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REPRODUCTIVE BIOLOGY AND SIZE AT SEXUAL MATURITY OF *PENAEUS MERGUIENSIS* (DE MAN, 1887) FROM THE SONMIANI BAY LAGOON, BALOCHISTAN, PAKISTAN

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ABSTRACT

The study investigates the vital aspects of reproductive biology: maturation stages of ovaries, spawning season and size at sexual maturity of *Penaeus merguiensis*. The sampling of *Penaeus merguiensis* De man, 1887 was conducted from the coastal waters of Pakistan during the period July 2006 to June 2007, from the Damb Bunder, Sonmiani Bay Lagoon locally known as Miani Hor (25° 27' N/ 66° 33' E). Five maturation stages were recognized by the variations in colour as well as development and arrangements of cells. These stages were designated as undeveloped, developing, nearly ripe, ripe and spent. The data show *P. merguiensis* spawn throughout the year with 2 or 3 peaks being different in different years. The peak spawning activity was observed in NE monsoon and pre monsoon. The results of one way ANOVA showed significant differences for ovarian developmental stages (colouration) and morphological parameters. The size at onset of sexual maturity at when fifty percent of the population was morphologically mature was estimated as (TL_{50} =15.50 cm), and can be significantly utilized in fisheries management as an indicator for minimum permissible capture size.

Keywords: Reproductive biology, penaeid shrimps, maturation stages, fisheries management, size at maturity.

INTRODUCTION

Penaeus merguiensis (de man, 1887) is one of the valuable commercial penaeid shrimp species found in the coastal waters of Pakistan. It comprises the bulk of the penaeid shrimp fisheries in the Pakistan that occur over mud or sand bottoms in shallow coastal areas. Like other penaeid shrimp, the process of reproduction occurs as a series of events from activation, through growth and gametogenesis in the gonads to the spawning of the gametes and recession of gonadal activity. Histological analysis has been widely used to describe ovarian maturation stages (Medina *et al.*, 1996; Quintero and Garcia, 1998; Ayub and Ahmed, 2002; Peixoto *et al.*, 2003; Amanat and Qureshi, 2011). The observation of visual traits, such as ovarian morphology and colour has been studied to evaluate female maturation (Castille and Lawrence, 1989; Ayub and Ahmed, 1992; Jayawardane *et al.*, 2003; Amanat and Qureshi, 2011). The spawning seasons of penaeid shrimps have been determined, by the percentage of mature females present in the catch or by changes in gonadal indices (Garcia, 1985; Minagawa *et al*., 2000; Crocos *et al*., 2001; Costa and Fransozo, 2004; Aragon-Noriega and Garcia-Juarez, 2007; Abrehouch *et al*., 2009; Nurul Amin *et al.*, 2010; Kumlu *et al.*, 2011; de Croos *et al*., 2011; Amanat and Qureshi, 2011; Erisman *et al.*, 2012). Two spawning periods have been reported in tropical penaeids. The female reach first maturity at about 6 months and reach second maturity at about 12 months, which means shrimp, may live for about 18 months (Dall *et al*., 1990; Staples and Rothlisberg, 1990). Variations in the length-weight relationship with sexes, species, seasons and sites have been reported for both wild and cultured populations of penaeid shrimps (Primavera *et al.*, 1998; Abowei, 2009; Nahavandi *et al.*, 2010; Deekae and Abowei, 2010; Oliveira Freitas *et al.*, 2011).

In Pakistan, Zupanovic (1971) determined the gonadal maturity of Pakistani penaeid shrimps and described their spawning seasons. Various authors also discussed the spawning seasons (Ahmed, 1980; Van Zalinge *et al*., 1987) and maturation (Sultana, 1985) of penaeid shrimps from Pakistani coastal waters. Hassan (1983) studied the extent of spawning seasons of penaeid shrimps on the basis of the abundance of their eggs and larvae. Ayub and Ahmed (1992, 2002) studied coloration and histology of ovaries and maturation and spawning penaeid shrimps (*P. penicillatus, P. merguiensis, M. affinis* and *Pp. stylifera*) from Karachi coastal areas. Amanat and Qureshi (2011) studied coloration and histology to examine ovarian maturation stages of *P. indicus* from Sonmiani Bay Lagoon, Balochistan. In present study, the maturation stages of female *P. merguiensis*, their spawning seasons, size at first maturity and length weight relationship are studied from Sonmiani Bay Lagoon, Balochistan, Pakistan.

MATERIALS AND METHODS

Study site: The length of Pakistan coast is about 990 km, consists of 320 km that falls in the province of Sindh and approximately 670 km that lies in the province of Balochistan, and Exclusive Economic Zone (EEZ) about 240,000 square km (Snead, 1985). The Sonmiani Bay or Miani Hor (25° 27' N/ 66° 33' E) is 95 km from Karachi has very arid climate with less than 200 mm of rain per year (Rasool *et al*., 2002).

Sampling methodology: A total of 1270 shrimps (429 immature females, 446 mature females and 395 males) were collected for the present study. The shrimps were procured from the local mole holders (middle man) ice fishery landings during the period of July, 2006 to June, 2007. The procured shrimp samples were sorted, sexed and identified (Tirmizi and Bashir, 1973; Bianchi, 1985). The ovaries of females of *P. merguiensis* were dissected out and colours of ovaries were noted, and then were fixed in Bouin's solution for 48 hours for histological studies (Amanat and Qureshi, 2011). Morphometric measurements as total length (TL), carapace length (CL), rostral length (RL), telson length (Ts.L) and body weight (wt) were measured to the nearest 0.1 cm. The females of *P. merguiensis* were considered as immature females as: I (undeveloped), II (developing) stages, III (nearly ripe), IV (ripe) and V (spent) stages of ovaries maturation on the basis of colouration. The percentages of nearly ripe, ripe and spent stages females of *P. merguiensis* caught were calculated and recorded to estimate the spawning season. During this study, undeveloped (I) and developing (II) stages females were grouped as immature females and nearly ripe (III), ripe (IV) and spent (V) were grouped as mature females. The spawning period was defined as the months in which the percentages of nearly ripe, ripe and spent ovaries were high (Amanat and Qureshi, 2011). Monthly data were grouped in seasons following Morrison *et al.* (1998) as NE monsoon season (Nov. to Jan.), pre monsoon (Feb. to Apr.), SW monsoon (May to Jul.) and post monsoon (Aug. to Oct.) to observe the seasonal pattern and variability in ovarian maturation stages. The size at first maturity (SFM) was determined by calculating the proportion of mature females (nearly ripe III, ripe IV and spent stage V) in each size class (Total length, TL). The size at which 50% of the individuals attain sexual maturity TL_{50} was estimated by fitting data to the least squares regression method (Bretini *et al*., 2007; Amanat and Qureshi, 2011; Saher and Qureshi, 2011).

Statistical analysis: One way analysis of variance (ANOVA) with nested treatment arrangement were carried out using the statistical package Minitab (Version 11.12) for differences in ovarian developmental stages (colouration), and morphological characters. The relative growth was studied for total length (TL) as independent variable, and body weight (Wt). Test of significance were accepted as significant at alpha = < 0.05 for statistical analysis. The constant of allometry "b = 3" was determined for each parameter by using power function $Y = ax^b$ and the equations were linearized by logarithmic transformation. A value b > 3 indicates positive allometry i.e., the growth is faster than TL, and a value b < 3 indicates negative allometry, indicating slow growth (Peixoto *et al*., 2004).

RESULTS AND DISCUSSION

Ovarian maturation: The reproductive biology of *P. merguiensis* was studied by correlating the macroscopic and microscopic characteristics and the gonadal developmental stages. The five ovarian maturation stages were recognized from clear pattern and variations in colour, as well as development and arrangements of cells. These stages were designated as undeveloped (translucent), developing (yellow), nearly ripe (light green), ripe (green) and spent (white/creamy). The present study showed that oogonia cells found throughout the ovarian development though they were predominated in the undeveloped and spent stages. In the undeveloped stage, oogonia were found as clustered in a well-defined area of the ovarian wall along the gonad, known as the "zone of proliferation" (Fig. 1a). This type of ovary was found in only young and immature shrimps. Whereas yolkless oocytes (YO_1) cells without nuclear membrane were observed during the developing (Fig. 1b) and nearly ripe (Fig. 1c) developmental stages with small number of oogonia and yolky oocytes cells with clear nuclear membrane were found in nearly ripe and well organized in the ripe stage (Fig. 1d). This stage was believed to be the last stage of maturity before spawning. Ripe ovaries were characterized by the presence of fully mature oocytes. A typical distinctive feature of this stage was the cytoplasm of mature oocytes shows conspicuous cortical rod at the cell periphery. After spawning the ovary was designated as spent, it was observed that ovarian organization disappears, leaving holes left by the released oocytes, as well as remains of disintegrating mature oocytes (Fig. 1e). Similarly, Sultana (1985) recognized the five developmental stages of ovaries in penaeid shrimps from the Pakistani coastal waters, based on the colour, size of the ovary and histological studies. Other studies related to ovarian histology in *P. merguiensis* from Gulf of Carpentaria, Australia suggested five ovarian developmental stages: quiescent, developing, early maturity, ripe and spent (Tuma, 1967) and immature, developing, early ripe, ripe and spent (Crocos and Kerr, 1983).

Earlier Van Zalinge *et al.* (1987) categorized the four stages (immature, maturing, mature and spent) of development in *P. merguiensis* and *M. affinis*. Ayub and Ahmed (1992) described four developmental stages

(undeveloped, developing, nearly ripe and fully ripe) of female gonads in *P. penicillatus*, *P. merguiensis* and *M. affinis* based on the colouration of ovaries. Later, Ayub and Ahmed (2002) reported six developmental stages (undeveloped, developing, nearly ripe, fully ripe and resorbing and resorbing/developing) on the basis of ovarian histology in the *P. penicillatus*, *P. merguiensis*, *M. affinis* and *Pp. stylifera*. Amanat and Qureshi (2011) reported the five developmental stages (undeveloped, developing, nearly ripe, ripe and spent) in *P. indicus.*

Relationship between Ovarian developmental stages and weight and size variations: Ovarian maturation shows size variations of different body parts (total length (TL), carapace length (CL), rostral length (RL), telson length (Ts.L)) of penaeid shrimps (Table 1). The monthly distribution of size-frequency (TL cm) of immature and mature females show immature females were found in June to September (Fig. 2). The results of one way ANOVA for *P. merguiensis* showed the significant difference for ovarian developmental stages with total length ($F = 24.02$, $P < 0.005$), carapace length ($F = 20.91$, $P < 0.005$), rostral length ($F = 2.32$, $P < 0.005$) and telson length ($F = 4.93$, $P < 0.05$).

Spawning Season: The monthly distribution of ovarian maturation stages in *P. merguiensis* showed the ripe and nearly ripe ovaries were observed throughout the year except in the months of November and May (Fig. 3), whereas the highest numbers of spent ovaries were found in November and May. The highest numbers of developing ovaries were found in July and April. Seasonal distribution showed that the mature ovaries, nearly ripe, ripe and spent (light green, dark green or creamy), were observed during the NE monsoon and pre monsoon seasons (Table 2). The stages of nearly ripe, ripe and spent were shown combined as females either just ready to spawn, spawning or just spawned versus non spawning females (Table 2). The mature females of *P. merguiensis* were observed throughout the study period, indicating the continuous spawning activity with peaks during the NE monsoon and Pre monsoon seasons.

The spawning periods of penaeid shrimps from the northeastern Arabian Sea have been studied for *M. affinis* (Subrahmanyam, 1967; Rao, 1968; Ramamurthy *et al.*, 1975), *P. indicus* (Rao, 1968; Amanat and Qureshi, 2011), *Pp. stylifera* (Mohammad, 1967; Rao, 1968). In general, spawning activity varied seasonally showing a bimodal pattern. Zupanovic (1971) reported the spawning seasons of *P. merguiensis* from December to April with peak in January and February. Van Zalinge *et al.* (1987) studied spawning activity of *P. merguiensis* throughout the year with peak spawning activity in April to May and August. Ayub and Ahmed (1992), observed two peaks of spawning major and minor peaks found in *P. merguiensis* from January to April and October. A seasonal and double peak pattern of reproductive activity appears to be typical for penaeid shrimps. These peaks usually occur during the transition period which separates the cold and the warm seasons (Garcia, 1985). Along the coastal areas of Pakistan, Hassan (1983) studied the spawning season of penaeid shrimps in the local waters on the basis of the abundance of penaeid eggs and larvae. He suggested *Penaeus* species spawns in winter, spring and late summer, which agrees with present study.

Mean Size at Maturity: The study of mean length, or age, at which shrimps spawn and recruitment occurs are important for fisheries management, particularly the cycle of events leading to reproduction and the timing of gamete release (Niamaimandi *et al*., 2008). In the present study, *P. merguiensis* was grouped into size classes (3 cm class interval) and the percentage occurrence in various stages of maturity in these groups was estimated. A total of 875 specimens of female *P. merguiensis* were studied during the study period, their size ranged from 7.1 to 27.0 cm. Females with immature ovaries had a total length of 11.1 to 11.3 cm. The mature individuals were found to have total length of 13.1 and above. In the size class, 13.1 to 15.0 cm the percentage of immature individuals was more than the mature ones, and majority attained maturity at about 15.1 to 17.0 cm size. The size at first maturity appears to be near about 13.1 cm total length (Table 3); however, the size at which L_{50} of the population was morphologically mature and the estimated size at onset of sexual maturity was 15.50 cm (Fig. 4). Earlier workers have also studied the size at first sexual maturity in penaeid shrimps and their observations are comparable to the study at hand. The size for first maturity was reported in *P. indicus* as 134 mm, *M. affinis* as 94 mm and *Pp. stylifera* as 70 mm by Rao (1968), in *P. indicus* as 130 mm by George *et al.* (1968), in *M. affinis* as 120 mm by Subrahmanyam (1967), in *P. semisulcatus* as 126 mm and *M. stebbingi* as 88 mm by Abdel Razek (1985), in *P. semisulcatus* as 15.7 cm by King (1995). The size of target species at maturity can be reduced due to fishing pressure.

Total length and body weight relationship: The total body length can be used to determine functional relationship between size and weight of penaeid shrimps. The total body length has been generally considered an independent variable in penaeid morphometric studies because it shows physiological changes throughout a shrimp's life history. In the present study, the linear and log transformed regression equations for mature females, immature females and males were presented in Table 4. The regression showed higher value of the slope 'b' for the mature females ($t = 24.8$; $P < 0.005$) as compared to immature females ($t = 21.8$; $P < 0.005$) and males ($t = 31.5$; $P < 0.005$) showed positive allometry (Table 4; Fig. 5). Sex based size dimorphism in penaeid with larger *paulensis* (Peixoto *et al.*, 2003). Despite the great sizes and faster growth rates in females as compared to males

Table 1. Descriptive studies of ovarian-developmental stages of *Penaeus merguiensis* from Sonmiani bay, Balochistan from July 2006 to June 2007 (SD = Standard Deviation; M = Mean).

Variables	N	Wet Weight (gm)		Total Length (cm)		Carapace Length (cm)		Rostral Length (cm)		Telson Length (cm)	
		Range	M±SD	Range	M±SD	Range	M±SD	Range	M±SD	Range	M±SD
Undeveloped	196	6.2-59.9	18.73±11.3	7.9-20.3	14.06±2.3	3.0-7.8	5.06±0.8	1.9-3.7	2.46±1.1	1.1-2.6	1.54±0.3
Developing	233	6.3-74.5	23.65±15.5	11.3-20.8	15.01±2.6	3.0-7.6	5.33±1.0	2.1-6.2	2.62±1.2	1.2-2.8	1.60±0.5
Nearly Ripe	124	12.0-79.8	27.08±16.9	12.7-24.1	16.01±3.1	4.4-8.2	5.67±0.9	2.6-4.2	2.81±1.0	1.4-2.7	1.71±0.5
Ripe	166	13.9-109.3	40.53±20.8	13.7-26.6	18.08±2.8	4.5-8.6	6.30±0.9	2.6-4.1	2.90±1.2	1.5-3.2	1.88±0.7
Spent	156	6.3-74.5	23.65±15.5	11.3-20.8	15.01±2.6	1.0-7.6	5.33±3.0	2.6-6.2	2.62±1.2	1.4-2.8	1.60±0.5

Table 2. Monthly and seasonal percent distribution of spawning and non spawning periods of *Penaeus merguiensis* data collected from the Sonmiani Bay lagoon, Balochistan during the study period.

S. No	Months	Season	Spawning (%)	Non spawning (%)
1	Jul. 06	SW	31.5	68.4
2	Aug. 06	Post	50.0	50.0
3	Sep. 06	Post	45.2	54.7
4	Oct. 06	Post	73.3	26.6
5	Nov. 06	NE	66.6	33.3
6	Dec. 06	NE	80.0	20.0
7	Jan. 07	NE	66.6	33.3
8	Feb. 07	Pre	78.9	21.0
9	Mar. 07	Pre	80.0	20.0
10	Apr. 07	Pre	33.3	66.6
11	May. 07	SW	57.8	42.1
12	Jun. 07	SW	20.6	79.3

Table 3. Percentage occurrence of female of *Penaeus merguiensis* in different stages of maturity in the various size groups data collected from the study area from July 2006 to June 2007.

Class Size	No	I	II	III	IV	V
7.1-9.0	20	100.0	-	-	-	-
9.1-11.0	21	100.0	-	-	-	-
11.1-13.0	102	47.0	52.9	-	-	-
13.1-15.0	312	23.0	39.1	23.0	8.9	5.7
15.1-17.0	134	17.9	17.9	17.9	26.8	19.4
17.1-19.0	98	4.0	20.4	20.4	32.6	22.4
19.1-21.0	116	6.8	22.4	17.2	36.2	17.2
21.1-23.0	48	-	-	20.8	41.6	37.5
23.1-25.0	14	-	-	66.6	33.3	-
25.1-27.0	10	-	-	-	100.0	-

has been documented for, *P. indicus* (Devi, 1986), *P. vannamei* (Chow and Sandifer, 1991), and *M. endeavouri* (Buckworth, 1992). Bigger female size may be due to a greater weight increase per moult cycle leading to a faster growth rate (Hansford and Hewitt, 1994). It was observed mature females are usually heavier than immature females of the same body length and carapace length. Increase in female size during maturation has been documented in *P. merguiensis* (Crocos and Kerr, 1983), *P. longistylus, P. latisulcatus* (Courtney and Dredge, 1988), and *M. affinis, M. ensis, M. joyneri, Pp. hungerfordi* (Chu *et al*., 1995). The higher weight of mature female is likely due to the additional weight of the ovaries, which has been reported to constitute up to 13% of the total body weight in wild *F.* economic value of shrimps in Pakistan, the information on the biology of

penaeid shrimps occurring in Pakistan especially from the coastal areas of Balochistan is scarce. The present study is designed with the aim to determine the maturation of ovaries of female penaeid shrimp and spawning seasons correlated with the vital aspects of morphometric and reproductive biology of *P. merguiensis*, commonly occurring shrimp in Sonmiani Bay Lagoon. This study can help fisheries management especially to develop regulations for the small scale seine fishery in Pakistan.

Table 4. Summary of linear regression and log transformed regression analysis of *Penaeus merguiensis.*

Y-variable	Sex	Regression equation	R^2	S.E	t-test	P	Allometry
TL vs. Wt	Immature	Wt = - 53.2 + 5.12 TL	0.870	0.98	21.8	<0.005	+ve
	female	log Wt = - 2.28 + 3.06 log TL	0.876				
	Mature	Wt = - 83.6 + 6.95 TL	0.926	1.44	24.8	<0.005	+ve
	female	log Wt = - 2.64 + 3.36 log TL	0.946				
	Male	Wt = - 42.2 + 4.24 TL	0.922	0.62	31.5	<0.005	+ve
		log Wt = - 2.43 + 3.17 log TL	0.873				

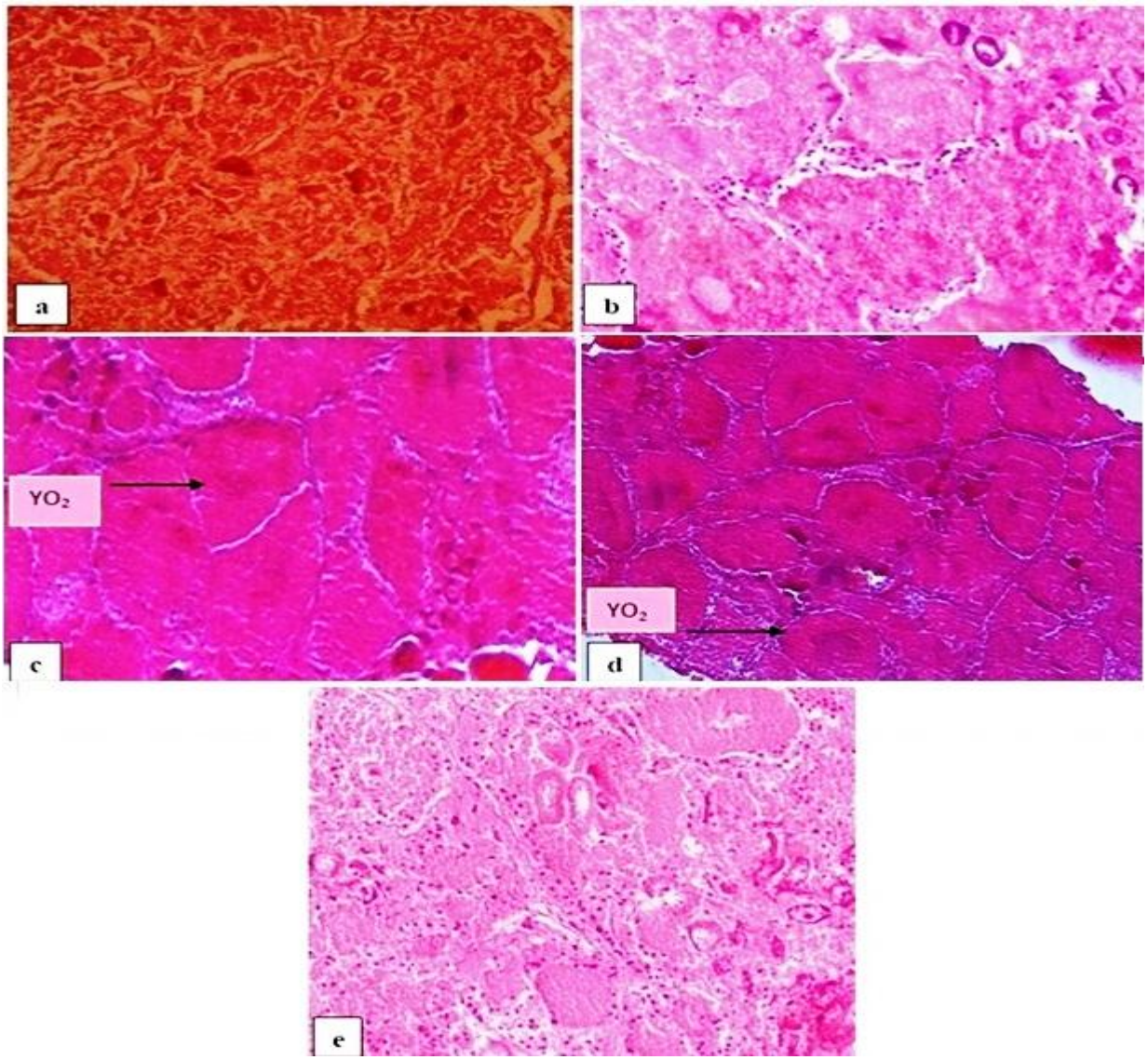

Figure 1. Histological section of different stages of ovarian maturation of *Penaeus merguiensis* (a) Undeveloped stage (b) Developing stage (c) Nearly Ripe stage (d) Ripe stage (e) Spent stage. (ZP = zone of proliferation, O = oogonia, YO_1 = yolkless oocytes, YO_2 = yolky oocytes).

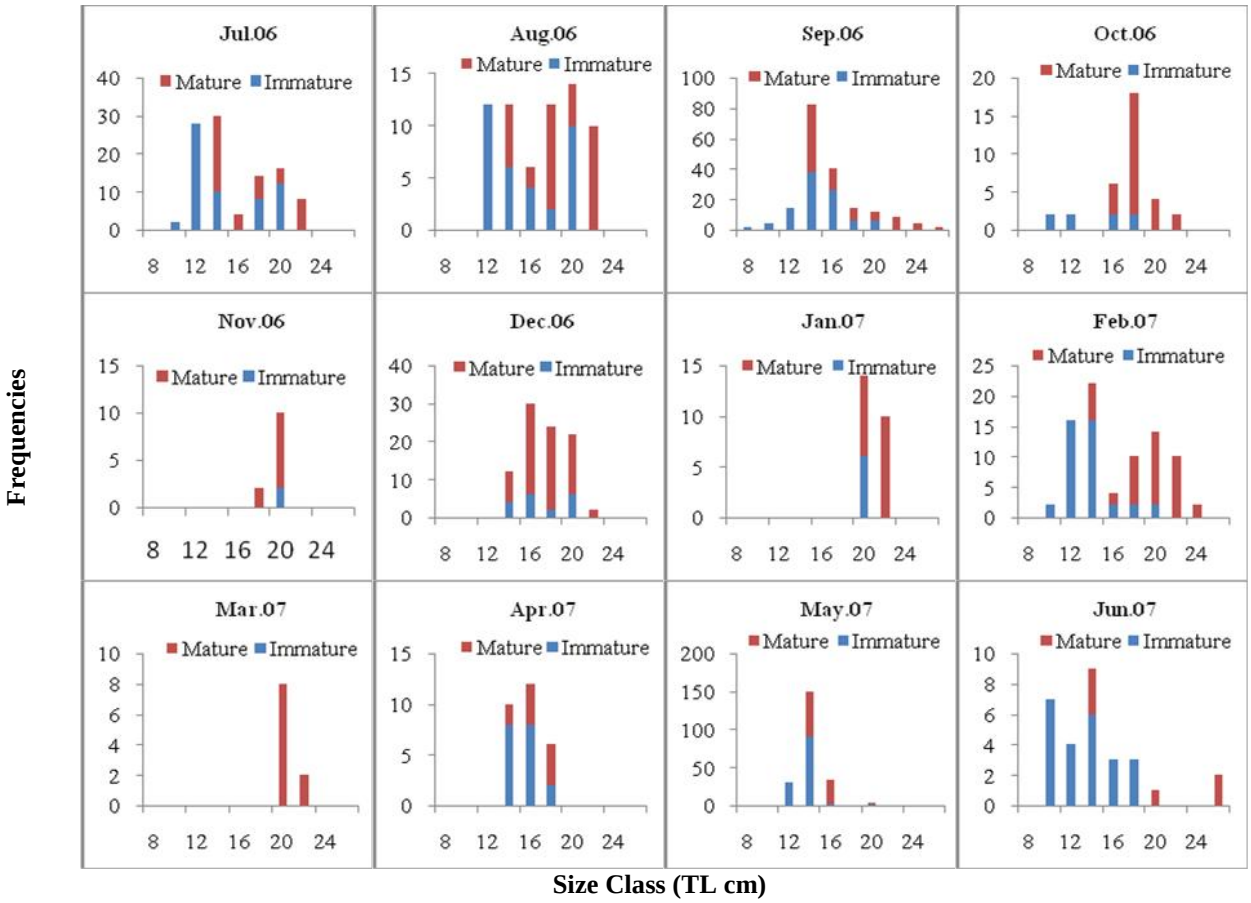

Figure 2. Size-frequency diagram of mature and immature females of *Penaeus merguiensis*.

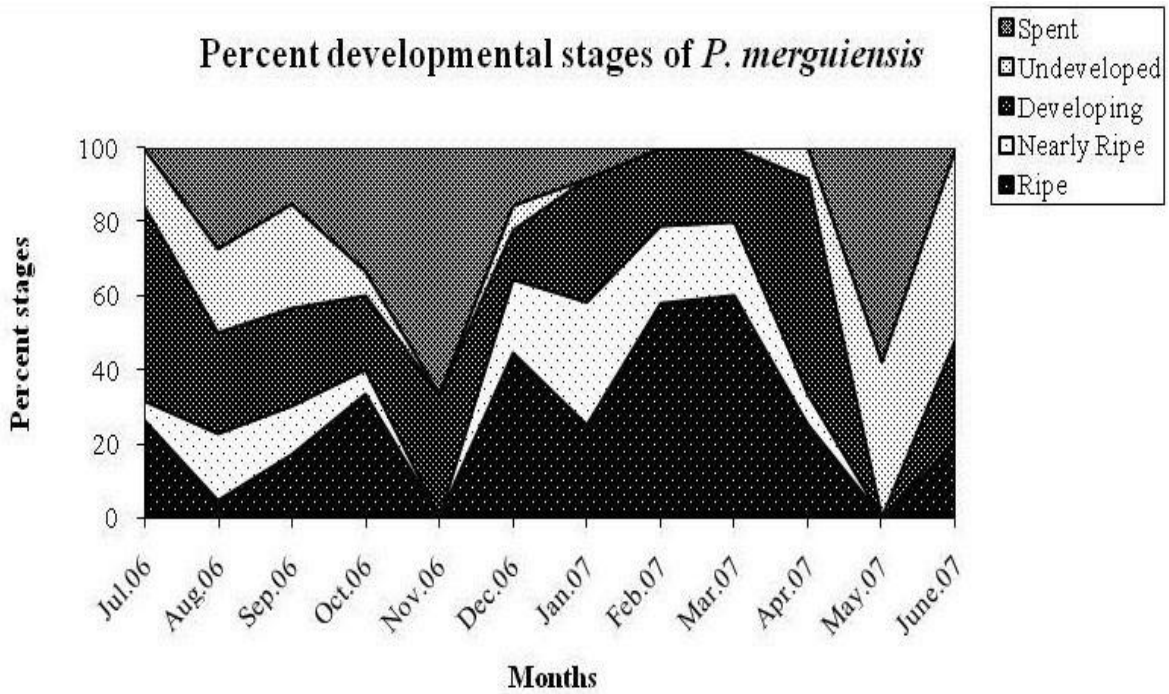

Figure 3. Monthly percent distribution of five ovarian developmental stages of *Penaeus merguiensis* from the Sonmiani Bay, Balochistan from July 2006 to June 2007.

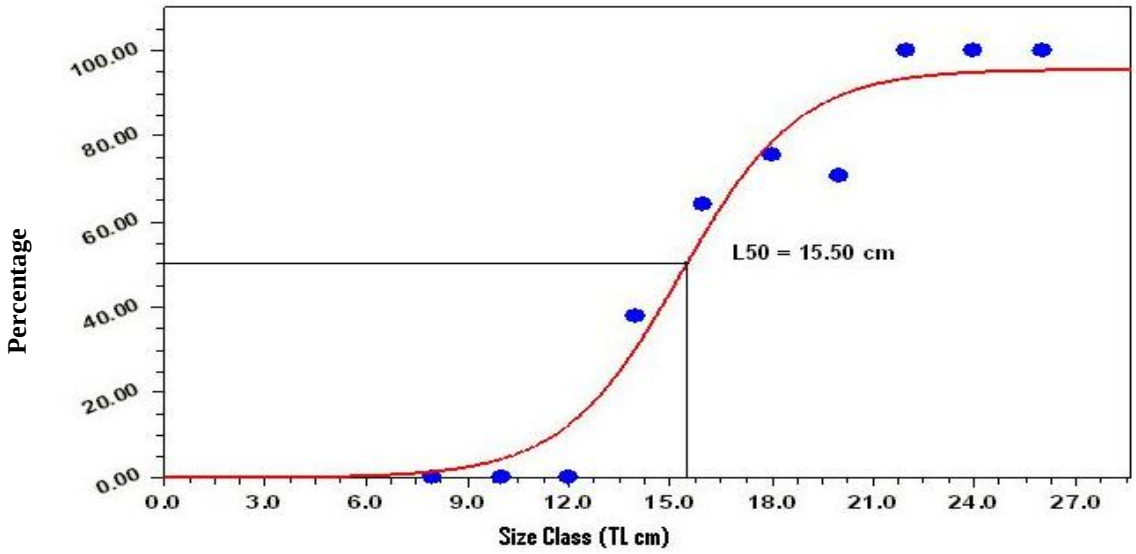

Figure 4. Sigmoid model for *Penaeus merguiensis* from the Sonmiani Bay Lagoon Balochistan, from July 2006 to June 2007.

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REFERENCES

Abdel Razek, F.A. (1985). Contribution to the biology of penaeid prawns of the Mediterranean coast of Egypt. J. Egypt. Vet. Med. Ass. 45: 17-28.

Abowei, J.F.N. (2009). The abundance, condition factor and lenght - weight relationship of *Cynoglossus senegalensis* (Kaup, 1858) from Nkoro River Niger Delta, Nigeria. Adv. J. Food Sci. Technol. 1: 56-61.

Abrehouch, A., M. Idaomar, A.A. Ali, H. Nhhala, and E.M. Talbaoui (2009). Broodstock feeding effects on spawning performances'(fertility, eggs and larvae quality) of the Mediterranean red porgy (*Pagrus pagrus*, Linnaeus 1758) during two years. African J. Food Sci. 3: 193-200.

Ahmed, M. (1980). The breeding and recruitment of marine animals of the coast of Pakistan bordering the Arabian Sea. Proc. 1st Pakistan Cong. Zool. Pp. 55-96.

Amanat, Z. and N.A. Qureshi (2011). Ovarian maturation stages and size at sexual maturity of Peneaus indicus (H. Milne Edwards, 1937) in the lagoon waters of Sonmiani Bay, Balochistan. Pakistan J. Zool. 43: 447-459.

Aragon-Noriega, E.A. and A.R. Garcia-Juarez (2007). Comparison of two methods to determine the maturity period in penaeid shrimps (Decapoda, Penaeidae). Crustaceana. 80: 513-521.

Ayub, Z. and M. Ahmed (1992). Maturation and spawning of some Penaeid shrimps of Pakistan (Arabian Sea). Mar. Res. 1: 29-35.

Ayub, Z. and M. Ahmed (2002). A description of the ovarian development stages in penaeid shrimps from the coast of Pakistan. Aquacul. Res. 33: 767-776.

Bertini, G., A.A. Braga, A. Fransozo, M.O. Dias, A. Correa, and F.A.M. Freire (2007). Relative growth and sexual maturity of the stone crab *Menippe nodifrons* Stimpson, 1859 (Brachyura, Xanthoidea) in Southeastern Brazil. Brazilian Arch. Bio. Tech. 50: 259-267.

Bianchi, G. (1985). Field guide to the commercial marine and brackish-water species of Tanzania. Prepared and published with the support of TCP/URT/4406 and FAO (FIRM) Regular program. FAO, Rome. Pp. 231.

Buckworth, R.C. (1992). Movements and growth of tagged blue endeavour prawns, Metapenaeus endeavouri (Schmii, 1926), in the western Gulf of Carpentaria Australia. Aust. J. Mar. Fresh. Res. 43: 1283-1299.

Castille, F.L. and A.L. Lawrence (1989). Relationship between maturation and biochemical composition of the gonads and digestive glands of the shrimps *Peneaus aztecus* and *Peneaus setiferus.* J. Crust. Biol. 9: 202-211.

Chow, S. and P.A. Sandifer (1991). Differences in growth, morphometric traits, and mail sexual

maturity among pacific white shrimp, *Penaeus vannamei*, from different commercial hatcheries. Aquacul. 165-179.

Chu, K.H., Q.C. Chen, L.M. Huang, and C.K. Wong (1995). Morphometric analysis of commercially important penaeid shrimps from the Zhujiang estuary, China. Fish. Res. 23: 83-93.

Costa, R.C. and A. Fransozo (2004). Reproductive biology of the shrimp *Rimapenaeus constrictus* (Decapoda: Penaeidae) in the Ubatuba region of Brazil. J. Crust. Biol. 24: 274-281.

Courtney, A.J. and M.C.L. Dredge (1988). Female reproductive biology and spawning periodicity of two species of king prawns. *Penaeus longistylus* Kubo and *Penaeus latisulcatus* Kishinouye, from Queensland's east coast fishery. Aust. J. Mar. Fresh. Res. 39: 729-741.

Crocos, P.J. and J.D. Kerr (1983). Maturation and spawning of the banana prawn *Penaeus merguiensis* in Albatross Bay, Gulf of Carpentaria, Australia. J. Exp. Mar. Biol. Ecol. 69: 37-59.

Crocos, P.J., Y.C. Park, D.J. Die, K. Warburton, and F. Manson (2001). Reproductive dynamics of endeavour prawns, *Metapenaeus endeavouri* and *M. ensis*, in Albatross Bay, Gulf of Carpentaria. *Australia*. Mar. Biol. 138: 63-75.

Dall, W., B.J. Hill, P.C. Rothlisberg, and D.J. Staples (1990). The biology of the Penaeidae. In: Blaxter, J. H. S., Southward, A. J. (Eds.). Advances in Marine Biology. 27. Academic press, London.

de Croos, M.D.S.T., S. Pálsson, and R.M.G.N. Thilakarathna (2011). Sex ratios, sexual maturity, fecundity, and spawning seasonality of *Metapenaeus dobsoni* off the western coastal waters of Sri Lanka. Invertebrate Rep. Develop.55: 110-123.

Deekae, S.N. and J.F.N. Abowei (2010). Macrobrachium Macrobrachion (Herklots, 1851) Length-Weight Relationship and Fulton's Condition Factor in Luubara creek, Ogoni Land, Niger Delta, Nigeria. Inter. J. Ani. Vet. Adv. 2: 155-162.

Devi, S.L. (1986). Growth and population dynamics of the Indian white prawn, Penaeus indicus H. M. Edwards, from Kakinada. Proc. I. Acad. Sci. 95: 629-639.

Erisman, B., O. Aburto-Oropeza, C. Gonzalez-Abraham, I. Mascareñas-Osorio, M. Moreno-Báez, and P.A. Hastings (2012). Spatio-temporal dynamics of a fish spawning aggregation and its fishery in the Gulf of California. *Scientific Reports* 2, Article number: 284.

Garcia, S. (1985). Reproduction, stock assessment models and population parameters in exploited penaeid shrimp populations. In: Rothlisberg, P. C., Hill, B. J., Staples, D. J. (Eds.). Second Australian Natl. prawn Seminar, NPS2, Cleveland, Australia. Pp. 139-158.

George, M. J., K. Raman, and P. K. Nair (1968). Observation on the off shore prawn fishery of Cochin. Indian J. Fish. 10: 460-499.

Hansford, S.W. and D.R. Hewitt (1994). Growth and nutrient digestibility by male and female Penaeus monodon: Evidence of sexual dimorphism. Aquacul. 125: 147-154.

Hassan, H. (1983). Distribution of penaeid larvae in the coastal waters of Pakistan. Ph. D. Thesis, University of Karachi, Pakistan.

Jayawardane, P.A.A.T., D.S. Mclusky, and P. Tytler (2003). Reproductive biology of *Metapenaeus dobsoni* (Miers, 1878) from the western coastal waters of Sri Lanka. Asian Fish. Sci. 16: 91-106.

King, J. E. (1995). Fisheries biology assessment and management. Blackwell Science Ltd. (Fishing News Books). Oseny Mead, Oxford. Pp.341.

Kumlu, M.T., S. R. Türkmen, M. Kumlu, O. T. Eroldoğan, (2011). Off-season maturation and spawning of the Pacific White Shrimp *Litopenaeus vannamei* in sub-tropical conditions. Turkish J. Fish. Aq. Sci. 11: 15-23.

Medina, A., Y. Vila, G. Mourente, and A. Rodriguez (1996). A comparative study of the ovarian development in wild and pond-reared shrimp, *Penaeus kerathurus* (Forskal, 1775). Aquacul. 148: 63-75.

Minagawa, M., S. Yasumoto, T. Ariyoshi, T. Umemoto, and T. Ueda (2000). Interannual, seasonal, local and body size variations in reproduction of the prawn *Penaeus (Marsupenaeus) japonicus* (Crustacea: Decapoda: Penaeidae) in the Ariake Sea and Tachibana Bay, Japan. Mar. Biol. 136: 223-231.

Mohammad, K.H. (1967). Penaeid prawns of the commercial shrimp fisheries of Bombay with notes on species and size fluctuations. Proceeding Symposium Crustacea. Mar. Biol. Ass. India. 4: 1408-1418.

Morrison, J.M., L.A. Codispoti, S. Gaurin, B. Jones, V. Manghnani, and Z. Zheng (1998). Seasonal variation of hydrographic and nutrient fields during the US JGOFS Arabian Sea process study. *Deep-Sea Research II*. 45: 2053-2101.

Nahavandi, R., S.M. Nurul Amin, M.S. Zakaria, and M.N. Shamsudin (2010). Growth and Length-Weight Relationship of *Penaeus monodon* (Fabricius) Cultured in Artificial Sea Water. Res. J. Fish. Hydro. 5: 52-55.

Niamaimandi, N., A. Arshad, S. K. Daud, C. R. Saed, and K. Bahram, (2008). Reproductive biology of the green tiger prawn (*Penaeus semisulcatus*) in

coastal waters of Bushehr, Persian Gulf. ICES J. Mar. Sci. Adv. Access. 1-7.

Nurul Amin, S.M., A. Arshad, S.S. Siraj, and S.B. Japar (2010). Reproductive seasonality and maturation of the sergestid shrimp, *Acetes japonicus* (Decapoda: *Sergestidae*) in coastal waters of Malacca, Peninsular Malaysia. African J. Biotech. 9: 7747-7752.

Oliveira Freitas, M., S. Machado Vasconcelos, M. Hostim-Silva, and H.L. Spach (2011). Length–weight relationships for fishes caught by shrimp trawl in Santa Catarina coast, south Atlantic, Brazil. J. App. Ichthy. 27: 1427–1428.

Peixoto, S., R. Soares, W. Wasielesky, R.O. Cavalli, and L. Jensen (2004). Morphometric relationship of weight and length of cultured *Farfantepenaeus paulensis* during nursery, grow out, and brood stock production phases. Aquacul. 241: 291-299.

Peixoto, S., R.O. Cavalli, F.D. Incao, A.M. Milach, and W. Wasielesky (2003). A comparative study of the ovarian histology of eyestalk ablation and unablated *Farfantepenaeus paulensis* after spawning. Boletim do Instituto de Sao Paulo. 28: 71-76.

Primavera, J.H. (1980). Sugpo (*Penaeus monodon*) broodstock. Aqua Guide Series No. 1. Aquaculture Department, SEAFDEC. Iloilo, Philippines.

Quintero, M.E.S. and A. Garcia (1998). Stages of gonadal development in the spotted pink shrimp *Penaeus brasiliensis*. J. Crust. Biol. 18: 680-685.

Ramamurthy, S., N.S. Kurup, and G.G. Annigeri (1975). Studies on the fishery of the penaeid prawn *Metapenaeus affinis* (Milne Edwards) along the Mangalore Coast. Indian J. Fish. 22: 243-254.

Rao, P.V. (1968). Maturation and spawning of the penaeid prawns of the southwest coast of India. FAO Fish. Rep. 57: 285-302.

Rasool, F., S. Tunio, S.A. Hasnian, and E. Ahmad (2002). Mangrove conservation along the coast of Sonmiani, Balochistan, Pakistan. Trees, Structure and Function. 16: 213-217.

Saher, N.U. and N.A. Qureshi (2011). Relative growth and morphological sexual maturity of *Ilyoplax frater* (Brachyura: Ocypodoidea: Dotillidae) from mangrove area of Korangi creek. Pakistan J. Zool. 43: 133-140.

Snead, R.E. (1985). Pakistan. In Bird, E. C. and M. L. Schwartz (eds.). The world's coastline. Von Nostrand Reinhold Company, New York, 735-740.

Staples, D.J. and P.C. Rothlisberg (1990). Recruitment of penaeid prawns in the Indo-Pacific. Proc. 2nd Asian Fish. Forum. Asian Fisheries Society, Tokyo. Japan.

Subrahmanyam, C.B. (1967). Notes on the bionomics of the penaeid prawn *Metapenaeus affinis* (Milne Edwards) of the Malabar Coast. Indian J. Fish. 10: 11-22.

Sultana, R. (1985). A comparative study of reproductive organ of selected penaeid prawns of Pakistan. M-Phil thesis, University of Karachi.

Tirmizi, N.M. and Q. Bashir (1973). Shore and off-shore penaeid prawns of northern Arabian Sea. Publication Department, University of Karachi, Pakistan.

Tuma, D.J. (1967). A description of the development of primary and secondary sexual characters in the banana prawns. *Penaeus merguiensis* De Man (Crustacea: Decapoda: Penaeinae). Aust. J. Mar. Fresh. Res. 18: 73-88.

Van Zalinge, N.P., M. Khaliluddin, and W. Khan (1987). Description of the shrimp fishery including a stratified sampling scheme for shrimps landings and effort at Karachi Fish Harbour. FAO, FI: DP/PAK/77/033 Field Documen.

Zupanovic, S. (1971). Shrimp explorations off the coast of West Pakistan. FAO Report, Pp. 88. Mimeo.