Reproductive Biology of the Short-Necked Clam, *Paphia undulata* (Born 1778) from Southern Negros Occidental, Central Philippines

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ABSTRACT

The short-necked clam, *Paphia undulata*, occurs in coastal muddy bottoms of Hinigaran, Binalbagan, and Himamaylan, Negros Occidental where it has an important contribution to fisheries. However, stocks in these areas are dwindling and in order to formulate sound management strategies, information on the reproductive biology of this species is a prerequisite. Also, knowledge on the reproduction of this species is a prelude to its laboratory breeding and rearing. Reproductive biology of the short-necked clam from the three areas was studied over an annual cycle. Short-necked clams were collected monthly from catches of compressor divers. Five gonad stages were described based on histological examinations: developing, mature, partially spawned, redeveloping, and spent. Immature or indeterminate gonads were also noted. Although occasional presence of hermaphrodite gonads was observed this species is still functionally dioecious with 1.00M: 1.02F sex ratio. Sexual maturity is attained at 42.6 mm for males and 44.8 mm for females. Short-necked clams have continuous breeding season. However, peak of spawning activities is on the months of August to November which coincide with the monsoon transition months probably due to the decrease in salinity and nutrient influx during these months. Organisms smaller than 45mm must not be collected and collection must be regulated during peaks of spawning activities to leave a portion of reproductively mature individuals to ensure sustainability of fisheries. However, in terms of laboratory breeding and rearing of this species, it is fundamental to consider the spawning peaks and size at sexual maturity to ensure successful spawning in the laboratory. Hence, broodstock to be used in the experiments must be sexually mature (>45mm) and collected during peaks of spawning activities.

Key words: Paphia undulata, reproductive biology, gonad stages, dioecious, size at sexual maturity, continuous breeding season, sustainability of stocks

INTRODUCTION

Paphia undulata (Born), or the short necked-clam (Fig 1.), occurs in muddy substrate (4-16m depth) along the coasts of Hinigaran, Binalbagan, and Himamaylan, Negros Occidental in Central Philippines. Because of their value to both local and export markets, there is indiscriminate harvesting of this resource. In fact, short-necked clams have already been determined as overexploited in these areas (Agasen et al. 1998), a situation which has worsened even more today (del Norte – Campos and Villarta 2010). Overexploitation will ultimately lead to biological and economic overfishing, especially so since the high demand for this resource can only be supplied by harvesting from natural stocks. Information on the reproductive biology of this species is a prerequisite for the formulation of management initiatives to develop sustainable exploitation of the resource in these areas. This is imperative since one potential cause of mismanagement is a poor understanding of the biology of the species. Furthermore, knowledge on the reproduction of this species is a prelude to its laboratory breeding and rearing.

Figure 1. The short-necked clam, *P. undulata,* locally known as " nylon shell".

This study was conducted to describe the reproductive biology of the short-necked clam, specifically to describe gonad stage development, determine spawning periodicity, sex ratios and minimum size at sexual maturity. In Thailand (Tuaycharoen 1984; http: www.fisheries.go.th/mf-umdec/subject3.htm) and in China (Zhijiang et al 1991), the reproductive biology of *P. undulata* has already been documented and the results of the present study are compared with these reports.

MATERIALS AND METHODS

A maximum of sixty (60) short-necked clams were collected monthly from August 2007 to July 2008 from catches of compressor divers in Hinigaran, Binalbagan, and Himamaylan, Negros Occidental (Fig. 2). Clams were packed in ice for transport to the laboratory where specimens were weighed, measured, and dissected. Shell length and shell width were measured to the nearest 0.05mm using a vernier caliper. Total (TW), viscera (VW), and gonad (GW) weights were

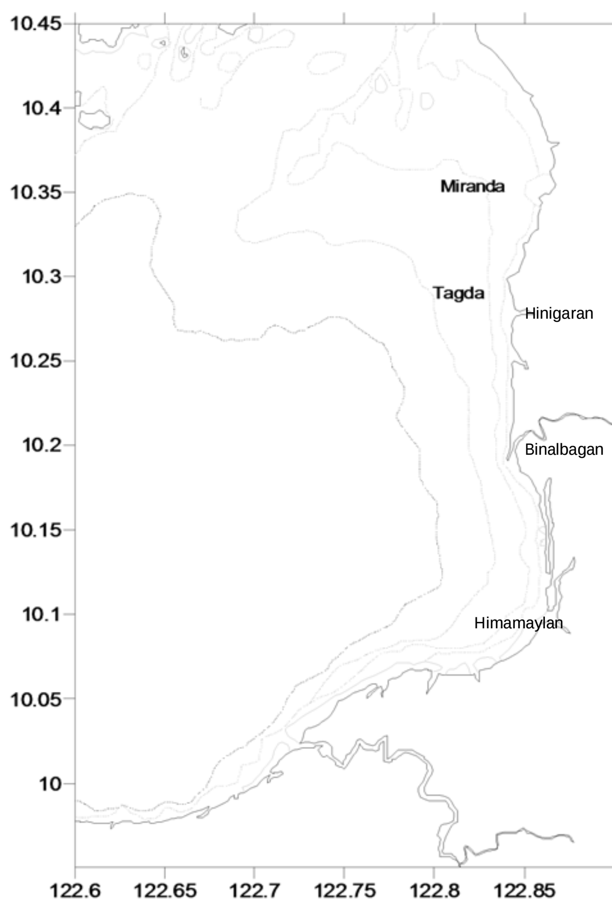

Figure 2. Site of collection *P. undulata* in coastal waters of Negros Occidental, Central Philippines.

measured to the nearest 0.01mg using a digital electronic balance. The gonadosomatic index (GSI %) of each individual was computed using the formula

GSI = VW/GW *100 (Sastry 1979)

and plotted against time.

After measurements, clams were dissected and the gonads were fixed in Bouin's solution. Gonads were then processed using standard histological procedures (Humason 1972). Sex was determined by examining clams under a compound microscope. Monthly and overall sex ratios were computed and their skewness tested (χ^2test). Gonad stages were described and classified into the following: developing, mature, partially spawned, redeveloping, and spent based on the predominant morphological appearance of the gametes (Tuaycharoen 1984; Rose et al. 1990; Ledesma-Fernandez and del Norte-Campos 2004; Kang et al. 2007). Monthly frequencies of gonad stages were then plotted against time.

Size at sexual maturity is defined as the smallest shell length staged with mature gonads.

RESULTS AND DISCUSSION

Sex ratio, Gonad morphology, and Size at sexual maturity

A total of 692 short-necked clams were collected. Of these 11.9% (82) were sexually indeterminate, 0.4 % (3) were hermaphrodites, 43.4% (300) were males and 44.4% (307) were females (Table 1). Male to female ratio was 1.00: 1.02 and based on Chi-square test, males and females are equally represented in the population. This means that the population is still in equilibrium, wherein inbreeding and competition for mates does not occur (Downing et al. 1989). This also shows that even if a portion of the potential spawning stock is left in the population, there will still be fertilization which eventually will lead to recruitment. Eventually this recruitment will translate to recovery of the stocks provided that sustainable exploitation of the resource is practiced in the area. Short-necked clams are functionally dioecious wherein male and female sexes are separate, with very low incidences of hermaphroditism. However, this species does not exhibit sexual dimorphism. Both male and female gonads are cream to pale orange in color regardless of sex, stage,

Table 1. Sex ratios of the short-necked clam of *P. undulata* from monthly samples (August 2007 – July 2008) collected from Hinigaran, Binalbagan, and Himamaylan Negros Occidental (M: male, F: female, H: hermaphrodite, IN: indeterminate).

Months	Male	Female	H	IN	Total(N)	Sex ratio M:F
Aug '07	23	36	1		60	1:1.57
Sept	24	36			60	1:1.50
Oct	26	31	1	1	59	1:1.19
Nov	13	20			33	1:1.53
Dec	31	25		4	60	1:1.81
Jan '08	29	30	1		60	1:1.03
Feb	31	29			60	1:0.94
Mar	37	22		1	60	1:0.60
Apr	14	14		32	60	1:1.00
May	17	16		27	60	1:0.94
Jun	21	22		17	60	1:1.05
Jul	34	26			60	1:0.76
Total (N)	**300**	**306**	**3**	**82**	**692**	**1:1.02**
%	43.35	44.36	0.43	11.85		

and size. Thus, it is not possible to determine the sex and characterize the gonad development of this species through external morphological examination.

Shell lengths of the collected clams ranged from 20.7mm to 71.9mm. The smallest shell length staged with mature gonads was 42.6mm for males and 44.8mm for females. Since this species does not exhibit sexual dimorphism, a nominal size of sexual maturity for both sexes is set at 45mm. Setting this as the minimum harvestable size ensures that at least a portion of the population is allowed to spawn and contribute to recruitment, enhancing the sustainability of the resource. In Thailand, the average size at sexual maturity is reported to be greater than 40mm (Tuaycharoen et al. 1984; Pongthana 1990), similar to the results in this study.

Gonad Stages

Histological analysis of the gonads showed four determinate stages for male (Figs. 3a-d) and five for female (Figs. 4a-e). Table 2 summarizes the description of the gonad stages.

Reproductive Stages and Spawning Periodicity

P. undulata has a protracted or continuous breeding season as supported by the co-occurrence of different reproductive stages in all the monthly samples of the population (Figs. 5-6). The presence of mature gonads in almost all months and the infrequent occurrence of spent stages are consistent with this species having a prolonged reproductive cycle. However, variation in the intensity of the reproductive activities results in peaks or periodicity in the reproductive phases. This pattern

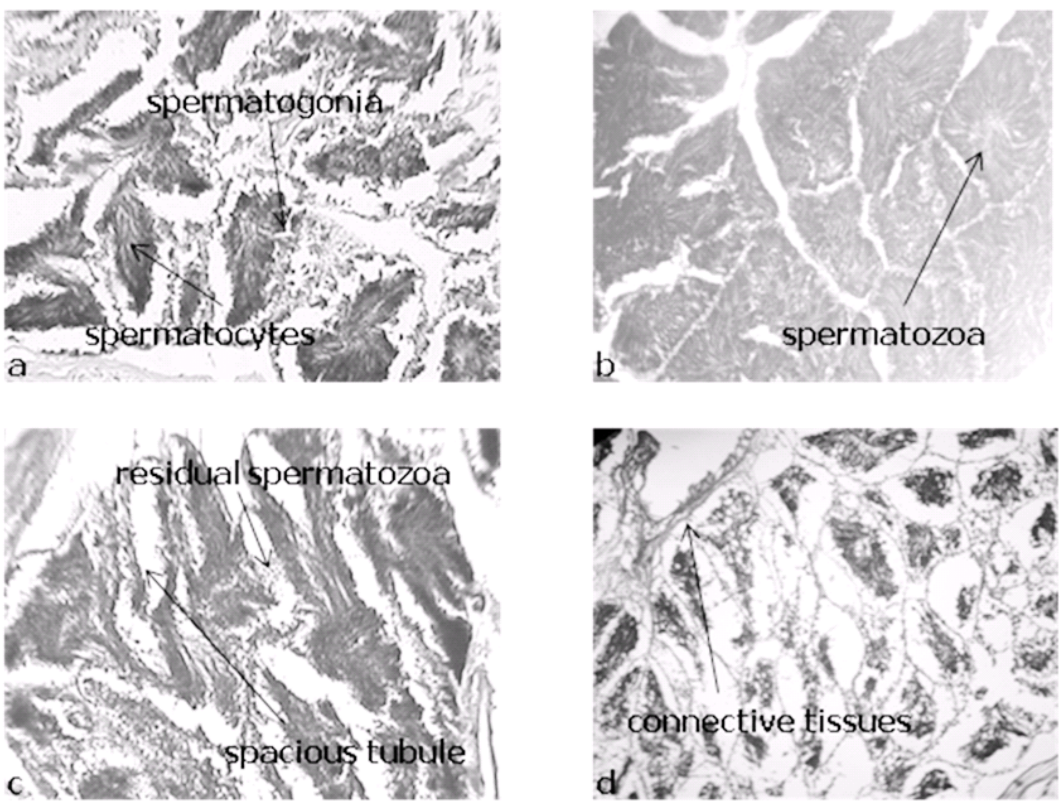

Figure 3a-d. Gonad stages of male short-necked clam, *P. undulata* a. developing, b. mature, c. partially spawned, d. redeveloping (Magnification (100x).

Table 2. Gonad stages of *P. undulata* collected from Hinigaran, Binalbagan, and Himamaylan, Negros Occidental on August 2007 to July 2008.

Stage	Male	Female
1. Immature/ Sexually indeterminate	No definite gonad region or follicle. No gamete proliferation. Sex cannot be determined.	
2.Developing	Rounded to expanded tubules with spermatogonia and spermatocytes. Few spermatozoa proliferate at the center.	Oogonia at different stages of development. Oocytes are attached to the edges but starting to fill the follicles.
3.Ripe	Tubules are elongated assuming rosette formation and filled with spermatozoa.	Follicles are filled with mature oocytes with prominent nucleus and nucleolus.
4. Partially spawned	Tubules show streaky appearance of streaming sperms. Spermatozoa still occupy the lumina but have numerous gaps.	Spacious acini, remaining mature oocytes at some acini. Gaps on the follicle walls.
5.Redeveloping	Connective tissue present. Some tubules are empty but generally surrounded by residual spermatozoa.	Connective tissues present. Oocytes at different stages are present. Some follicles are empty.
6.Spent		Empty follicles. May contain residual oocytes at the connective tissues.

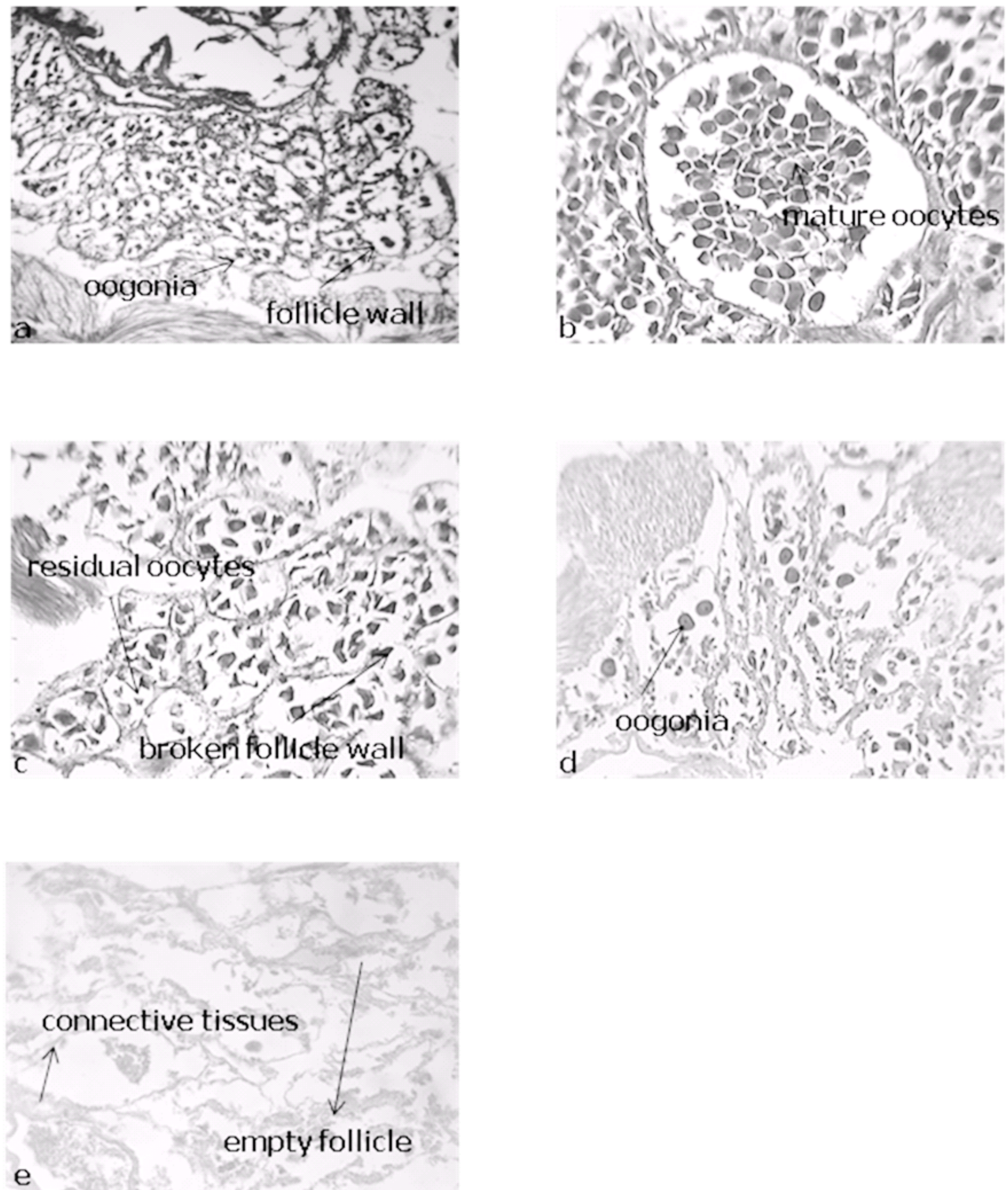

Fig. 4a-e. Gonad stages of female short-necked clam, *P. undulata* a. developing, b. mature, c. partially spawned, d. redeveloping, e. spent (Magnification (100x).

of reproduction is exhibited by both male and female clams. At the start of the study (August 2007), a high frequency of partially spawned females was observed and this remained high until November. This was followed by prolonged gametogenesis from December to July, wherein the dominant stages were developing and mature. On the other hand, male short-necked clams showed a more protracted breeding pattern as shown by the dominance of developing and mature gametes in almost all months, and by the absence of spent stages. The latter is attributed to the smaller size of sperm relative to egg cells, resulting to a lower energetic cost of reproduction typical in males. This is believed to be a strategy to ensure availability of mature sperm whenever females spawn, thus allowing synchronicity between male and female reproductive cycles. Since short-necked clams are broadcast spawners, synchronicity of reproductive cycles between the sexes is necessary to ensure successful fertilization.

Protracted breeding seasons with periodicity over an annual cycle is commonly exhibited by tropical bivalve species such as *Scapharca inequivalvis* (Ledesma-Fernandez and del Norte-Campos 2004), *Anodontia edentula* (Samentar et al. 2004), and *Gari elongata* (Nabuab and del Norte-Campos 2006). This is because seasonal patterns of gonad development result from responses to within-year changes in environmental factors (Sastry 1979; Mackie 1984), although seasonal variation in the tropics may be minimal. High spawning activities of male and female short-necked clams coincides during the months of August to November (transition months to the Northeast Monsoon). A stronger signal is observed during these months likely due to lower salinities related to the influx of riverine water (Palla et al. in prep.). Influx of riverine water, furthermore, increases terriginous inflow of organic matter which enhances nutrients in the water. Nutrient influx-induced spawning has also been observed in *S. inequivalvis* (Ledesma-Fernandez and del Norte-Campos 2004) and *G. elongata* (Nabuab and del Norte-Campos 2006) from Banate Bay in eastern Panay, about 60km north of the study area. The months of August to November are considered as the peak in spawning for both male and female clams. Subsequent recruitment occurred in the following months of January to March (del Norte-Campos and Villarta 2010).

Gonadosomatic indices (GSI) for male (8.53-14.15 %) and female (9.59-13.63%) short-necked clams showed minimal variation over an annual cycle (Figs. 7-8), which is consistent with extended gametogenesis in this species. However, above average GSI values were observed during the Northeast Monsoon months coinciding with the peak of reproductive activities. Other studies show that *P. undulata* has two spawning peaks: April – May and August – November in Trat Province, Thailand (Tuaycharoen 1984) and in May and October in China (Zhijiang et al 1991). These studies show that the species spawns during pre- and post-monsoon months, possibly with varying degrees in peak activity. However, the spawning season in the present study is more similar to the spawning peak (August to October) observed in the population of short-necked clams in Samut Sakhon Province, Thailand (Jindalikit, undated). This illustrates that reproductive activity (gametogenesis and spawning) of *P. undulata* varies from one area to another, possibly in response to the local environmental conditions.

SUMMARY AND CONCLUSIONS

P. undulata is a functionally dioecious bivalve that exhibits no sexual dimorphism. However, occasional incidence of hermaphroditism was observed. Sex ratio is 1.00M: 1.02F, which shows that the male and female portions of the population are equally represented. It attains sexual maturity at 42.6mm in males and 44.8mm in females. The effective size at sexual maturity can be taken as 45mm. Five gonad stages were described in the short-necked clams: developing, mature, partially spawned, redeveloping, and spent. Based on the monthly frequency distribution of the gonad stages and the GSI, *P. undulata* has a protracted breeding season with high spawning activities in the transition months to the Northeast Monsoon (August to November) probably due to high nutrient influx during these months. Spawning of male and female clams also coincides during these months, showing synchronicity between male and female gonad development. The reproductive cycle of *P. undulata* varies in different locations probably due to the differences in the local conditions. In terms of laboratory breeding and rearing of this species, it is fundamental to consider the spawning peaks and size at sexual maturity to ensure successful spawning in the laboratory. Thus, broodstock to be used in the experiments must be sexually mature (>45mm) and collected during peak spawning months (August to November).

Regarding sustainable exploitation of this resource, it is imperative to leave a portion of the spawning stock in the population to allow continuous breeding and recruitment. Thus, gathering of individuals smaller than 45mm must be prohibited and collection must be regulated during the months of peak spawning activity (August to November).

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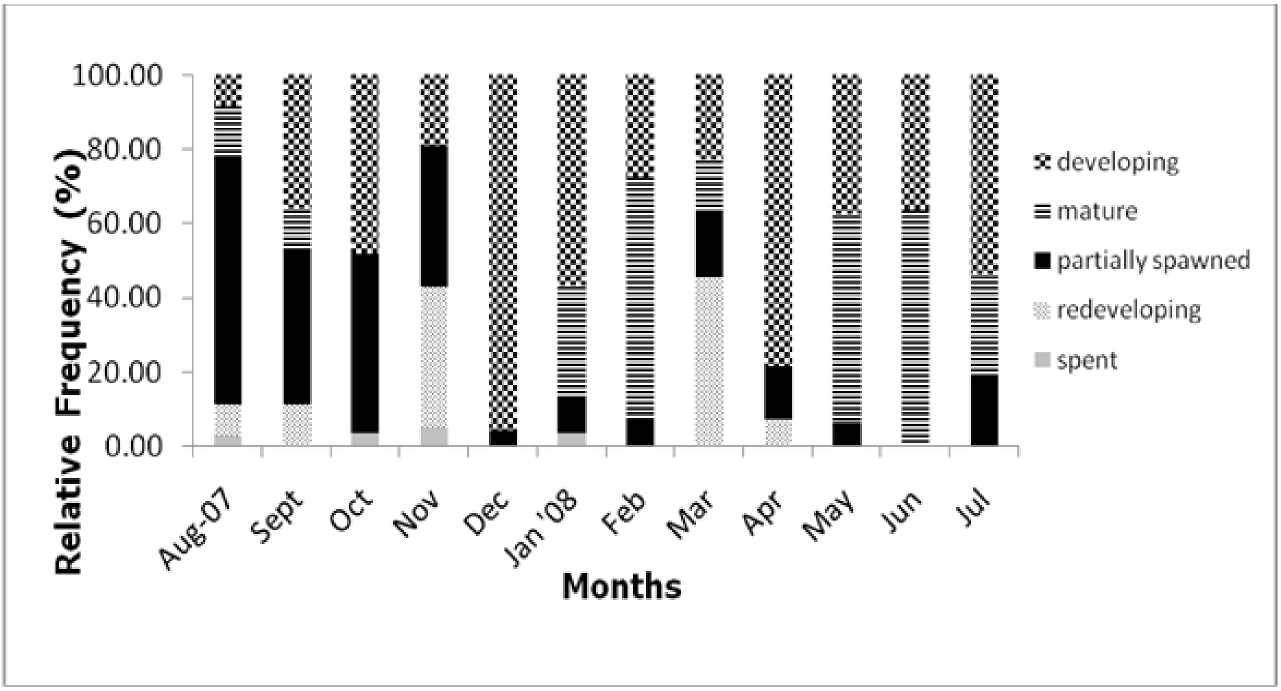

Figure 5. Frequency distribution of gonad stages in female (n=307) *P. undulata* collected from August 2007 to July 2008 in Hinigaran, Binalbagan, and Himamaylan, Negros Occidental.

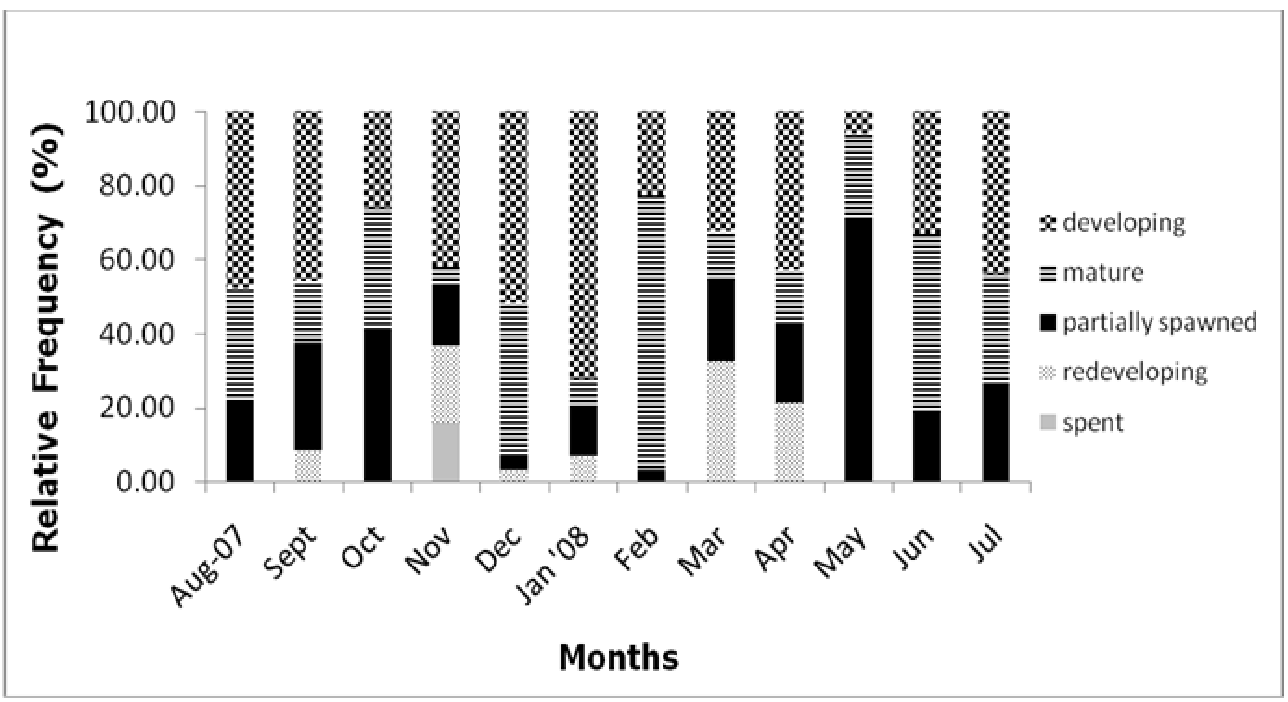

Figure 6. Frequency distribution of gonad stages in male (n = 300) *P. undulata* collected from August 2007 to July 2008 in Hinigaran, Binalbagan, and Himamaylan, Negros Occidental.

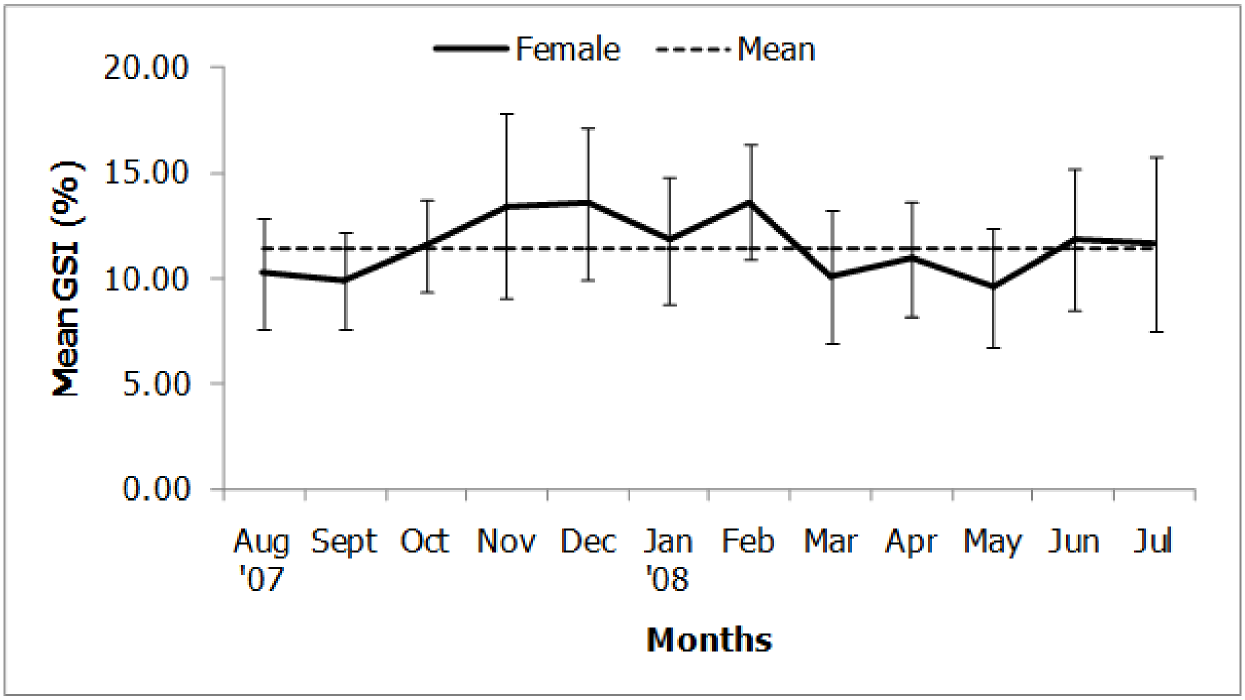

Figure 7. The Gonadosomatic Index (GSI) of female *P. undulata* collected from Hinigaran, Binalbagan, and Himamaylan, Negros Occidental from August 2007 to July 2008.

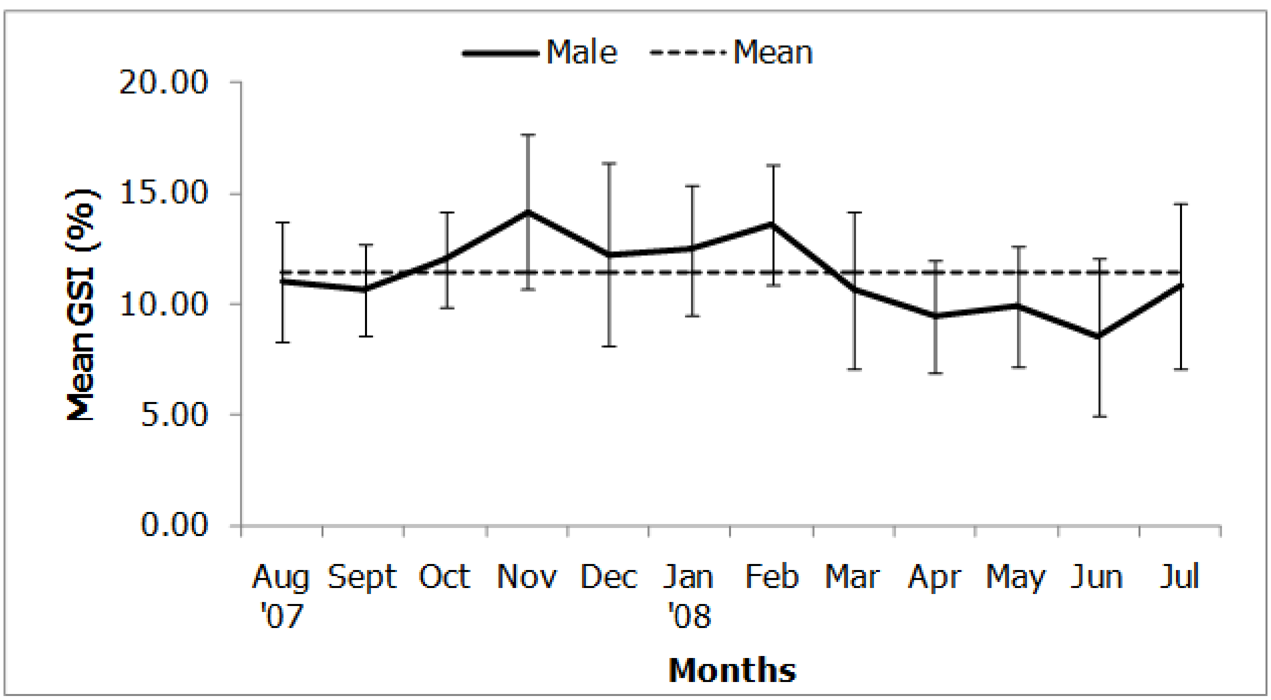

Figure 8. The Gonadosomatic Index (GSI) of female *P. undulata* collected from Hinigaran, Binalbagan, and Himamaylan, Negros Occidental from August 2007 to July 2008.

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