBL (15.6 ‰), LPST (12.3 ‰), and the lowest was CRCT (0.0 ‰). It rarely rains in the dry season (January–May) and rains heavily in the wet season (June–December), with monthly precipitation values of 400 mm (Le et al., 2006; Tran et al., 2020b; Dinh et al., 2021).

In this study, trawl nets with 1.5 cm in the cod-end were used to catch the fish. Nets were set at the highest tide in each study site and retrieved after 2–3 h to collect specimens, according to Dinh et al. (2015). After identification using the external description of Tran et al. (2013), fish was anaesthetized in a tricaine methanesulfonate (MS222) solution and stored in 5% formalin fluid and transported to the laboratory. In this study, the fish use was assessed and approved by The Council for Science and Education, School of Education, Can Tho University (Animal Welfare Assessment No.: TQ2019-05/KSP).

### 2.2. Fish and data analysis

Fish specimens were measured their total length (TL, 0.1 cm) and weight (W, 0.01 g) before removing ovaries which were visu-

ally classified into six maturation stages using the criteria described for *Parapocryptes serperaster* stated by Dinh et al. (2016).

The ovarian weight was scaled to the nearest 0.1 mg and was used to calculate the gonadosomatic index as  $GSI = 100 \times (G/W)$  (G: ovarian weight and W: total fish body weight) Sturm (1978). A combined analysis of GSI and gonad frequent occurrence was used to determine the fish spawning season (Alonso-Fernández et al., 2011; Dinh and Le, 2017).

Size at first maturity ( $L_m$ ) was known as the length when 50% of fish reach sexual maturity and estimated as  $P = 1/(1 + \exp[-r \times (TL - L_m)])$  (P: the proportion of mature individuals in a length class) (Zar, 1999).

According to Bagenal (1967), batch fecundity (F) was determined as  $F = (n \times G)/g$  (n: the number of oocytes in sub-sample; g: the weight of sub-sample; and G: the ovarian weight). Oocyte diameter per ovarian stage was determined by randomly measuring 30 oocytes in each ovary using Motic Image-Pro Plus v.2.0. Ovarian were histologically examined using the staining procedure suggested by Dinh et al. (2016) for gamete developmental determination.

The relationships between fish size (TL and W) and batch fecundity were quantified using logarithmic regression. The monthly and spatial variations of GSI was quantified by One-way ANOVA. All tests were performed using SPSS software v.21 at a significant value of 5%.

## 3. Results

### 3.1. Ovarian development and spawning pattern

The ovaries of *G. giuris* were composed of two chambers adjacent to the fish's spine and were fixed by many connective membranes. These vesicles gradually increased in size from long, narrow tubes to bulging tubes filled with eggs through the development stages.

In stage I, the ovary was roughly 1 mm in width and light white, lying close to the spine. The ovary length was nearly one-third of the abdominal sinuses (Fig. 2a). Observing the ovary's histological structure showed the appearance of the primary oocytes (PO), oocyte with round nucleus accounting for a significant proportion compared to the cell. The histological structure showed that there were oogonia (O) and germ cells (GC) (Fig. 2f).

In stage II, the ovaries are typically light yellow, with no visible seeds under a magnifying glass, and accounting for about 1/2 of the abdominal sinuses (about 2–3 cm) (Fig. 2b). The majority of the primary vitellogenic oocytes (PVO) were found in the ovary (Fig. 2g). Cytoplasm did not appear yolk, multiply and round, liked alkaline and with pale color.

Stage III ovaries exhibited tubular shape, round, accounting for 3/4 of the volume of the abdominal sinuses, bright yellow, blood vessels to multiply oocytes, can distinguish oocytes, oocytes sticking together, difficult to separate (Fig. 2c). PVOs changed to the nutrient growth phase; the oocyte began to accumulate, many vacuoles appeared (no color), the large nucleus became pale purple. In this stage, the ovaries consisted mainly of PVO and secondary vitellogenic oocytes (SVO) (Fig. 2h). The cytoplasm was still alkaline but weak; the yolk appeared pink of Eosin.

Stage IV ovaries were seen to occupy most of the volume of abdominal sinuses, appeared darker yellow than stage III, lightly pressed on the abdomen of the sex products that was not shed yet (Fig. 2d). Ovaries in this stage mainly consisted of post vitellogenic oocytes (PsVO) with the nucleoli in the center of the nucleus and hydrated oocytes (HMO) (Fig. 2i). The nucleus was small and had no particular shape. The nucleus slowly dissolved

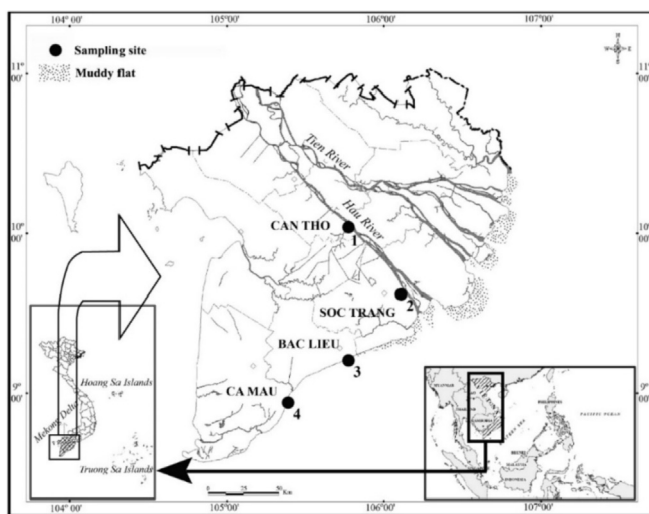
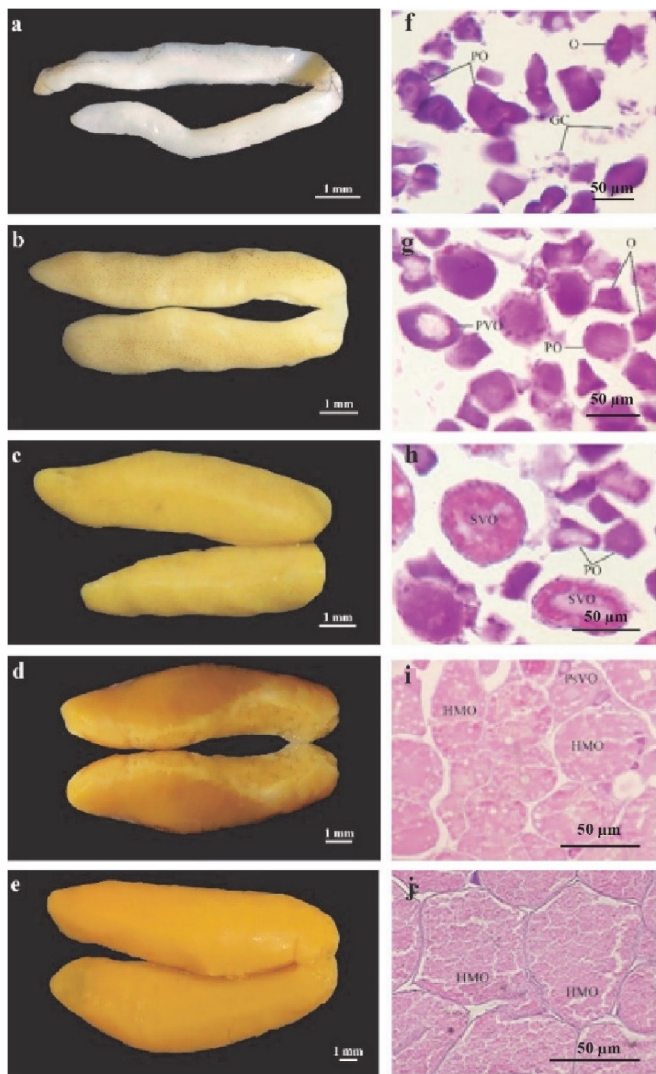


Fig. 1. The sampling location in the Vietnamese Mekong Delta modified from Fig. 1 produced by Dinh (2018) (sampling area; 1: Cai Rang, Can Tho; 2: Long Phu, Soc Trang; 3: Hoa Binh, Bac Lieu; 4: Dam Doi, Ca Mau).



**Fig. 2.** Ovarian morphology and structure of *Glossogobius giurus* (a-e: stage I-V ovarian morphology; f-j: stages I-V ovarian histology; GC: germ cells, O: oogonia, PO: primary oocyte, PVO: primary vitellogenic oocytes, SVO: secondary vitellogenic oocytes, PsVO: post vitellogenic oocytes, HMO: hydrated oocytes; samples were from Cai Rang, Can Tho and Long Phu, Soc Trang).

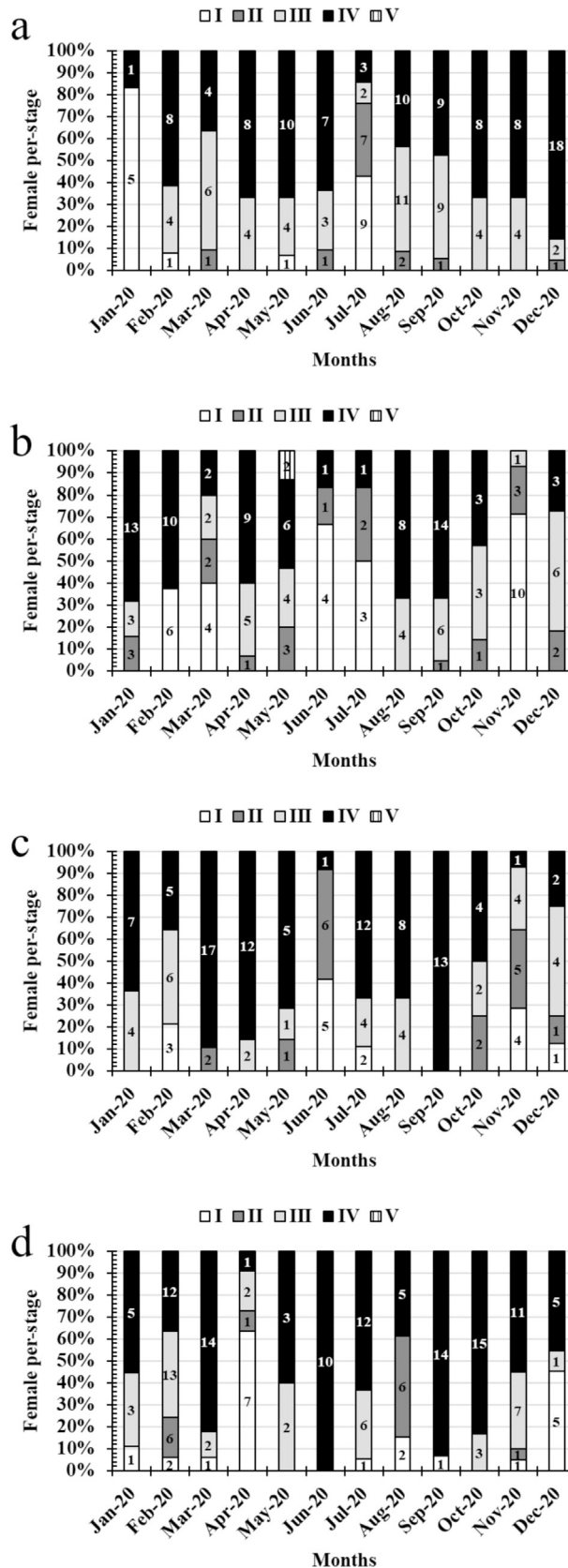
into the nuclear fluid, while the vacuole appeared much and increased in size.

In stage V, at maximum size, oocytes are separate and visible to the naked eye. The ovaries reached full size, were seen to occupy most of the volume of the abdominal sinuses and appeared dark yellow (Fig. 2e). The oocyte contained many lipid particles mixed with the yolk, so the oocyte slowly turned opaque and shiny (Fig. 2j). No fish with stage VI ovaries were found in the present study as the fish moved to their breeding grounds.

This goby was a multiple spawner with different oocyte stages, including PVO, SVO, PsVO, and HMO in mature ovaries at four sites.

**3.2. Ovarian appearance frequency, gonadosomatic index and spawning season**

Fig. 3 represents for monthly appearance frequency of ovaries at the four sites. This Figure showed that most mature and ripe ovaries were found monthly the freshwater in CRCT to the salinized region in LPST and brackish water areas in HBBL and DDCM, seeming that *G. giurus* could spawn throughout the year.



**Fig. 3.** Ovaries stages compositions of *Glossogobius giurus* at study sites (a: Cai Rang, Can Tho; b: Long Phu, Soc Trang; c: Hoa Binh, Bac Lieu; d: Dam Doi, Ca Mau; number in each column: number of individuals).

As the primary time of egg releasing determination, the gonadosomatic index (GSI) change over the entire study year was used.



Actually, during the primary spawning time, *GSI* was usually higher than the rest of the months. In the freshwater region (CRCT), *G. giuris* could release eggs mainly in the later dry season (in April) as *GSI* reached the highest value in this month (One-way ANOVA,  $n = 176$ ,  $F = 9.74$ ,  $P < 0.001$ ) (Fig. 4a). But this goby was able to release eggs mainly in the main wet season (in September) in three remaining sites as *GSI* of these sites fluctuated and reached the highest point in September ( $n_{LPST} = 152$ ,  $F_{LPST} = 8.23$ ,  $P_{LPST} < 0.001$ ;  $n_{HBBL} = 150$ ,  $F_{HBBL} = 13.75$ ,  $P_{HBBL} < 0.001$ ;  $n_{DDCM} = 181$ ,  $F_{DDCM} = 5.03$ ,  $P_{DDCM} < 0.001$ ). Specifically, at LPST, *GSI* displayed a slight fluctuation in the period from January to June. From July, this index increased and reached a peak in September, then fell to the lowest level in November (Fig. 4b). Like LPST, *GSI* in HBBL changed over the months, reaching the highest value in September (Fig. 4c). Among the studied sites, in DDCM, the *GSI* showed the lowest fluctuation amplitude. The *GSI* increased sharply in September and did not differ much in the remaining months (Fig. 4d). Besides, the average value of the *GSI* index in the four regions has the same value ( $n = 659$ ,  $F = 1.49$ ,  $P = 0.21$ ).

### 3.3. Size at first maturity and fecundity

The first maturity ( $L_m$ ) was taken as the length at which 50% of the individuals reach maturity stages (here, stages III and IV). Size at first maturity of *G. giuris* was seen to varied over sampling location, reaching the highest lengths in the freshwater region in CRCT ( $6.14 \pm 0.17$  SE) (Fig. 5a) and the shortest in salinization area in LPST ( $4.82 \pm 0.66$  SE) (Fig. 5b). In brackish water, the goby showed similar values in length at first maturity ( $5.59 \pm 0.69$  SE in HBBL and  $5.85 \pm 0.52$  SE in DDCM) (Fig. 5c-d). The batch fecundity of *G. giuris* goby was high, ranging from 5,118 eggs to 100,003 eggs. This fecundity had a positive relationship with the fish length and weight due to the high determination values of these regressions ( $n_{length} = 24$ ,  $r_{length}^2 = 0.76$ ;  $n_{weight} = 24$ ,  $r_{weight}^2 = 0.77$ ). It can be seen that the larger the size of the fish was, the higher the number of eggs were released.

The *G. giuris* eggs were oval. The average length and width egg diameter showed the highest values in DDCM ( $0.74 \pm 0.01$  SE mm length and  $0.28 \pm 0.01$  SE mm width), while the shortest value was recorded in CRCT ( $0.70 \pm 0.01$  SE mm length and  $0.25 \pm 0.01$  SE mm width). The length and width of eggs diameter of this goby were  $0.70 \pm 0.01$  and  $0.27 \pm 0.01$  SE in LPST, and  $0.72 \pm 0.01$  and  $0.27 \pm 0.01$  SE in HBBL, respectively (Fig. 6). However, the difference between the length and width of eggs at the study sites was

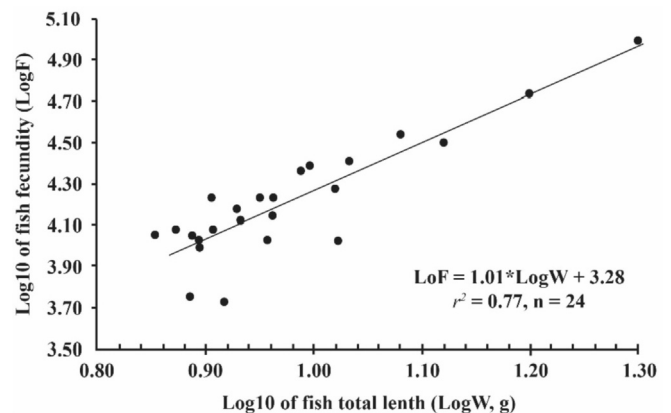


Fig. 5. Length at first mature of *Glossogobius giuris* (a: Cai Rang, Can Tho; b: Long Phu, Soc Trang; c: Hoa Binh, Bac Lieu; d: Dam Doi, Ca Mau).

not statistically significant ( $n_{length} = 15$ ,  $F_{length} = 1.33$ ,  $P_{length} = 0.22$ ;  $n_{width} = 15$ ,  $F_{width} = 1.42$ ,  $P_{width} = 0.31$ ).

## 4. Discussion

The histological structure of *G. giuris* showed that this fish released eggs several times over the spawning season as different stages of oocytes (PVO, SVO, PsVO, and HMO) were observed in the mature ovaries. As such over the course of one year, the fish could spawn many times, which was found in this species in Bangalore (Narayanawamy and Mohan, 2014). The multi-spawner was also found in its congeners, *G. sparsipapillus*, in the VMD, as different stages of oocytes were observed in mature ovaries in its congener (Ho et al., 2021; Nguyen et al., 2021). In some gobies in VMD, e.g., *Pseudapocryptes elongatus* (Tran, 2008), *Boleophthalmus boddarti* (Dinh et al., 2015), *P. serperaster* (Dinh et al., 2016), *Periophthalmodon schlosseri* (Tran et al., 2019), and *Pn. septemradiatus* (Dinh et al., 2020), as different stages of oocytes were observed in their mature ovaries, displayed multiple spawner, releasing eggs many during the spawning period. The multiple spawner was also found in some other gobies living in and our VMD, e.g., *Amphiprion ocellaris* in Malaysia (Khoo et al., 2018) and *Butis koilomatodon* (Dinh et al., 2021) in VMD as four types of oocytes from PVO to SVO, PsVO, and HMO were observed in their mature ovaries.

The variation of *GSI* related to fish reproducing behaviour and *GSI* value was higher in months when fish spawned (Alonso-Fernández et al., 2011). A combination of ovarian occurrence frequency and *GSI* showed that this fish could release eggs throughout a year, with a peak in April in the freshwater region (CRCT) and in September in salinization (LPST) and brackish (HBBL and DDCM) areas. It seemed that the significant difference in salinity between these sites impacted its spawning season. This goby in downstream and estuarine regions spawned mainly in the wet season, which could be because the environment was more favourable for fish reproduction during that time. The main peak of egg releasing could be varied with locations as *G. giuris* in the present study spawned mainly in April and in September but in December in Patuakhali, Bangladesh (Roy et al., 2014), June–October in Kissorgonj, Bangladesh (Hossain, 2014) and April–June Payara River, Bangladesh (Qambrani et al., 2016). It could be concluded that this goby released eggs mainly from the late dry season to the wet season. Likewise, its congener, *G. sparsipapillus* living in VMD, showed spatial variation in main egg releasing time as this goby released eggs dominantly in July–September at Soc Trang and Bac Lieu provinces (Nguyen et al., 2021) but in September–November at Tra Vinh province (Ho et al., 2021), caused by the difference in salinity between

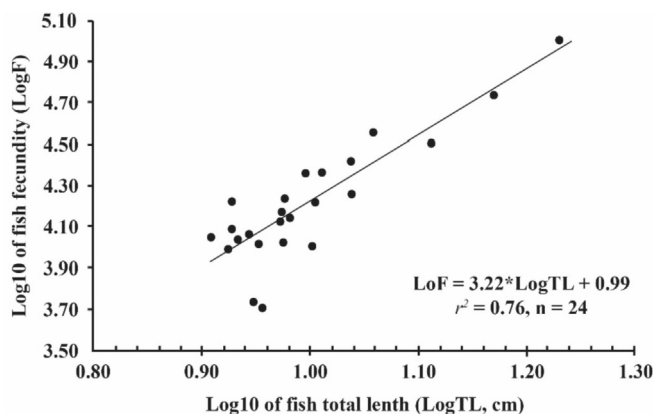
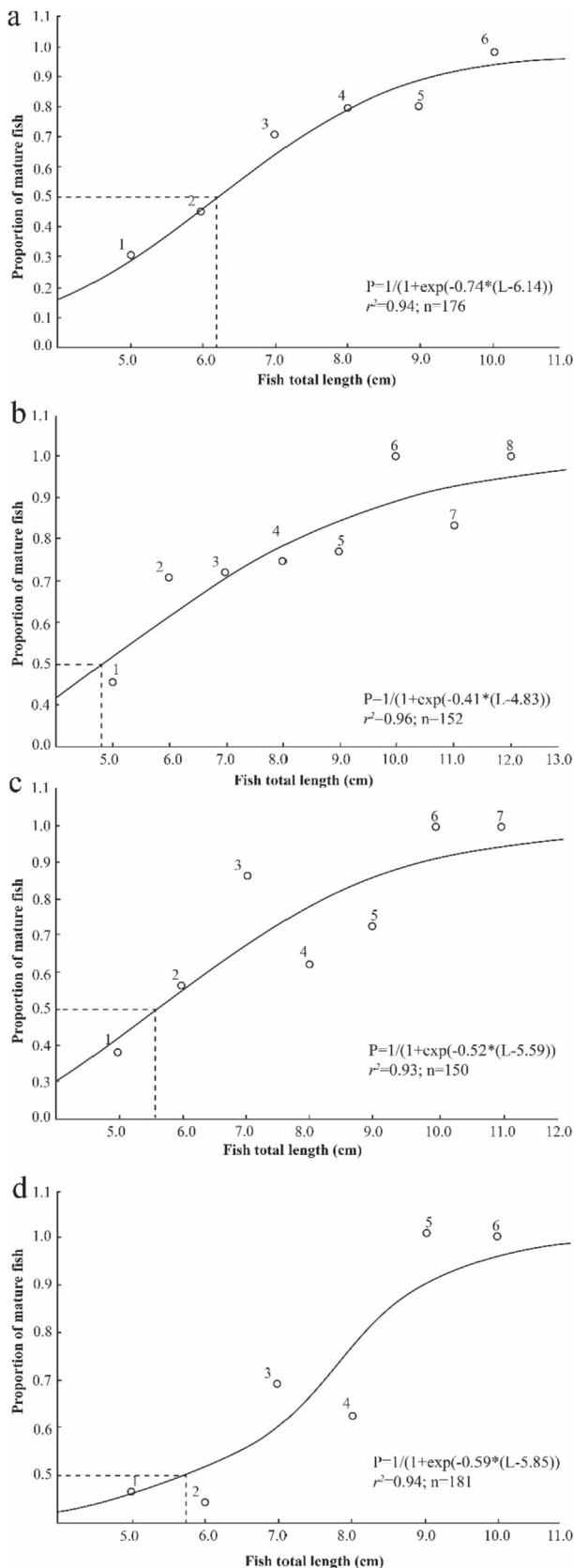


Fig. 4. Gonadosomatic index of *Glossogobius giuris* at study sites (a: Cai Rang, Can Tho,  $n = 176$ ; b: Long Phu, Soc Trang,  $n = 152$ ; c: Hoa Binh, Bac Lieu,  $n = 150$ ; d: Dam Doi, Ca Mau,  $n = 181$ ; difference letter (a, b and c): monthly gonadosomatic index (*GSI*) variation per sampling site).



**Fig. 6.** Relationship between fecundity (LogF) and fish total length (LogTL) and body weight (LogW) of *Glossogobius giurus*.

these provinces. The wet season was also the spawning season of some fishes living in VMD, especially gobies. For example, *Bs. boddarti* spawned mainly from August to October (Dinh et al., 2015)

(Table 1). The species *P. serperaster* spawned primarily in September (Dinh et al., 2016); *Eleotris melanosoma* released eggs dominantly during a period of four months from September to November (La and Dinh, 2017). Both *B. butis* (Dinh and Le, 2017) and *B. koilomatodon* (Dinh et al., 2021) could release for year-round (Table 1). Besides, the temperature was also an important factor impacting the spawning season. For example, in Korea, *Tridentiger trigonocephalus*, *Acentrogobius pflaumi*, *Chasmichthys dolichognathus*, and *T. obscurus* spawned in the spring-summer season from May to July when the weather is warmer (Baek et al., 2004; Baek et al., 1985; Hwang and Baek, 2013; Jin et al., 2006). The various in egg releasing peak among these gobies suggested that the primary spawning time was species-specific and varied with location.

Size at first maturity of fish ( $L_m$ ) was species-specific and related to environmental changes, e.g., *B. koilomatodon* (Dinh et al., 2021). Indeed,  $L_m$  of *G. giurus* was seen regulated by salinity variations as it matured earlier in LPST where it became salinized in the dry season than in sampling locations exhibiting the freshwater conditions all year round (CRCT). The  $L_m$  of *G. giurus* could be changed with location as this value in the present study was lower than in the previous study in Payara River, Bangladesh (Qambrani et al., 2016) (Table 1). The spatial variation in  $L_m$  was also found in its congener, *G. sparsipapillus* living in VMD, as this value of its congeners ranged from 6.1 to 8.9 TL cm (Nguyen et al., 2021) (Table 1). Likewise, *Pn. septeradiatus* living along Hau river in VMD also displayed a spatial change in  $L_m$  since this value ranged from 6.05 to 6.78 TL cm (Dinh et al., 2020) (Table 1). The  $L_m/TL$  ratio was used when comparing  $L_m$  between species as total length change with species. The ratio of *G. giurus* in the research was lower than in the previous study on this fish (Qambrani et al., 2016) (Table 1), indicating that this species in VMD matured earlier than Payara River, Bangladesh, and the environmental condition in VMD could be more favourable to this fish species. Likely, this goby matured earlier than its congener, *G. sparsipapillus* in VMD, because its  $L_m/TL$  was lower than that of *G. sparsipapillus* (0.42–0.68) (Nguyen et al., 2021) (Table 1). The  $L_m/TL$  of *G. giurus* was lower than that of some other gobies living in and out of its habitats, e.g., *Ps. barbarus* (0.79) (Etim et al., 2002); *Pd. elongatus* (0.69) (Tran, 2008); *Bs. boddarti* (0.68) (Dinh et al., 2015), *Stigmatogobius pleurostigma* (0.73) (Dinh and Tran, 2018), and *Trypauchen vagina* (0.84) (Dinh, 2018), *Pn. septemradiatus* (0.57–0.64) (Dinh et al., 2020) and *B. koilomatodon* (0.43–0.67) (Dinh et al., 2021) (Table 1). It could be seen that *G. giurus* was matured earlier than these gobies.

With higher fecundity, fish species could recover their population in spite of higher larval mortality impacted by unpredictable environmental factors (McDowall, 1997). Besides, batch fecundity ( $F$ ) of gobies increased with fish size and varied with species ranging from 100 eggs/female in *Eviota lacrimae* to ~500,000 eggs/female in *Awaous guamensis* (Ha and Kinzie, 1996). Like other gobies,  $F$  of *G. giurus* was high and increased with fish size (TL and W) due to the high determination values of their regression relationships. Besides,  $F$  could change with distribution site (Lehtonen et al., 2016), e.g., *Pn. septemradiatus* living along the Hau river showed a batch fecundity of 969–19,536 eggs/female (Dinh et al., 2020). Indeed,  $F$  of *G. giurus* in the present study was 5,118–100,003 and lower than that of this species Patuakhali, Bangladesh (88,495–264,104) (Hossain, 2014) and in Kissorgonj, Bangladesh (14,987–716,400) (Roy et al., 2014) (Table 1). The  $F$  of *G. giurus* was higher than that of some gobies living in and out of VMD; for example,  $F$  of *Ps. barbarus* in Nigeria ranged from 900 to 24,000 eggs/female (Etim et al., 2002) (Table 1). This value of *Pd. elongatus* (Tran, 2008) and *Bs. boddarti* (Dinh et al., 2015) in VMD was 2,100–29,400 eggs/female and 9,800–33,800 eggs/female, respectively (Table 1). The  $F$  of *P. serperaster* ranging from

**Table 1**  
Spawning season, size at first maturity and fecundity in some gobies species.

Species	Spawning season	$L_m/TL$	Size at first maturity (cm)	Batch fecundity (eggs/female)	Distribution	The source
<i>Periophthalmus barbarus</i>	–	0.79	10.2	900–24,000	Nigeria	Etim et al. (2002)
<i>Pseudapocryptes elongatus</i>	July to October	0.69	15.4	2,100–29,400	Mekong Delta	Tran (2008)
<i>Glossogobius giuris</i>	December	–	–	88,495–264,104	Patuakhali, Bangladesh	Roy et al. (2014)
<i>Glossogobius giuris</i>	June to October	–	–	14,987–716,400	Kissorgonj, Bangladesh	Hossain (2014)
<i>Boleophthalmus boddarti</i>	August to October	0.68	11.52	9,800–33,800	Mekong Delta	Dinh et al. (2015)
<i>Parapocryptes serperaster</i>	September	0.69	15.8	6,000–11,700	Mekong Delta	Dinh et al. (2016)
<i>Glossogobius giuris</i>	April–June	0.38	9.5	7,346 – 39,750	Payara River, Bangladesh	Qambrani et al. (2016)
<i>Stigmatogobius pleurostigma</i>	March to November	0.73	4.14	3,100–5,650	Mekong Delta	Dinh and Tran (2018)
<i>Trypauchen vagina</i>	June to August	0.84	16.59	4,000–12,750	Mekong Delta	Dinh (2018)
<i>Periophthalmodon septemradiatus</i>	Year-round	0.57–0.74	6.05–6.78	969–19,536	Mekong Delta	Dinh et al. (2020)
<i>Glossogobius sparsipapillus</i>	July to November	0.42–0.68	6.1–8.9	8,568–95,191	Mekong Delta	Nguyen et al. (2021)
<i>Butis koilomatodon</i>	Year-round	0.43–0.67	4.8–6.7	3,085–32,087	Mekong Delta	Dinh et al. (2021)
<i>Glossogobius giuris</i>	April	0.32	6.14	5,118–100,003	Cai Rang, Can Tho	This study
	September	0.25	4.82		Long Phu, Soc Trang	This study
	September	0.29	5.59		Hoa Binh, Bac Lieu	This study
	September	0.30	5.85		Dam Doi, Ca Mau	This study

6,000 to 11,700 eggs/female (Dinh et al., 2016) and *B. koilomatodon* ranging from 3,085 to 32,087 eggs/female (Dinh et al., 2021) was also lower than that of *G. giuris* (Table 1). However, this value was not significantly different from *G. sparsipapillus*, with a batch fecundity of 8,568–95,191 eggs/female (Nguyen et al., 2021) (Table 1). The difference in *F* of *G. giuris* in the present study and other gobies showed that the population recovering capacity of *G. giuris* was higher than others.

In fish species, a larger egg size provided more nutrients for fish embryo development, increasing their larval survival rate (Nguyen and Pham, 2013). In the present study, the egg diameter of *G. giuris* was relatively equal to *G. aureus* living in VMD (0.20 mm length and 0.77 mm width) (Nguyen et al., 2014), suggesting that these two species could share a similar embryo development and larval survival rate. The fish egg diameter could change with their distribution location as *Pn. schlosseri* egg diameter was 0.07–0.36 mm in Malaysia (Mazlan and Rohaya, 2008), 0.20–0.30 mm in the Naf River, Bangladesh (Saha, 2013) and ~0.32 mm in VMD (Tran et al., 2019). The egg diameter of *S. pleurostigma* (Dinh and Tran, 2018), *Pn. septemradiatus* (Dinh et al., 2020) and *G. sparsipapillus* (Nguyen et al., 2021) in VMD was ~0.40 mm, 0.26–0.48 mm and ~0.38 mm, respectively, indicating that these gobies species could show a lower in embryo development and larval survival rate compared to *G. giuris*. The difference in egg diameter among these gobies showed that the egg diameter was species-specific, and *G. giuris* could be adapted well to their habitat compared to other gobies.

## 5. Conclusions

*Glossogobius giuris* was a multi-pawner spawning throughout the year, with a peak in April at CRCT and in September at three remaining sites. Batch fecundity ranged from 5,118 to 100,003 eggs/female and increased concerning fish size, yet varied with oversampling locations. The fish was seen to mature firstly at 7.24, 7.18, 7.43, and 6.57 cm TL in CRCT, LPST, HBBL, and DDCM, respectively. Its  $L_m$  was regulated by salinity changes among the four sampling sites. These findings provide essential information for fish conservation efforts and artificial reproduction studies.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## References

- Alonso-Fernández, A., Alós, J., Grau, A., Domínguez-Petit, R., Saborido-Rey, F., 2011. The use of histological techniques to study the reproductive biology of the hermaphroditic Mediterranean fishes *Coris julis*, *Serranus scriba*, and *Diplodus annularis*. Mar. Coast. Fish. 3 (1), 145–159. <https://doi.org/10.1080/19425120.2011.556927>.
- Baek, G.W., Kim, J.W., Huh, S.-H., 2004. Maturation and spawning of striped goby (*Acentrogobius pflaumi*) (Teleostei: Gobiidae) collected in the Gwangyang Bay, Korea. Korean J. Fish. Aquat. Sci. 37 (3), 226–231. <https://doi.org/10.5657/kfas.2004.37.3.226>.
- Baek, H.J., Kim, H.B., Lee, T.Y., Lee, B.D., 1985. On the maturity and spawning of the Longchin goby *Chasmichthys dolichognathus* (HILGENDORF). Korean J. Fish. Aquat. Sci. 18 (5), 477–483.
- Bagenal, T.B., 1967. A short review of fish fecundity. In: Gerking, S.D. (Ed.), The biological basis of freshwater fish production. John Wiley, New York, pp. 89–111.
- Berra, T.M., 2001. Freshwater fish distribution. Academic Press.
- Diep, A.T., Dinh, Q.M., Tran, D.D., 2014. Species composition of gobiidae distributed in the coastal areas, Soc Trang Province. VNU J. Sci. Nat. Sci. Technol. 30 (3), 68–76.
- Dinh, Q.M., 2008. Data of survey on the species composition of fishes in Hau Basin at An Phu district, An Giang province. Can Tho Univ. J. Sci. 10, 213–220.
- Dinh, Q.M., 2011. The species composition and distributive characteristics of Perciformes in Hau river basin in Can Tho city, Vietnam. J. Sci. Hanoi Univ. Educ. 56 (7), 160–168.
- Dinh, Q.M., Ly, T.V., 2014. Preliminary study result of length – weight of tank goby, *Glossogobius giuris*, distributing in Soc Trang. Can Tho Univ. J. Sci. 2014 (2), 220–225.
- Dinh, Q.M., Nguyen, T.T.G., Nguyen, T.K.T., 2015. Reproductive biology of the mudskipper *Boleophthalmus boddarti* in Soc Trang. Tap chi Sinh hoc 37 (3), 362–369. <https://doi.org/10.15625/0866-7160/v37n3.6720>.
- Dinh, Q.M., Qin, J.G., Dittmann, S., Tran, D.D., 2016. Reproductive biology of the burrow dwelling goby *Parapocryptes serperaster*. Ichthyol. Res. 63 (3), 324–332. <https://doi.org/10.1007/s10228-015-0502-7>.
- Dinh, Q.M., Le, T.T.M., 2017. Reproductive traits of the duckbill sleeper *Butis butis* (Hamilton, 1822). Zoolog. Sci. 24 (5), 452–458. <https://doi.org/10.2108/zs170013>.
- Dinh, Q.M., Phan, Y.N., Tran, D.D., 2017. Population biology of the goby *Glossogobius giuris* (Hamilton 1822) caught in the Mekong Delta. Asian Fish. Sci. 30 (1), 26–37. <https://doi.org/10.33997/j.afs.2017.30.1.003>.
- Dinh, Q.M., 2018. Aspects of reproductive biology of the red goby *Trypauchen vagina* (Gobiidae) from the Mekong Delta. J. Appl. Ichthyol. 34 (1), 103–110. <https://doi.org/10.1111/jai.13521>.
- Dinh, Q.M., Tran, N.T.T., 2018. Reproductive biological traits of the goby *Stigmatogobius pleurostigma* (Bleeker, 1849) from the Mekong Delta, Vietnam. Indian J. Fish. 65 (1), 20–25. <https://doi.org/10.21077/ijf.2018.65.1.68188-04>.
- Dinh, Q.M., Tran, L.T., Ngo, N.C., Pham, T.B., Nguyen, T.T.K., 2020. Reproductive biology of the unique mudskipper *Periophthalmodon septemradiatus* living from estuary to upstream of the Hau River. Acta Zoologica 101 (2), 206–217. <https://doi.org/10.1111/azo.12286>.



- Dinh, Q.M., Lam, T.T.H., Nguyen, T.H.D., Nguyen, T.M., Nguyen, T.T.K., Nguyen, N.T., 2021. First reference on reproductive biology of *Butis koilomatodon* in Mekong Delta, Vietnam. *BMC Zool.* 6 (1), 1–14. <https://doi.org/10.1186/s40850-021-00072-y>.
- Etim, L., King, R.P., Udo, M.T., 2002. Breeding, growth, mortality and yield of the mudskipper *Periophthalmus barbarus* (Linnaeus 1766) (Teleostei: Gobiidae) in the Imo River estuary, Nigeria. *Fish. Res.* 56 (3), 227–238. [https://doi.org/10.1016/S0165-7836\(01\)00327-7](https://doi.org/10.1016/S0165-7836(01)00327-7).
- Fontoura, N.F., Braun, A.S., Milani, P.C.C., 2009. Estimating size at first maturity (L50) from Gonadosomatic Index (GSI) data. *Neotrop. Ichthyol.* 7 (2), 217–222. <https://doi.org/10.1590/S1679-62252009000200013>.
- Froese R., Pauly D., 2021. FishBase. [www.fishbase.org], Access: 2021.
- Ha, P.Y., Kinzie, R.A., 1996. Reproductive biology of *Awaous guamensis*, an amphidromous Hawaiian goby. *Environ. Biol. Fish.* 45 (4), 383–396. <https://doi.org/10.1007/BF00002531>.
- Ho, N.K., Nguyen, T.M., Dinh, Q.M., 2021. Reproductive traits of the goby *Glossogobius sparsipapillus* Akihito & Meguro, 1976 in Tra Vinh province, Vietnam. *J. Environ. Biol.* 42 (SI), 879–886. [https://doi.org/10.22438/jeb/42/3\(SI\)/JEB-23](https://doi.org/10.22438/jeb/42/3(SI)/JEB-23). In this issue.
- Hossain, M.S., 2014. Reproductive characteristics of Bele, *Glossogobius giuris* from Mithamoin Haor, Kishoreganj, Bangladesh. *World J. Fish Marine Sci.* 6 (6), 537–543. <https://doi.org/10.5829/idosi.wjfm.2014.06.06.86210>.
- Hwang, I.J., Baek, H.J., 2013. Reproductive cycle of chameleon goby, *Tridentiger trigonocephalus* in the southern coastal waters of Korea. *Devel. Reprod.* 17 (4), 353. <https://doi.org/10.12717/DR.2013.17.4.353>.
- Islam, M.N., 2004. Eco-biology of freshwater gobi, *Glossogobius giuris* (Hamilton) of the River Padma in relation to its fishery: A review. *J. Biol. Sci.* 4 (6), 780–793.
- Jakobsen, T., Fogarty, M.J., Megrey, B.A., Moksness, E., 2016. Fish reproductive biology: implications for assessment and management. John Wiley & Sons.
- Jin, Y.S., Park, C.B., Kim, H.J., Lee, C.H., Song, Y.B., Kim, B.H., Lee, Y.D., 2006. Reproductive cycle of dusky tripletooth goby *Tridentiger obscurus* in Jeju island, Korea. *Korean J. Ichthyol.* 18 (3), 184–192.
- Khoo, M.L., Das, S.K., Ghaffar, M.A., 2018. Growth pattern, diet and reproductive biology of the clownfish *Amphiprion ocellaris* in waters of Pulau Tioman, Malaysia. *Egypt. J. Aquatic Res.* 44 (3), 233–239. <https://doi.org/10.1016/j.ejar.2018.07.003>.
- La, H.T.N., Dinh, Q.M., 2017. Reproductive pattern, morphological and histological characteristics of gonads of the goby *Eleotris melanosoma* from the coastline in Soc Trang. *VNU J. Sci.: Nat. Sci. Technol.* 33 (3), 79–86.
- Le, K.N., Son, N.H., Nguyen, T.N.H., Le, H.A., Tran, V.D., Nguyen, T.D., Tran, D.D., Ha, P.H., To, T.M.H., Nguyen, T.V., et al., 2018. Fish species composition in Hau River Basin at Hau Giang Province. *VNU J. Sci.: Natural Sci. Technol.* 34 (1), 90–104. <https://doi.org/10.25073/2588-1140/vnunst.4723>.
- Le, T., Nguyen, M.T., Nguyen, V.P., Nguyen, D.C., Pham, X.H., Nguyen, T.S., Hoang, V.C., Hoang, P.L., Le, H., Dao, N.C., 2006. Provinces and City in the Mekong Delta. In: Le, T. (Ed.), *Geography Provinces Cities in Vietnam*, vol. VI. Education Publishing House, Ha Noi, pp. 49–94.
- Lehtonen, T., Wong, B., Kvarnemo, C., 2016. Effects of salinity on nest-building behaviour in a marine fish. *BMC Ecol.* 16 (1), 1–9. <https://doi.org/10.1186/s12898-016-0067-y>.
- Macinnis, A.J., Corkum, L.D., 2000. Fecundity and reproductive season of the round goby *Neogobius melanostomus* in the upper Detroit River. *Trans. Am. Fish. Soc.* 129 (1), 136–144. [https://doi.org/10.1577/1548-8659\(2000\)129%3C0136:FARSOT%3E2.0.CO;2](https://doi.org/10.1577/1548-8659(2000)129%3C0136:FARSOT%3E2.0.CO;2).
- Mazlan, A.G., Rohaya, M., 2008. Size, growth and reproductive biology of the giant mudskipper, *Periophthalmodon schlosseri* (Pallas, 1770), Malaysian waters. *J. Appl. Ichthyol.* 24 (3), 290–296. <https://doi.org/10.1111/j.1439-0426.2007.01033.x>.
- McDowall, R.M., 1997. The evolution of diadromy in fishes (revisited) and its place in phylogenetic analysis. *Rev. Fish Biol. Fish.* 7 (4), 443–462. <https://doi.org/10.1023/A:1018404331601>.
- Miller, P.J., 1984. The topology of gobioid fishes. In: Potts, G.W., Wootton, R.J. (Eds.), *Fish reproduction: Strategies and Tactics*. Academic Press, Orlando, London, United Kingdom, pp. 119–153.
- Narayanawamy, S.Y., Mohan, M.R., 2014. Histopathological studies on hypophysis and ovary of freshwater fish *Glossogobius giuris* (Hamilton). *World J. Pharmaceut. Sci.* 3 (8), 841–862.
- Nguyen, H.D.T., Nguyen, T.T.H., Tran, C.C., Nguyen, T.N.Y., Dinh, Q.M., 2021. Ovarian development, spawning characteristics, size at first mature and fecundity of *Glossogobius sparsipapillus* (Gobiiformes: Gobiidae) living along estuarine and coastal regions in the Mekong Delta, Vietnam. *Acta Zoologica Bulgarica* 73 (2), 253–260.
- Nguyen, K.V., Pham, T.M., 2013. Breeding techniques for freshwater fish. Can Tho University Publishing House, Can Tho.
- Nguyen, M.T., Huynh, T.N.L., Nguyen, T.P., Tran, D.D., 2014. Some reproductive biological characteristics of the *Glossogobius aureus* Akihito & Meguro, 1975 distributed in Ben Tre coastal areas. *Can Tho Univ. J. Sci.* 2, 169–176.
- Nguyen, T.H.D., Nguyen, H.T.T., Tran, T.C., Nguyen, Y.T.N., Dinh, Q.M., 2020. Morphometric and meristic variations of *Glossogobius sparsipapillus* along the coastline in the Mekong Delta, Vietnam. *Int. J. Zool. Animal Biol.* 3 (1), 1–9. <https://doi.org/10.23880/izab-16000211>.
- Phan, G.H., Le, L.T.T., Dinh, Q.M., Truong, N.T., Nguyen, T.H.D., 2021. Length-weight relationship, growth pattern and condition factor of *Glossogobius giuris* caught from coastal areas in the Mekong Delta. *AAEL Bioflux* 14 (3), 1478–1485.
- Qambrani, G.R., Soomro, A.N., Palh, Z.A., Baloch, W.A., Tabasum, S., Lashari, K.H., Qureshi, M.A., 2016. Reproductive biology of *Glossogobius giuris* (Hamilton), in Manchar Lake Sindh, Pakistan. *J. Aquacul. Res. Devel.* 7 (1), 392–394. <https://doi.org/10.4172/2155-9546.1000392>.
- Reavis, R.H., 1997. The natural history of a monogamous coral-reef fish, *Valenciennesa strigata* (Gobiidae): 2. behavior, mate fidelity and reproductive success. *Environ. Biol. Fishes* 49 (2), 247–257. <https://doi.org/10.1023/A:1007320708862>.
- Riede, K., 2004. In: The “Global register of migratory species” - first results of global GIS analysis. *Biological resources and migration*, Berlin, Springer, pp. 211–218.
- Roy, A., Hossain, M.S., Rahman, M.L., Salam, M.A., Ali, M.M., 2014. Fecundity and gonadosomatic index of *Glossogobius giuris* (Hamilton, 1822) from the Payra River, Patuakhali, Bangladesh. *J. Fish.* 2 (2), 141–147. <https://doi.org/10.17017/jfish.v2i2.2014.42>.
- Saha, B., 2013. Mudskipper, *Periophthalmodon schlosseri* (Pallas) from the Naf river. *Bangladesh J. Sci. Ind. Res.* 47 (4), 449–452. <https://doi.org/10.3329/bjsir.v47i4.14076>.
- Sturm, M.G.D.L., 1978. Aspects of the biology of *Scomberomorus maculatus* (Mitchill) in Trinidad. *J. Fish Biol.* 13 (2), 155–172. <https://doi.org/10.1111/j.1095-8649.1978.tb03423.x>.
- Talwar, P.K., Jhingran, A.G., 1991. *Inland fishes India adjacent countries*, Vol. 2. Rotterdam, Netherlands, Balkema.
- Teichert, N., Valade, P., Fostier, A., Lagarde, R., Gaudin, P., 2014. Reproductive biology of an amphidromous goby, *Sicyopterus lagocephalus*, La Réunion Island. *Hydrobiologia* 726 (1), 123–141. <https://doi.org/10.1007/s10750-013-1756-6>.
- Thresher, R.E., 1984. Reproduction in reef fishes. TFH Publications, United States.
- Tran, D.D., 2008. Some aspects of biology and population dynamics of the goby *Pseudapocryptes elongatus* (Cuvier, 1816) in the Mekong Delta PhD thesis. Malaysia, Universiti Malaysia Terengganu.
- Tran, D.D., Shibukawa, K., Nguyen, T.P., Ha, P.H., Tran, X.L., Mai, V.H., Utsugi, K., 2013. Fishes of Mekong Delta. Can Tho, Can Tho University Publisher, Vietnam.
- Tran, D.D., Cao, H.V., Dinh, Q.M., Tran, L.X., 2020a. An assessment of fisheries resources in the coastal water of the Mekong Delta, Vietnam. *AAEL Bioflux* 13 (6), 3683–3693.
- Tran, D.D., Nguyen, V.T., To, H.T.M., Nguyen, T.T., Dinh, Q.M., 2020b. Species composition and biodiversity index of gobiid assemblage in estuarine areas of the Mekong Delta, Vietnam. *Egyptian J. Aquatic Biol. Fish.* 24 (7), 931–941. <https://doi.org/10.21608/ejabf.2020.131385>.
- Tran, D.D., Le, B.P., Dinh, Q.M., Duong, N.V., Nguyen, T.T., 2021. Fish species composition variability in Cu Lao Dung, Soc Trang, Vietnam. *AAEL Bioflux* 14 (4), 1865–1876.
- Tran, L.T., Son, M.S., Vo, C.N.M., Hoang, H.D., Dinh, Q.M., 2019. Reproductive biology of *Periophthalmodon schlosseri* (Pallas, 1770) along the coastline in Soc Trang and Bac Lieu. *Tap chi Sinh hoc* 41 (2se), 229–240. <https://doi.org/10.15625/0866-7160/v41n2se.14153>.
- Trinh, K.N., Tran, D.D., 2012. The status of capture fisheries and management of marine fishes in Soc Trang Province. *Can Tho Univ. J. Sci.* 24b, 46–55.
- Zar, J.H., 1999. *Biostatistical Analysis*. United States, Prentice Hall, New Jersey.