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RESEARCH ARTICLE

Reproductive Biology of the Aquarium Marine Fish *Abudefduf vaigiensis* (Quoy & Gaimard, 1825) from Iligan Bay, Southern Philippines

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ABSTRACT

Abudefduf vaigiensis is one of the top ten aquarium reef fish in the world, but the supply of this ornamental fish species is mainly from the collection of wild populations. This current study investigated some aspects of the reproductive biology of Indo-Pacific sergeant *A. vaigiensis* (Quoy and Gaimard 1825) from Iligan Bay, Southern Philippines from August 2021 to August 2022. Monthly samples of 35 to 45 individuals per class size with a range of 6.8 to 15.3 cm (TL) were collected to examine the sex ratio, maturity stages and spawning period, gonado-somatic index (GSI), length at first maturity (L_{50}), and the batch fecundity (BF) of the species. The sex ratio showed female dominance (1:1.09) among size classes and across months. The spawning period displayed a peak during the inter-monsoon or warm month (April) and extends up to the beginning of the Southwest monsoon months (June and July). The higher GSI observed during these months clearly reinforced the occurrence of spawning. Histological investigation during this period displayed the existence of hydrated oocytes, tertiary vitellogenic ovaries, and post-ovulatory follicles (POF), which indicate the recent spawning event. Likewise, in males, numerous spermatozoa in the lumen of tubules in the testes were detected as well as the occurrence of remaining spermatozoa in the lumen of lobules in the sperm duct. The length at first sexual maturity of males (9.44 cm TL) was slightly shorter than females (10.32 cm TL). Batch fecundity significantly increased (p-value = 0.00) with body length and weight respectively.

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1. INTRODUCTION

Marine fauna such as fish and invertebrates are widely collected from the coral reef habitats throughout the Indo-Pacific but the exact number of species that are currently available in the trade is still difficult to estimate due to the unorganized, multifaceted, and fragmented supply system (Cohen et al. 2013; Rhyne et al. 2012; Larkin 2008; Prakash et al. 2017). The marine ornamental fish trade includes around 1000 fish species; the main supplying countries are the Philippines and Indonesia (Perera and Cumaranatunga 2009; Ochavillo et al. 2004; Muyot et al. 2019).

In the Philippines, the marine ornamental fish sector mainly involved the gathering of wild, native, and endemic species from coral reef areas and traded mainly for the export market (Muyot et al. 2018; 2019). This bleak scenario puts strong pressure on the wild populations (Bruckner 2005). Despite its contribution to export trade, the marine ornamental fish sector has been criticized for an unsustainable harvest of fish from wild habitats and the illegal use of sodium cyanide, which has made a negative impression on the sector (Muyot et al. 2018). A substitute source of marine ornamental fish, captive-bred ornamental fish generated through aquaculture, is an evolving trend in the global marine ornamental fish trade (Swet and Pedersen 2018), but the Philippines has not made any attempt in this field. There is a wide-ranging opportunity for trade and livelihood for marine ornamental fish, but specific issues and concerns of the sector have to be recognized and addressed to attain all-out benefits from the industry while safeguarding the sustainability of marine fishes in the wild. Over the past decades, the Philippine Bureau of Fisheries and Aquatic Resources (BFAR) has initiated programs and policy thrusts for the ornamental fish industry. Recently, to enable the development of the many sectors in the fisheries industry in terms of research, development, and production, the Comprehensive National Fisheries Industry Development Plan (CNFIDP) 2016-2020 was established (DA-BFAR 2016). This included the ornamental fish sector, but the lack of comprehensive baseline information on this sector makes it difficult to ascertain the appropriate avenues to address challenges in the industry. The taxonomic profile of the global ornamental fish trade clearly indicates the importance of fish species belonging to Family Pomacentridae. The dominance of pomacentrid species accounts for 42% of all fish sold internationally (Perera and Cumaranatunga 2009). The Family Pomacentridae, of which the genus *Abudefduf* is a member, has a circumglobal distribution and is quite diverse with over 385 species primarily inhabiting tropical and warm temperate waters, with majority of species occurring in the Indo-west and Central Pacific regions (Thresher 1984; Nelson 1994; Helfman et al. 1997; Allen 1998; Allen and Woods 1980; Allen 1991; Bessa et al. 2007; Feitosa et al. 2012; Litsios et al. 2012; Cowman and Bellwood 2013; Froese and Pauly 2015). The genus *Abudefduf* is represented by 20 species (Aguilar-Medrano and Barber 2016). The members of the genus are among the world's top ten most traded marine ornamental fishes (Wabnitz et al. 2003).

A. vaigiensis is one of the world's most popular aquarium reef fish (Rajesh et al. 2022; Vella et al. 2016; Gopakumar 2007). This species has five prominent vertical black bars, and the body has a white to light or dark bluish coloration with a yellow top. The coloration of each specimen is more pronounced just after being caught. The specimens had XIII+12 to 14 dorsal fin rays, II+11 to 13 anal fin rays, and I+4 to 5 ventral fin rays with a maximum length of 20.0 cm TL (de Beaufort 1962; Allen 1991; Randall 1996, 2007; Froese and Pauly 2015). *A. vaigiensis* is known as a benthopelagic fish that feeds on benthic as well as free-swimming organisms (Mundy 2005). The adult fish inhabits the upper edge of outer reef slopes and inshore rocky reefs, whereas juveniles are associated with drifting seaweed (Safran and Omori 1990). Several species are easily maintained in tanks, but, fishers who catch them in the wild have limited knowledge of their reproductive biology. Accordingly, overfishing has been reported in the Philippines due to ineffective fisheries management (Dalzell and Ganaden 1987; Pomeroy 2012). Back then, in the Southern part of the Philippines, particularly near the study area, the marine aquarium fish trade that included *A. vaigiensis* was practiced but eventually stopped due to insufficient supply, and often, they were taken from the wild. In order to help the sustainability of wild populations, it is important to explore the possibilities of breeding these economically important species in captivity. Before breeding and rearing them in captivity, having a good knowledge of their reproductive biology is a prerequisite. The present study is designed with a view to identifying the reproductive biology and gonadal development of *A. vaigiensis* to provide some biological information, including sex ratio, maturity stages and spawning period, gonadosomatic index (GSI), length at first sexual maturity (L_{50}), and batch fecundity (BF).

2. MATERIALS AND METHODS

Thirty-five to forty-five samples of *A. vaigiensis* with a class size of 6.8 to 15.3 cm (TL) were collected monthly from August 2021 to August 2022 from the coastal waters of Iligan Bay (Figure 1). The Bay is located in the southern part of Mindanao Sea, east of Panguil Bay (Figure 2) and west of Macajalar Bay. It lies approximately between 123°43'15" east longitude, and 8°30'31" north latitude. It has an

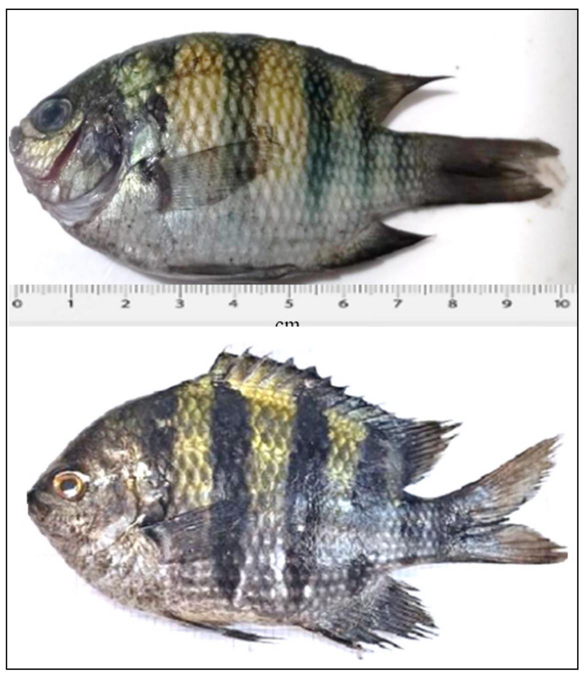

Figure 1. Photographs of the *A. vaigiensis* specimens examined in this study.

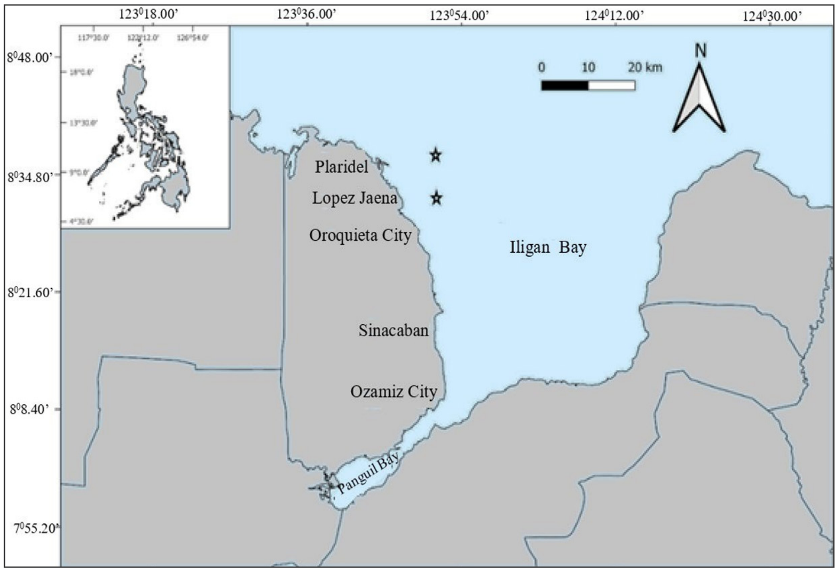

Figure 2. Map of the study area in Northern Mindanao showing the different fish landing sites (stars) monitored in the present study.

estimated coastline of 170 km with an area of about 2,390 km^2 (Alino 2002). BFAR classifies Iligan Bay as a leading fishing ground for its rich fishery resources and living space for wildlife assemblages and serves as a vital food producer (Lacuna and Alviro 2014).

The samples were purchased from the catch landings of the bottom-set longline, bottom-set gill net, and spear artisanal fisheries who went fishing near the coral reef sanctuaries in Capayas Island Marine Sanctuary (CIMS) and Mansabay Bajo Reef in Lopez Jaena, and Baobaon Fish and Marine Sanctuary in Plaridel, in the province of Misamis Occidental. These sites are endowed with rich marine life that has sustained the livelihood and subsistence of its populace for decades (de Guzman et al. 2009).

Each individual fish was measured in terms of total length (TL) to the nearest 0.1 cm and weight of 0.1 g. Their gonad's weight was measured to the nearest 0.01 g using digital analytical balance JT1003B. The ratio between males and females was determined and tested using the Chi-square goodness of fit test (Zar 1984). Sex was recognized based on gonad color and shape (Palla and Sotto 2021). Sex ratio was calculated based on the total number of males and females documented and the ratio expressed as male: female. The spawning period was determined from the highest percentage of spawning capable individuals (hydrated oocytes and with tertiary vitellogenic oocytes) and then further confirmed using the results of GSI analysis. The gonado-somatic index (GSI) was computed using the formula (Devlaming et al. 1982) of $GSI = 100 \times G/W$, where, (G) is the gonad weight and (W) is the body weight.

For histological analysis, gonads were fixed in Bouin's solution for 24 h and stored in 90% ethanol for succeeding analysis. Histological processing was done by taking gonad sub-samples of 3–5 mm cut transversely from the mid-section, embedded in paraffin and sectioned transversely into 5–7 μ thickness. Four to six replicates for each sectioned gonad were mounted on glass slides, stained, and counterstained with hematoxylin and eosin, respectively (Eagderi et al. 2013). The maturity of gonads was determined based on the criteria of Nikolsky (1963) and Amin et al. (2016) as follows: Stage I (immature) - gonads are thread-like and thin, testes are whitish and opaque, while ovaries are pinkish and translucent; II (maturing) - gonads become larger and occupying one third to half of the body cavity, and ova are minute and visible with slight yolk; III (nearly ripe) - gonads occupy about two-thirds of the length of the body cavity. In the ovary, the eggs become larger, yellow, and easily extruded with pressure. Testes have a pure white color, and their walls become thin; IV (ripe) - gonads occupy the entire body cavity. Testes are white milt run from the vent of males and eggs from females on pressure from their abdomen; V (spawning) - Ovaries are compact, reddish organs, rounded with wide anterior edges, and vascularized with blood vessels. Testes decrease in size and appear flaccid and flabby; and VI (spent) - gonads are flaccid. The ovary has a dark red color, and few residual eggs are visible. The testes have a gray-brown color, and there may be a little residual milt. Maturity stages were identified based on microscopic and macroscopic examination of gonads for use in identifying the size at first maturity.

The size at first maturity (L_{50}) was derived from the proportion of matured individuals (Stage III and IV) into each 1.0 cm size class. It was calculated using linear regression and fitted to the logistic model using the formula of $P = 1/(1 + \exp[r(L\ L_{50}))$, where: r is the slope and L is the length of the fish. Additionally, the batch fecundity (BF) was assessed for 45 females using the gravimetric method (Hunter and Macewicz 1985; Murua et al. 2003), which was done by counting the oocytes from a known weight in triplicate sub-samples. Only the tertiary vitellogenic and hydrated oocytes were considered. The expected number of oocytes was calculated using the formula of $BF = \{[\Sigma i(o_i/w_i)]/n\}^* W_O$, where: o_i is the oocyte count of the sub-sample, w_i is the gonad weight of the sub-sample, n is the number of sub-samples, and W_O is the weight of the ovary. The relationships between BF and total length and weight were derived from the regression function in MS Excel 2016.

3. RESULTS

3.1 Sex ratio

A total of 440 (210 males, 230 females) Indo-Pacific sergeant *A. vaigiensis* were examined in this study. The size class ranged from 6.8 to 15.3 cm TL for both sexes (Table 1). Accordingly, the most frequently recorded size class was from 9 cm to 9.9 cm (n = 141), dominated by males, followed by 10-10.9 cm (n = 140) (p < 0.05), dominated by females. The overall sex ratio based on size groups showed that females considerably outnumber males (Table 1).

The chi-square test revealed that the abundance of males and females over the duration of the study did not show significant (p > 0.05) differences, but raw numbers do indicate females outnumbering males (Table 2). The highest number of males (22) was observed in October 2021 and May 2022, while the lowest number (10) was in April 2022. On the contrary, the highest percentage of females (24) occurred in April 2022, and the lowest value (10) in January. The number of males and females was similar during February when the immature and mature stages were recorded for both sexes.

Table 1. Variations of sex ratio with length of *A. vaigiensis* caught from Western Iligan Bay, Southern Philippines, during August 2021-August 2022.

Length group (cm)	Fish No.	Male	Female	M:F Ratio	X^2	p value
6-6.9	4	-	4	-	-	-
7-7.9	26	17	9	1:53	2.46	0.12
8-8.9	70	37	33	1:89	0.23	0.63
9-9.9	141	78	63	1:81	1.60	0.21
10-10.9	140	54	86	1:1.59	7.31	0.01*
11-11.9	32	11	21	1:1.91	3.13	0.08
12-12.9	15	7	8	1:1.42	0.07	0.80
13-13.9	5	3	2	1:67	0.20	0.65
14-14.9	5	2	3	1:1.5	0.20	0.65
15-15.9	2	1	1	1:10	0.00	1.00
Total	440	210	230	1:1.09	1.25	0.34

Note: Level of significance p < **0.01

Table 2. Monthly sex ratio of *A. vaigiensis* with corresponding Chi-square (X^2) values from August 2021 to August 2022 from Western Iligan Bay, Southern Philippines.

Month/s	Fish No.	Male	Female	M:F Ratio	X^2	p value
August2021	33	17	16	1:94	0.03	0.86
September	33	19	14	1:74	0.76	0.38
October	34	22	12	1:55	2.94	0.09
November	35	18	17	1:94	0.03	0.87
December	30	12	18	1:1.50	1.20	0.27
January	30	20	10	1:50	3.33	0.07
February	30	15	15	1:1	0.00	1.00
March	30	13	17	1:1.31	0.53	0.47
April	34	10	24	1:2.40	5.76	0.01*
May	45	22	23	1:1.05	0.02	0.88
June	35	12	23	1:1.09	3.46	0.06
July	33	13	20	1:1.54	1.48	0.22
August2022	38	17	21	1:1.24	0.42	0.52
Total	440	210	230	1:1.09	0.91	0.34

Note: Level of significance p < **0.01

3.2 Monthly distribution of maturity stages and spawning period

The results showed that the spawning period of females harmonized with the spawning period of males. It reached its peak during intermonsoon or the warm month (April and May) and continued during the Southwest (SW) monsoon (June, July). However, no spawners (Stage V) were observed at the end of the SW monsoon (October) and in all the Northeast monsoon months (November to February). These months were dominated by the immature stages, and there were no records for the ripe (IV) and spent (VI) stages. Both sexes recorded only the immature stage during the month of October (Figure 3).

The frequency of maturity stages of males and females based on sectioned gonads is presented in Figures 4 and 5. Female gonads at the immature and maturing stage were characterized by oocytes in primary growth (PG), and primary and secondary vitellogenesis (Vtg1 and Vtg2, respectively), but no oocytes in tertiary vitellogenesis (Vtg3) (Figure 4). In ripe and spawning-capable females, large proportions of Vtg3 and hydrated oocytes (HO) could be seen, as well as some oocytes in atresia and postovulatory follicles were present. In the spent stage, there were postovulatory follicles, oocytes in atresia, and some Vtg1 and Vtg2. On the other hand, the immature stage in male gonads was characterized by large proportions of primary spermatocytes (Sc1) and small amounts of spermatozoa (Sz) (Figure 5), while

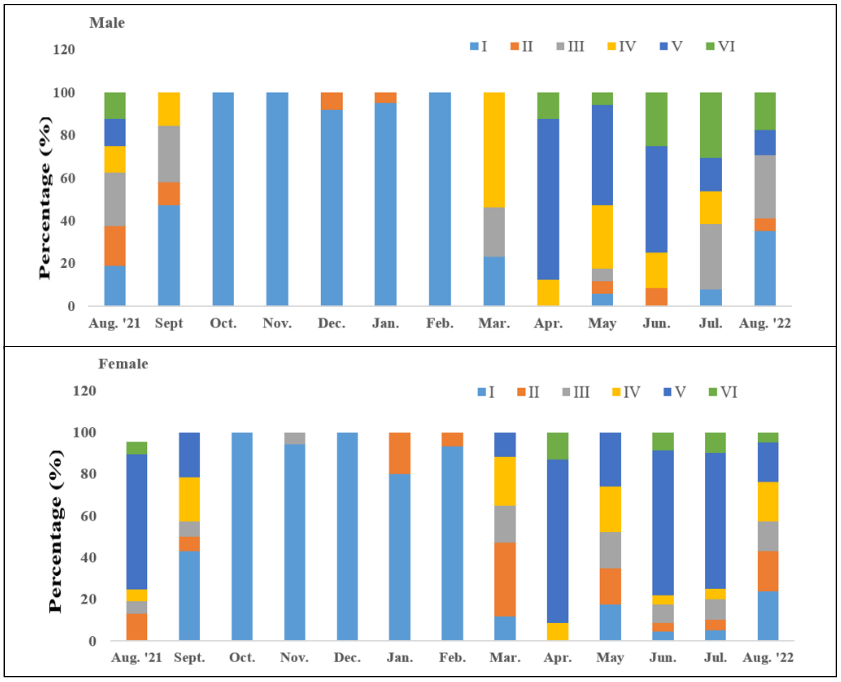

Figure 3. Monthly variation of maturity stages *A. vaigiensis* following criteria of Nikolsky (1963) and Amin et al. (2016) (August 2021 to August 2022, pooled data).

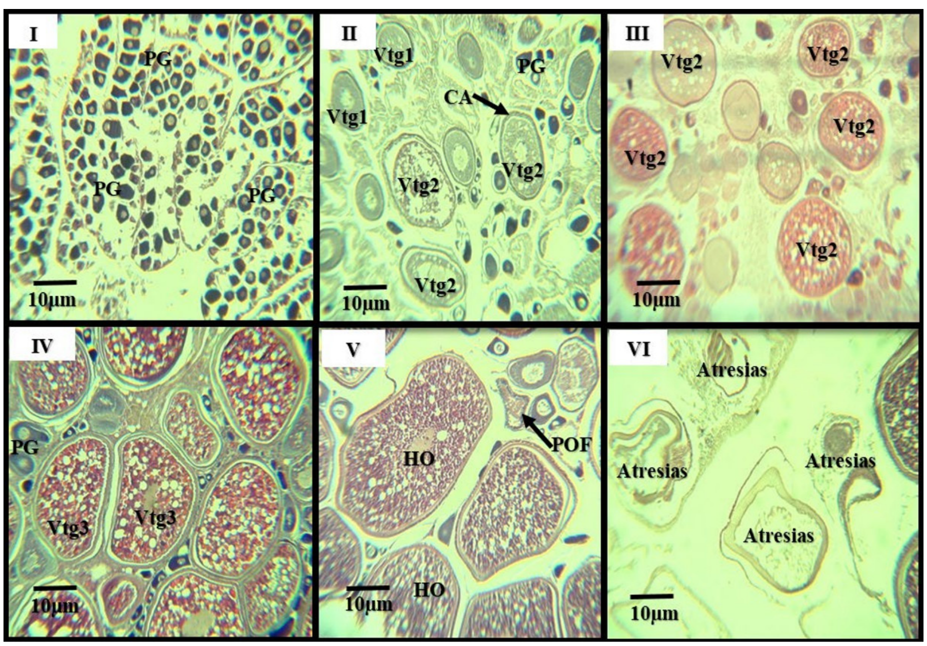

Figure 4. Sectioned gonads of *A. vaigiensis*. Female I – immature; II – maturing; III - nearly ripe; IV – ripe; V – spawning/running; VI – spent. (Abbreviations: PG - primary growth, Vtg1 - primary vitellogenic, Vtg2 - secondary vitellogenic, Vtg3 - tertiary vitellogenic, CA - cortical alveolar oocyte, HO - hydrated oocyte, and POF - post-ovulatory follicle).

spawning capable gonads had large proportions of spermatozoa, and small amounts of primary or secondary spermatocytes (Sc2) (Fig. 3). Spermatids predominated in gonads at the spent stage, with residual spermatozoa and large empty spaces in the lumen of lobules (Figure 5). The existence of hydrated oocytes and tertiary vitellogenic ovaries was an indication of an approaching and recent spawning, respectively. Also, the occurrence of post-ovulatory follicles (POF) was an indication of the recent spawning event. Likewise,

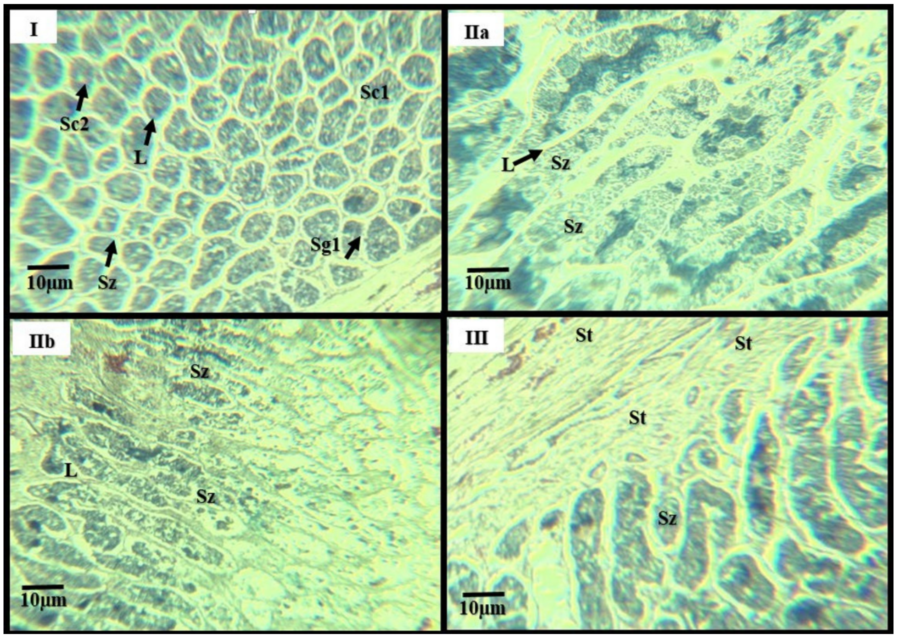

Figure 5. Sectioned gonads of *A. vaigiensis* Male I – maturing; II – spawning/running; and III – spent. (Abbreviations: Sg1-primary spermatogonia, Sc1-primary spermatocyte, Sc2-secondary spermatocyte, St-spermatid, Sz-spermatozoa, and L-lumen).

in males, spawning was obvious when spermatozoa are numerous, as well as when remaining spermatozoa was present in the lumen of lobules in the sperm duct.

3.3 Gonadosomatic index

Monthly variations in the gonadosomatic index (GSI) for both sexes of *A. vaigiensis* are depicted in Figure 6. The highest GSI values for males and females were recorded in the summer of April (8.56; 8.24). There was a slight difference between the trend of the values for males and females. For males, there were increasing GSI values from March, then reaching its peak in April, then gradually declining from May to August 2022. Meanwhile, in females, it started its increase in March, reaching its peak in April, a noticeable decrease in May, and again an increase in June, then a decline from July to August. These results were consistent with a high percentage of spawning-capable individuals in the gonadal maturity stages (Figure 3). Relatively higher GSI values were recorded during the spawning months, and lower GSI values in the months with no recorded spawning activity. The lower values were observed from the late Southeast monsoon (October) and in all Northeast monsoon months (November to February) for both sexes.

3.4 Length at first maturity (L_{50})

The L50 for *A. vaigiensis* differed between sexes, with females slightly longer than males. The logistic curves showing the relationship between sexes and the proportion of 50% maturity was estimated to reach 9.44 cm in males, whereas the females with 50% maturity were observed at 10.32 cm (Figure 7).

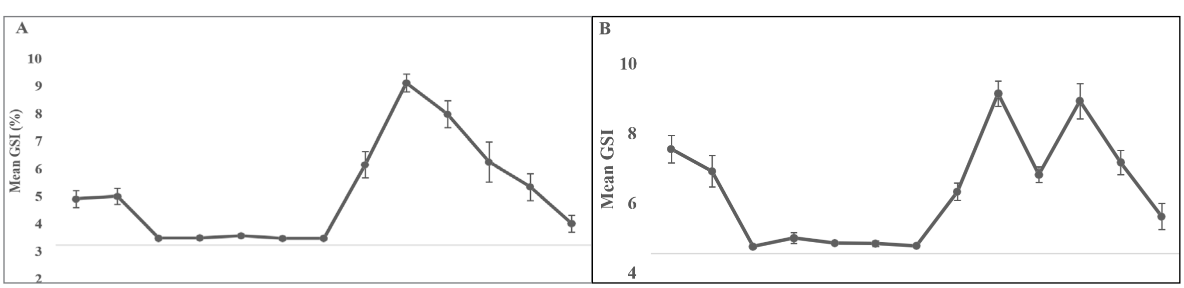

Figure 6. Temporal variation of mean gonado-somatic index of male (A) and female (B) *A. vaigiensis*. Error bars = standard error.

3.5 Batch fecundity

Batch fecundity (BF) varied from 12,815 to 49,600 oocytes (10–15.20 cm, TL) with a mean of 28,170 ± 930 oocytes (mean ± SE) (10.40 cm, TL). The results showed positive correlations between BF and length and weight. Although there was individual variation, batch fecundity significantly increased (p-value = 0.00) with body length and weight, respectively (Figure 8).

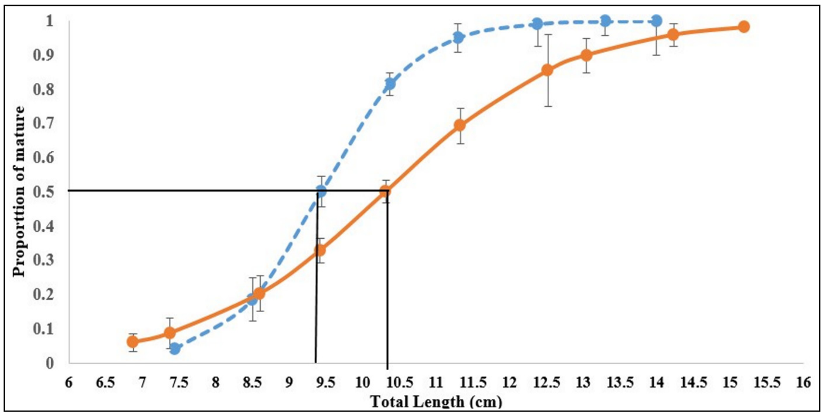

Figure 7. Length at 50% sexual maturity (L_{50}) of *A.vaigiensis*. A solid orange line with a circular marker represents females, while a broken blue line represents males.

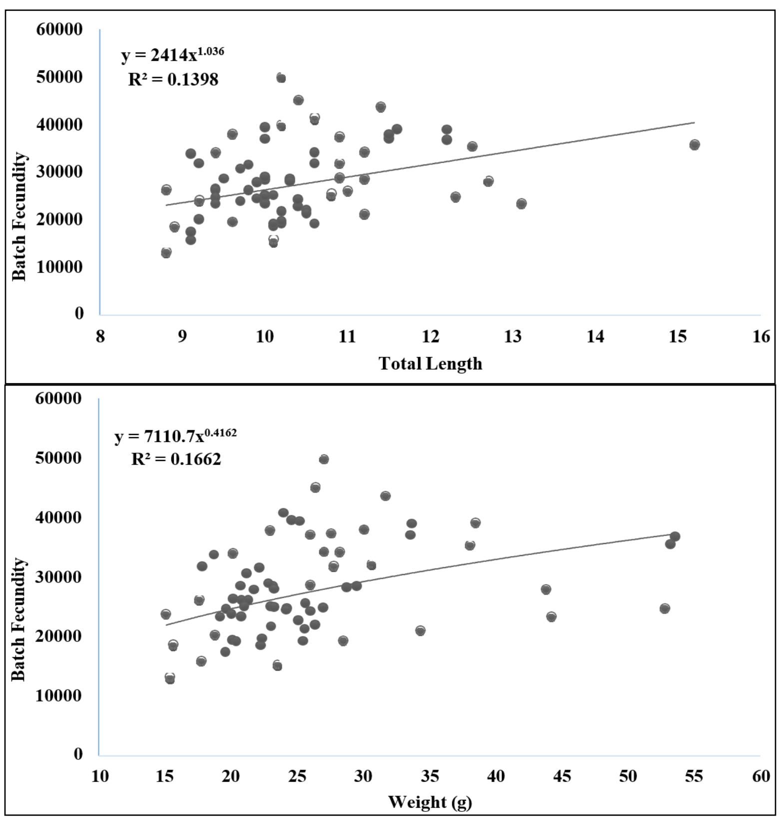

Figure 8. Relationship between total length and batch fecundity (P value = 0.00**), and relationship between weight and batch fecundity (P value = 0.00**) in *Abudefduf vaigiensis*.

4. DISCUSSION

4.1 Sex ratio

Sex ratio is an important stock characteristic for fisheries management because, as a population parameter, it is included in various models that are used for the estimation of spawning stock biomass and total population fecundity (Marshall et al. 2006; Tsikliras et al. 2010) and is also among the factors determining the reproductive potential of a stock (Jakobsen et al. 2009). In the current study, the sex ratio has slightly deviated to the predominance of females. Though the males dominated in some months, the overall results revealed female dominance. These results indicate that females were more vulnerable to fishers than males during the sampling period. A similar observation was documented by Sudhakar and Shameem (2009) in which the female *A. vaigiensis* marginally dominated the catch with the average sex ratio of 1: 1.36 from the shallow waters of Visakhapatnam coast. On the contrary, Rajesh et al. (2022) reported more males than females of *A. vaigiensis* from the southeast coast of India. Unlike some species of Pomacentridae, *A. vaigiensis* does not present sexual dimorphism of size. These species are gonochoristic but display sexual monomorphism. This is true for the species that form heterosexual pairs like the pair-forming coral-reef fish (Yabuta and Berumen 2013; Nowicki et al. 2018; Shiratsuchi et al. 2020).

Moreover, the current study showed a significant predominant group size of 10 to 10.9 cm. This might be due to mortality rates, longevity, and differential growth characteristics between the sexes (Nanami et al. 2010; Palla et al. 2016; Palla and Sotto 2021). Grimes (1987) stressed that the size bias in sex is also site- and species-dependent. Also, the number of female fish considerably increases during the spawning seasons from April to July. The significant value ($p < 0.05$) of the female ratio during the warm month of April may refer to the reproduction strategy of the species (Thresher 1984). Contrary to the 'theoretical' 1:1 sex ratio, which is assumed to occur in nature (Roff 1992), unbalanced adult sex ratios are quite common in fishes and are generally related to sexual differences in growth, mortality, or energetic cost of reproduction (Charnov 1993; Marshall et al. 1998). Sampling biases attributed to fishing at different depths or because of spatial or vertical separation of sexes could also account for skewed sex ratios (Sims et al. 2001). Additionally, the sex ratio across time and size groups is variable, attributed to migration and growth and mortality rates between sexes (Palla and Soto 2020).

4.2 Monthly distribution of maturity stages and spawning period

In fishery biology studies, it is important to determine the cycle of maturation and depletion of gonads (Qasim 1973). The dynamics of gonad maturation is a good tool to indicate the time in which females are capable of reproducing (Bessa et al. 2007). The physical act in which the fish freely release their eggs and sperm into the body of water is known as spawning. It is basically the fish's mode of mating and producing offspring. Maturity is clearly linked with the growth rate of fish, and spawning in a population is possibly geared to external events when conditions for the newly produced broods are most favorable. There is a diversity of patterns of spawning by reef fishes on the seasonal, lunar, and daily time scales (Robertson 1991).

The influence of season on gonad maturity and the spawning period of *A. vaigiensis* in Iligan Bay was clear. The peak of the spawning activity was documented during intermonsoon or the warm months (April and May) and at the beginning of the Southwest (SW) monsoon (June and July). There was no spawning in the late SW monsoon (October) and in all Northeast monsoon months (November to February). This implies that *A. vaigiensis* in Iligay Bay spawned intermittently, and spawning was perhaps seasonal. The same result was also recorded in other pomacentrid species *Chromis limbaughi* in which summer is undoubtedly the most reproductively active season (González-Félix et al. 2019). Undoubtedly, increasing water temperature and daylight hours, among other factors, play key roles in this pattern, which corresponds well with those of other pomacentrids, such as *Stegastes rectifraenum*, with a spawning season from March to October, and *Microspathodon dorsalis* and *Abudefduf troschelii*, both with spawning seasons lasting from April to October (Hernández-Olalde et al. 2008). In addition, *A. vaigiensis* seems to be a partial spawner because spawning capable females had mature oocytes, as well as oocytes at other stages of development, i.e., asynchronous development, a feature described also for the partial spawners *S. rectifraenum, M. dorsalis,* and *A. troschelii* (Hernández-Olalde et al. 2008; González-Félix et al. 2019).

Moreover, during these spawning months, most of the gonads attained maturity when investigated histologically. The presence of tertiary vitellogenic (Vtg3), post-ovulatory follicles, and hydrated oocyte (HO) in the gonadal section of females and the occurrence of several spermatozoa in the lumen of lobules and spermatocytes in the testis of males proved that there is an imminent and current spawning (Palla and Sotto 2016). Histologically, the presence of numerous tertiary vitellogenic, hydrated oocytes and post-ovulatory follicles in females and the occurrence of several spermatozoa in the lumen of lobules and spermatocytes in the testis confirmed that spawning is evident. In small-size classes, the primary stages of oocytes were observed. Fish belonging to the same size class showed similar ovarian development stages, which is a good indication of their synchronous reproductive development.

The chief spawning period with two pulses documented in this study, specifically in females, is distinctive in the Indo-Pacific region, which specifies that *A. vaigiensis* in Iligan Bay is an insular species. This means that this fish species inhabits islands or isolated bodies of water, often exhibiting unique adaptations to their specific environment and can develop special traits or looks that are different from fish found elsewhere. The first pulse in April might be due to the warm temperature's impact on oocyte development, while in June and July, the abundance of nutrients. The frequency distribution of oocytes in ripe ovaries of *A. vaigiensis* shows their sequential spawning pattern, and thus, if they are bred in captivity, appropriate arrangements would be made to gather the eggs laid in batches or fry developing from them (Perera and Cumaranatunga 2009).

4.3 Gonadosomatic index

The maturation pattern of *A. vaigiensis* in the current study is confirmed by the monthly analysis of the GSI trend (Fig. 5), both in males and females. It is clear that seasonal changes in the GSI of *A. vaigiensis* corresponded well with the stages of gonad maturity. When arranged by the gonad developmental stage, GSI values were greatest in fish with gonads at the ripe and spawning capable stages, reflecting active vitellogenesis and spermatogenesis mainly during the intermonsoon or the warm month of April. Then, GSI decreased during the Northeast monsoon, when fish were reproductively inactive. A similar seasonal pattern in GSI was observed in the damselfish *A. troschelii* (Bessa et al. 2007).

Several researchers documented continuous reproduction along the year for *Amphiprion melanopus* (Ross 1978), and for *Abudefduf saxatilis* (Albrecht 1969; Prappas et al. 1991). The GSI values found in this study (0.33–8.56) are comparable to those reported previously for another pomacentrid species, *Chromis pelloura*, ranging from approximately 0.2 to 1.4, but very high GSI values of up to 8.5 for *C. notata*, have been observed (Lee and Lee 1987). Females attained higher mean GSI than males because the size of the ovary was bigger than that of the testes at the same maturity stage.

4.4 Length at 50% sexual maturity

The length at first sexual maturity L_{50} is a very significant parameter in fisheries research to regulate the minimum legal size and the optimum mesh size that may be required to maintain the suitable spawning stock and to guarantee at least one spawning for the mature individuals (Amin et al. 2016). In the present study, *A. vaigiensis* displayed variation in the length at first sexual maturity L_{50} maturity between the two sexes. The male reached 50% first sexual maturity at a shorter length (9.44 cm) than the female (10.32 cm). These variations in the L_{50} ratio were suggested to be inherent in environmental and biological conditions across locations (Grimes 1987). The estimation of length at first sexual maturity in this study showed some variation from the other studies. In *Parma microlepis*, an Australian pomacentrid, the first maturation occurs around 115 mm, with mature individuals from 106 mm (Tzioumis and Kingsford 1999), *A. saxatilis* from São Paulo, Brazil reported 9.44 of 114 and 123 mm (Bessa et al. 2007), *A. glaucus* from Minicoy atoll, Lakshadweep had a 9.44, of 60 mm (TL) (Pillai and Mohan 1990). Under diverse environmental conditions, the onset of sexual maturity could differ across different species, even among congeners, explaining the differences obtained in this study compared to earlier published results.

4.5 Batch Fecundity

Fecundity refers to the number of oocytes that are likely to be laid by a fish during the breeding season. It is an important biological parameter that plays a role in evaluating the commercial potentials of fish stocks (Gómez-Márquez 2003; Kant et al. 2016; Amin et al. 2016). Successful fisheries management, including practical aquaculture, relies on having an accurate assessment of fecundity to understand the recovery ability of fish populations (Lagler 1956; Nikolskii 1969; Tracey et al. 2007). The relation between female size and fecundity makes it promising to estimate the possible egg output (Chondar 1977) and the potential reproductive capacity of fish stocks and offspring in a season (Qasim and Qayyum 1963; Lowerre-Barbieri 2009).

In the present study, the fecundity estimates of *A. vaigiensis* vary from 12,815 to 49,600 oocytes (10–15.20 cm, TL). Fecundity significantly increased with total length, fish weight, and ovary weight. A somewhat similar result was recorded from the shallow waters of the Visakhapatnam coast, in which fecundity ranged from 11,294 to 40, 208 for *A. vaigiensis* (Sudhakar and Shameem 2009). Batch fecundity estimates vary in some pomacentrid species, such as in the clown fish *Amphiprion latezonatus* and *A. akindynos* (10,300 to 33,140 oocytes and 2,160 to 26,890 oocytes: Richardson et al. 1997), *A. clarkia* (8,000 to 17,500 oocytes: Bell 1976), and in the damselfish *Dascyllus trimaculatus* (809 to 9,634), *D. aruanus* (2,125 to 7,157: Pillai et al.1985) and in *D. reticulatus* (1,032 to 1,993: Vijay Anand 1990). These differences in fecundity estimate may be affected indirectly by other factors through differences in energy allocation strategies and the influence on fish body size or weight of (1) environmental factors influencing condition (such as temperature and food availability), (2) preceding spawning activity, or (3) density-dependent effects (Plaza et al. 2002; Kurita et al. 2003; Takasuka et al. 2005; Kim et al. 2006).

5. CONCLUSION

This study recognized the reproductive biology of the Indo-Pacific sergeant *A. vaigiensis* from Iligan Bay, Southern Philippines. It observed that this species is a gonochoristic ornamental reef fish without sexual dimorphism.

The highest GSI values for both sexes were recorded in the summer of April. The observed spawning period was during the intermonsoon or the warm month (April) and extended during the SW monsoon (June, July). These results were clearly supported by the histological examination of the gonads, which showed active spermatogenesis in males and vitellogenesis in females. Estimated batch fecundity showed positive correlations between BF against length and weight, indicating a significant increase in total length, fish weight, and ovary weight. Finally, the latest discoveries emphasize the importance of promoting the creation of a captive breeding program to support and maintain the ornamental fish trade. Additionally, it underscores the need to either stop fishing altogether or, at the very least, rigorously enforce regulations for the extraction of wild organisms within the country.

CONFLICTS OF 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.

ETHICS STATEMENT

No scientific and research ethics are violated.

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