

Population demography of two emperor breams *Lethrinus lentjan* (Lacepede, 1802) and *Lethrinus nebulosus* (Forsskal, 1775), along Tuticorin coast, Gulf of Mannar, India

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Abstract

Lethrinids are significant to the global socio-economic profile; however, there is limited understanding of their population size structure, exploitation status, maturity and life cycle characteristics. The present study, based on samples collected between March 2019 and February 2020, examined the population demography of two major reef species, *Lethrinus lentjan* (Pink-ear emperor) and *L. nebulosus* (Spangled emperor) from the Gulf of Mannar, south-east coast of India. The length-frequency distribution of both species indicated that smaller fishes (<15 cm) were prevalent near the seagrass meadows. In contrast, the sub-adults and adults (>15 cm) were significantly distributed over the coral reef regions. Both species exhibited multiple spawning peaks on a temporal scale. It was evident that fishes in the modal length class 15-30 cm are extremely vulnerable to fishing mortality (F). The study emphasises the importance of understanding the ecological dynamics of reef fish species to enhance resource management through gear restriction and prioritising areas for juvenile conservation.

Introduction

Family Lethrinidae, commonly known as emperors, emperor breams and pig-face breams, are a group of highly valuable fishes found in reef areas, including shallow seagrass meadows, with distribution from the reef crest and slopes to depths of a few hundred meters (Carpenter and Allen, 1989). They are native to the tropical and subtropical Indo-Pacific areas and contribute considerably to the commercial and recreational fishing harvest from reefs (El-Gammal, 1988). The family comprises 39 species, with 29 in the genus *Lethrinus* (Carpenter and Niem, 2001). Most of the emperors are considered protogynous hermaphrodites with a steady transition from female to male before sexual maturity (Sadovy and Liu, 2008; Grandcourt *et al.*, 2010). These species are indeed referred to as non-functional hermaphrodites due to the presence of both ovarian and testicular

tissues in a single gonad, but functionally gonochorists (Sadovy and Liu, 2008).

Although little is known about their distribution and abundance pattern, *Lethrinus* species are among the most actively sought fishes (Mapstone *et al.*, 2004; Welch *et al.*, 2008) having significantly high fishing pressure throughout their range. Due to their high demand in the export market and a lack of trade control, the species has been overharvested. They are extensively targeted by small-scale artisanal fisheries to semi-commercial-scale fishing vessels that use bottom long-lines and trawlers (Blaber *et al.*, 2005).

The life history characteristics of fishes such as reproduction and recruitment are often correlated with natural mortality (Pauly 1980), lifespan (Hoenig 1983), reproductive allocation (Lester *et al.*, 2004; Charnov 2008) and species response to exploitation (Dulvy *et al.*, 2005).



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Underestimating these perspectives can lead to biased stock evaluations, which may hinder achieving uniformity in resource utilisation. (Bellido *et al.*, 2011). Thus, biological datasets from any fished population evidence a trend in the harvest intensity of the species and the anticipated data on the dynamics of overharvested stocks. The present study therefore investigates the population characteristics of *Lethrinus lentjan* and *L. nebulosus* in the Gulf of Mannar and their present level of exploitation and the potential management practices for sustainable utilisation.

Materials and methods

Study site and sampling protocol

Tuticorin (8.7642°N; 78.1348°E), known as the Pearl City of India, is located on India's south-east coast (Fig. 1), within the Gulf of Mannar Marine Biosphere Reserve (GoMBR). The region experiences the south-west monsoon (SWM), which brings little rainfall, and the north-east monsoon (NEM), delivering heavy downpours and occasional gales from November to mid-December. The landed specimens of *L. lentjan* and *L. nebulosus* were collected fortnightly between March 2019 and February 2020, identified and measured for total length (in cm) and weight (in gm) before being transported to the laboratory for biological studies. Lethrinids are mainly targeted using hooks and lines as well as traps in the study area; while juveniles measuring less than 10 cm were captured by shore seines near the shallow seagrass habitat surrounding Vaan Island (8.83639°N 78.21047°E) while targeting other pelagic teleosts.

Data analysis

Estimation of growth parameters

von Bertalanffy growth function (K) and asymptotic length (L_{∞})

The von Bertalanffy growth model (VBGM), was used to describe the growth of *L. lentjan* and *L. nebulosus* in the present study. The typical VBGM is represented by the formula (von Bertalanffy, 1938):

$$L_t = L_{\infty} (1 - e^{-k(t-t_0)})$$

where L_t is the length of fish at a time (or age) t ; L_{∞} is the mean asymptotic length; K is the growth coefficient; t_0 is the hypothetical age at which fish length equals zero

Length-frequency dataset with a constant size class (5 cm) was used to obtain the optimal growth parameters using the FiSAT II software (Gayanilo *et al.*, 2005) and the ELEFAN I module (Pauly, 1986).

Mortality and recruitment

Mortality was estimated using the length-converted catch curve (Pauly, 1983) and the Beverton–Holt method (Beverton and Holt, 1957). Virtual population analysis (VPA) was predicted by employing fishery-dependent catch data using the mortality estimates (Jennings *et al.*, 2001). VPA uses fishing (F) and natural (M) mortality to describe the influence of fishing pressure on stock size. Beverton and Holt (1966) developed the yield per recruit (Y/R) model which is calculated using the values of M/K and L_c . The Y/R was approximated by applying the knife-edge method as incorporated in FiSAT II software.

Reproductive aspects

Gonadosomatic index (GSI)

Gonads were removed from the visceral cavity, weighed (± 0.1 g) and placed in fixative (5% formaldehyde) to assess the reproductive patterns through histological examination and by estimating the gonadosomatic index (GSI). The GSI was calculated for both sexes to determine the spawning season using the following equation:

$$GSI = \frac{\text{Gonad weight (g)}}{\text{Body weight (g) - Gonad weight (g)}} \times 100$$

The stages of oocyte maturity were assigned based on the descriptions of West (1990) and other components such as the relative thickness of the ovary wall, atretic oocytes and post-ovulatory follicles (Bean *et al.*, 2003; Marriott *et al.*, 2010). The

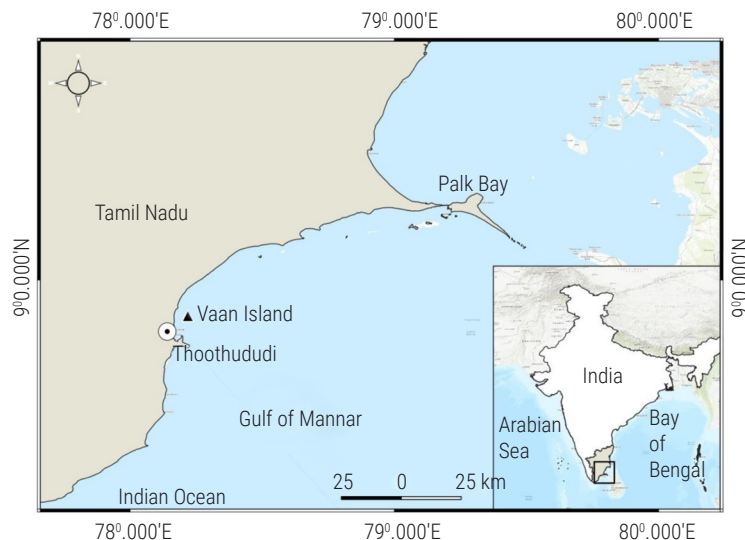


Fig. 1. Location map of the study area

functional and maturity developmental stages of testes were based on classification by Grier (1981).

Size at maturity (L_{m50})

The size/length at first maturity is the size at which 50% of the population attains sexual maturity and is estimated according to Froese and Binohlan (2000) following a length-based empirical model. The size at first maturity solely depends on environmental and ecological factors and the biological features of the animal.

Fecundity

Fecundity is the total number of mature eggs in a fish's ovary before spawning (Alam and Pathak, 2010). It is a key tool for assessing fish population dynamics and life histories and was estimated using the equation:

$$F = \frac{\text{Sub sample egg count}}{\text{Gonad sub sample weight (g)}} * \text{Total gonad weight (g)}$$

Results

Growth characteristics

During the study, 996 specimens of *L. lentjan* (624) and *L. nebulosus* (372) were sampled. In both species, small-sized

fishes (5.1 to 20.0 cm) comprised 12 to 18% of the samples, while median lengths (20.1 to 40.0 cm) represented over 74% and the larger fishes (>40 cm) accounted for 8 to 14%. Juvenile lehrinid habitats are distinctly different from those of adults, a clear strategy that facilitates feeding and minimises predation risk (Fig. 2). Unfortunately, this habitat shift has resulted in the accidental capture of significant numbers of juveniles. Undersized fish are consistently observed across seasons, with many emperors measuring under 15 cm total length being caught using shore seines with a mesh size of 10 to 30 mm. These seines operate in shallow seagrass beds, less than 3 nautical miles from shore and are specifically designed to target smaller pelagic fish.

The population parameters from the present study and those reported from earlier investigations are presented in Table 1. The L_{∞} and K values were 52.60 cm, 1.10 y^{-1} and 63.10 cm, 0.48 y^{-1} for *L. lentjan* and *L. nebulosus*, respectively (Fig. 3). The total mortality estimated independently for each fish species across seasons revealed that total mortality (Z) was the highest for *L. lentjan* (2.35) than for *L. nebulosus* (1.32). Similarly, the highest natural (M) and fishing (F) mortalities were observed for *L. lentjan* (1.63 and 0.72) than (0.90 and 0.42) for *L. nebulosus*. The VPA shows that 20 to 30 cm sized *L. lentjan* are highly susceptible to fishing mortality, with the modal class 15 to 25 cm displaying higher numerical abundance in catch rate (Fig. 4a). However, the catch composition of *L. nebulosus*, was numerically predominated by 25 to 35 cm sized specimens (Fig. 4b).

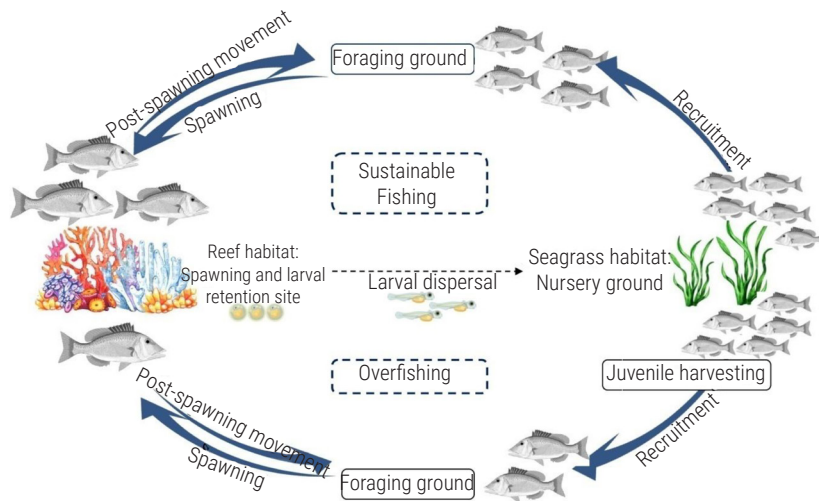


Fig. 2. Schematic illustration of the habitat shift and implication of overharvesting in lehrinids

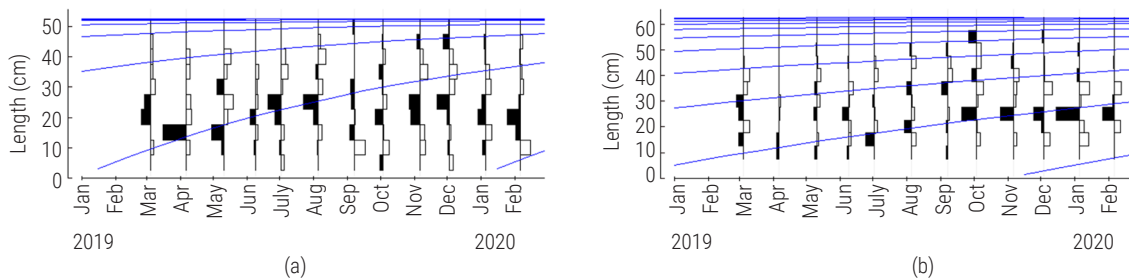


Fig. 3. von Bertalanffy growth model for (a) *L. lentjan* and (b) *L. nebulosus*

Table 1. Comparison of population parameters of *L. lentjan* and *L. nebulosus* from the Gulf of Mannar and other regions (Z-Total mortality, M-Natural mortality, F-Fishing mortality, E-Exploitation rate)

Location	Species	L_{∞} (cm)	K (Y^{-1})	Z (Y^{-1})	M (Y^{-1})	F (Y^{-1})	(E)	Source
Saudi Arabia	<i>L. lentjan</i>	-	-	1.53	0.31	1.22	-	Elsayed <i>et al.</i> (2020)
Wadge Bank, India	<i>L. lentjan</i>	53.5	0.25	-	-	0.79	0.56	Karuppasamy <i>et al.</i> (2019)
Tuticorin, India	<i>L. lentjan</i>	78.8	0.37	1.28	0.55	0.73	0.57	Vasantharajan <i>et al.</i> (2017)
Southern Gulf, UAE	<i>L. nebulosus</i>	-	-	0.44	0.22	0.22	-	Grandcourt <i>et al.</i> (2011)
Persian Gulf, Oman coast	<i>L. nebulosus</i>	67.2	0.16	1.13	0.57	0.56	0.50	Motlagh <i>et al.</i> (2010)
Southern Persian Gulf	<i>L. nebulosus</i>	66.2	0.11	0.56	0.20	0.36	-	Grandcourt <i>et al.</i> (2006)
Emirate of Abu Dhabi	<i>L. lentjan</i>	37.2	0.16	-	0.23	-	-	Grandcourt (2002)
Mauritius Coast	<i>L. nebulosus</i>	78.26	0.23	1.41	0.62	0.79	0.56	Rathacharen <i>et al.</i> (1999)
Gulf of Mannar, India	<i>L. lentjan</i>	52.60	1.10	2.35	1.63	0.72	0.30	Present study
	<i>L. nebulosus</i>	63.10	0.48	1.32	0.90	0.42	0.31	

A major recruitment was observed for both species in the mid-year between June and September with a substantial rise in fish stock. The current levels of exploitation for *L. lentjan* and *L. nebulosus* were 0.30 and 0.31 respectively. The maximal exploitation rate (E_{max}) for *L. lentjan* and *L. nebulosus* was estimated to be 0.62 and 0.67, respectively. The exploitation level that would result in a reduction of the unexploited biomass by 50% ($E_{0.5}$) is 0.33 for *L. lentjan* (Fig. 4c) and 0.34 for *L. nebulosus* (Fig. 4d).

Reproductive characteristics

Gonad histology

Histological investigation indicated that the ovaries are asynchronous, containing oocytes at various developmental stages simultaneously (Fig. 5a-f). Based on the histological observations, the oogenesis pattern in both letrnid species followed a distinct

progression. In Immature Stage I, the ovaries were predominantly composed of oocytes at the pre-perinucleolar, early perinucleolar, and late perinucleolar stages. In Stage II (early maturation), oocytes were observed in three distinct stages, including late perinucleolar, primary yolk vesicle and secondary yolk vesicle stages. In Stage III (mature), the ovaries were predominantly occupied by vitellogenic oocytes, characterised by the presence of tertiary yolk globules (Yg) and lipid droplets. Stage IV (spawning/running) showed a significant drop in the number of yolk-laden oocytes across all ovarian regions, accompanied by an increase in the number of post-ovulatory follicles. At this stage, the initial signs of vitellogenic atresia and the presence of empty follicles were also noted. In both letrnid species, active spermatogenesis was evident, comprising three major testicular stages viz., immature, mature, and spawning/running. Histological cross-sections of the testes revealed two distinct zones; an outer proliferative region and an inner region containing the sperm duct system. During the early spawning

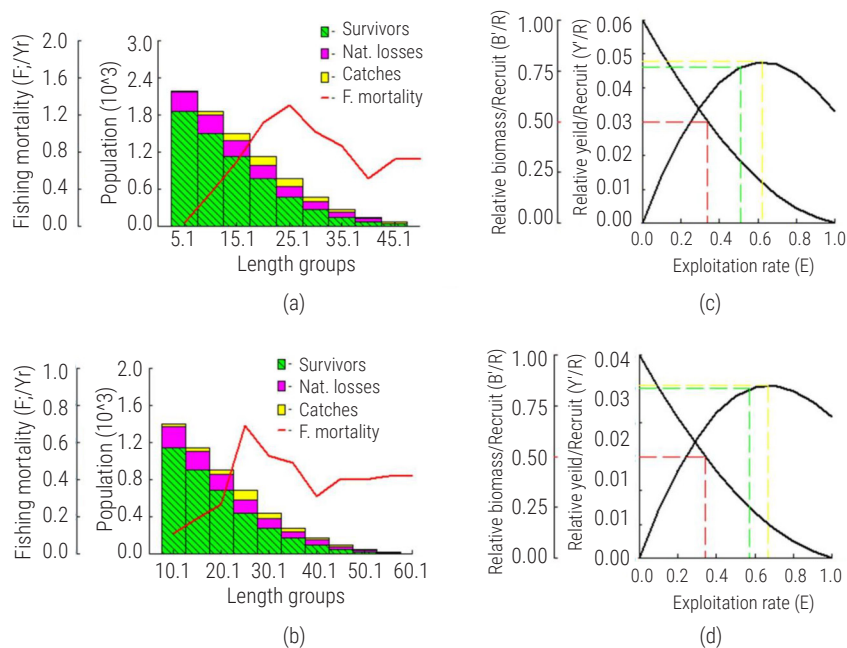


Fig. 4. Virtual population analysis (VPA) and yield-per-recruit analysis (Y/R) for *L. lentjan* (a and c) and *L. nebulosus* (b and d)

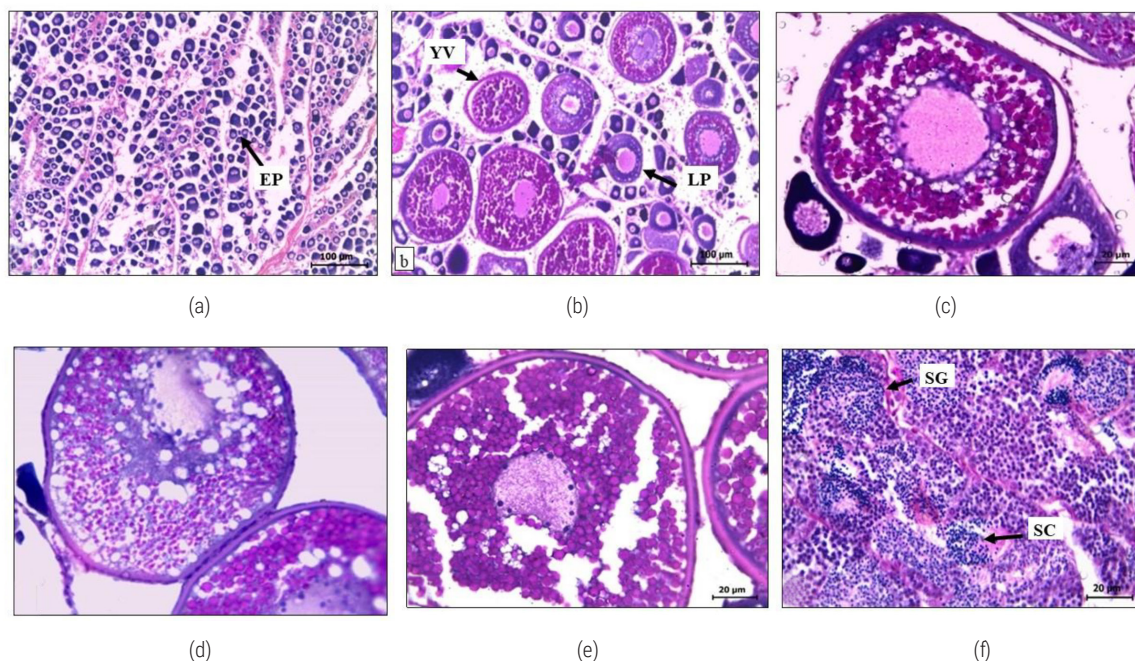


Fig. 5. Transverse sections of gonads in *L. lentjan* (a) Pre-maturation (PM) stage oocyte; (b) Maturation stage oocyte, (c) Matured stage oocyte; (d) Primary yolk globule (PYG) stage; (e) Secondary yolk globule (SYG) stage; (f) Matured male gonad with spermatogonium (SG) and spermatocytes (SC), EP-Early perinucleolar stage, LP-Late perinucleolar stage, YV-Yolk vesicle stage oocyte

stage, testes were predominantly composed of spermatogonia and spermatocytes, with occasional clusters of spermatozoa. In contrast, during the peak spawning period, all stages of spermatogenesis were present and the testes were densely packed with mature spermatozoa (Table 2).

Spawning seasonality

Figs. 6 and 7 show the monthly GSI and the distribution of gonadal (ovarian) maturity stages. Gonad histology reveals that actively spawning and spawning competent fishes peaked from October to February, aligning with the GSI trend and the spawning season. For *L. lentjan*, the minimal mean monthly ovarian GSI was 0.68% (April) and the maximum was 2.04% (February). Additionally, the testicular GSI ranged between 0.35 and 0.69%. Between May and September, mean monthly values of ovarian GSI in *L. nebulosus* were considerably lower (0.89 - 0.93%), however, they peaked at 1.05% in

October and reached 1.45% in March. The highest testicular GSI of 0.71% was observed in February, whereas the lowest (0.28%) was recorded in April. The finding denotes peak spawning in October, with a subsequent decline in December and then an increase through January and probably March; furthermore, most females were perceived in the regressing phase throughout May. These results suggest that both lethrinid species spawn in batches and spawning occurs throughout the year with two significant peaks. Spawning competent male fishes in all sub-phases were recorded in February, consistent with higher GSI. However, the gonadal recrudescence resumed in May and September, indicating a resting phase in male fishes.

Size at first maturity (L_{m50}) and fecundity

The length at which 50% of female fishes reached sexual maturity was 28.5 cm for *L. lentjan* and 30.3 cm for *L. nebulosus*. These

Table 2. Macroscopic description of the maturity stages of gonads in *L. lentjan* and *L. nebulosus*

Phase	Female	Male
Immature/resting	Ovaries are small; often flesh-coloured or wine-coloured. Tubular shaped and transparent. Oocytes not recognised with naked eye.	Testes very small, transparent and thread-like
Maturing	Ovaries one third of body cavity length, variable in colour from pinkish to yellow hue, rich in blood vessels and many oocytes were visible through the ovary wall	Testes flat to partially swollen, tapering towards anterior end, cream in colour and characterised by the presence of a single blood vessel along the ventral side
Mature	Ovaries occupy two thirds to full length of body cavity. Rounded and full, yellow to radish in colour with oocytes clearly rounded, lightly transparent	Testes white; rich in blood vessels, almost triangular in shape at posterior end.
Spawning	Ovaries resemble those of the previous stage, but with spaces between oocytes and can be extruded with gentle pressure on the abdomen.	Testes are swollen, white to ivory in colour. Gonad walls loose, soft and unsymmetrical. Sperm can be extruded with gentle pressure.
Spent	Ovaries shrunken (not completely empty) to about 2/3 length of body cavity. Ovary reddish with brown tinges at anterior ends.	Testes grey, flaccid, with brown tinges along the ends of the lobes.

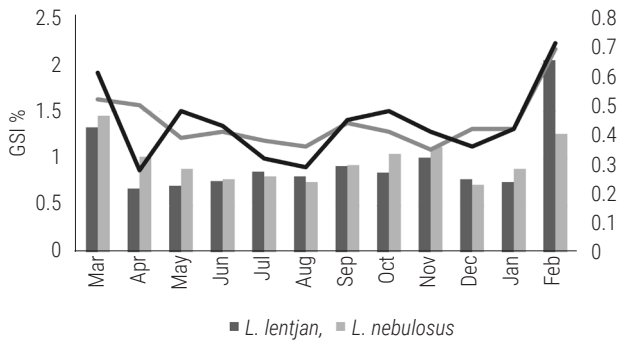


Fig. 6. Mean monthly variations in GSI %, with bars and line plots signifying female and male GSI respectively

predicted $L_{m_{50}}$ values are greater than the length at first capture (L_c) (23.31 and 26.67 cm, respectively), indicating that the exploited stocks have not yet reached the stage of first sexual maturity or spawning. Furthermore, due to the smaller sample size of male fishes, length at first maturity in males of either species was not calculated. During the investigation, females ranging from 29 to 42 cm TL had a mean fecundity of 79,652 eggs per female in *L. lentjan* and 4.89105 eggs per female in *L. nebulosus*.

Discussion

Growth characteristics

The pattern of habitat shifts during the development of fish in tropical seas typically involves migration from shallow shelf regions to deeper, more spatially segregated habitats (Adams *et al.*, 2006; Kimirei *et al.*, 2011). The shelf offers a variety of biotopes with lower predator densities compared to offshore environments (Parrish, 1989). This allows juvenile fish to find the resources and refuge they need to grow before transitioning to the open ocean. Fundamentally, the structure of fish assemblage is highly influenced by various physical and biological factors, including depth, habitat complexity, temperature, predation, competition, larval dynamics and recruitment variability (García-Charton *et al.*, 2004). Along

tropical coastlines, coral reefs and sea grasses are integrated habitats coexisting or isolated on distinct spatial scales. To optimise food acquisition and reduce resource competition among species, these potentially heterogenic habitats support ontogeny (Kimirei *et al.*, 2013). The present study reveals a significant ontogenetic shift, showcasing how organisms transition in their habitat use from seagrass to coral reefs. This transition highlights the dynamic nature of their development and reliance on diverse ecosystems. This shift may be a strategic part of the fish's life history, allowing better feeding opportunities, predator avoidance, or facilitating the onset of sexual maturity by moving to an environment that supports spawning and enhances gamete survival. However, because several coexisting species share similar habitats and resources, fishing one species can have significant unintended impacts on others. Therefore, implementing proper regulatory measures, such as gear restrictions in ecologically sensitive and productive ecosystems, is crucial for the survival and development of juveniles.

In the present study, the asymptotic length (L_{∞}) for *L. lentjan* was 52.60 cm, which is lower than suggested in earlier studies by Vasantharajan *et al.* (2017) (78.8 cm) and Rathacharen *et al.* (1999) (78.26). However the results for *L. nebulosus* (63.10) were almost equivalent to those obtained by Grandcourt *et al.* (2002; 2006) (61.08, 66.2 cm) and Motlagh *et al.* (2010) (67.2 cm), but lesser when compared to the estimates of Vasantharajan *et al.* (2012) (79.9 cm). The relatively lower value obtained may be attributed to persistently high fishing pressure. The growth coefficient K reported earlier by Vasantharajan *et al.* (2017) along this coast is lower (0.37 yr^{-1}) than in the present study, possibly due to the sample size analysed which is substantially higher (5760 specimens). Besides, reports from Tanzania (1.00 yr^{-1}) (Benno, 1992), Yemen (0.48 yr^{-1}) and Kenya (0.25 yr^{-1}) (Aldonov and Druzhinin, 1979) also show comparatively lower growth rates. The values of K observed from previous research by Grandcourt *et al.* (2002, 2006) (0.14, 0.11), Chedia (2021) (0.15) and Motlagh *et al.* (2010) (0.16) for *L. nebulosus*, were lower than the current finding (0.48), signifying that the species is growing under favourable ecological conditions. The variations in growth rates may be ascribed to fluctuations in environmental factors like temperature, seasonality, population density and anti-predatory behaviours (Kuparinen *et al.*, 2011).

Mortality coefficients (Z , M and F) are more important in assessing fish population dynamics because they represent biomass loss

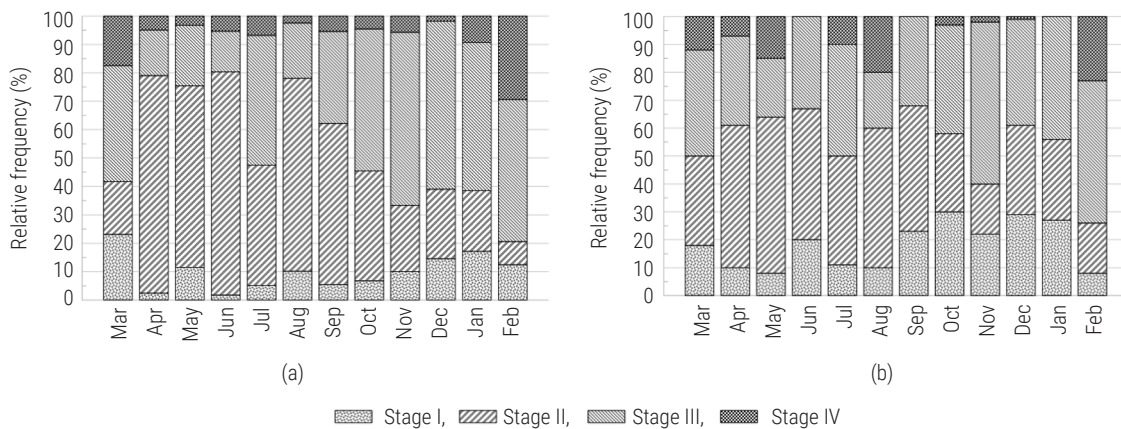


Fig. 7. Monthly ovarian maturation pattern and its relative frequency in (a) *L. lentjan* and (b) *L. nebulosus*

due to environmental conditions and fishing pressure. The current estimate of fishing mortality for *L. lentjan* was substantially lower than those reported by Vasantharajan *et al.* (2017) (0.73), Zaahkouk *et al.* (2017) (0.79), Karuppasamy *et al.* (2019) (0.79) and Elsayed *et al.* (2020) (1.22) (Table 1). Similarly, the fishing mortality evaluated for *L. nebulosus* was relatively lower than the reports by Motlagh *et al.* (2010) (0.56) and Mehanna *et al.* (2012) (1.03).

According to Gulland (1971), the optimum exploitation of stock is predicted on the assumption that fishing mortality equals natural mortality, or $E = 0.5$. Grandcourt *et al.* (2003) and Abdallah *et al.* (2010), reported that the *L. nebulosus* in the United Arab Emirates is overexploited, with exploitation rate (E) values of 0.64 and 0.67, respectively. Hicks and McClanahan (2012) observed an exploitation value of 0.82 for *L. lentjan* in Kenyan waters. The E values reported in this study indicate that the current exploitation rate for *L. lentjan* and *L. nebulosus* populations is significantly lower than in other regions. The length-structured VPA reveals that fishing pressure on the species was greater in the length range of 20.0 - 30.0 cm ($L_c > L_{50}$). Karuppasamy *et al.* (2018) also observed similar values (20.5 to 31 cm) in the Wadge Bank. Targeting immature individuals may hamper their growth and reproduction, leading to a decline in landings and potentially resulting in the stock's extinction.

Reproductive characteristics

Comprehensive data on the reproductive development of most emperors appear to be rare (Ebisawa, 1990). According to Nzioka (1979) in East Africa, several lethriniid species have two spawning seasons, one in September/October and the other in January/February; this indeed correlates to the results obtained in the present study. GSI and histological investigations of gonads revealed that females were more prevalent than males in landings from February to March and September to November. The simultaneous presence of growing sperm crypts and peripheral sperm sinuses characterises the sex transition in *L. nebulosus*, consistent with other protogynous hermaphroditic coral reef fishes (Sadovy, 1996). Kuo and Lee (1990) noted a prolonged spawning season from September to February along Australia's north-western shelf, while peak spawning in Hormozgan Province, Iran, occurs in March and in the southern Arabian Gulf, mainly from April to May (Grandcourt *et al.*, 2006). This study found significant GSI peaks in October and February, with minor peaks in warmer months, indicating batch spawning. The primary spawning seasons for both species are October to November and January to March, with minor spawning phases in April and July. Monthly variations in photoperiod, rainfall, turbidity, temperature and other environmental variables are thought to regulate the maturation of gonads and trigger spawning (Allsop and West, 2003).

Toor (1964) and Grandcourt *et al.* (2011) reported the length at which 50% of *L. lentjan* reach maturity (L_{m50}) as 28.7 cm (SL) in the Indian Ocean and 27.7 cm (FL) in the southern Arabian Gulf, consistent with the current estimate. In contrast, the L_{m50} for *L. nebulosus* is lower than in other populations, such as in Western Australia, where it is 35 cm (FL) (Marriott *et al.*, 2010). Factors influencing size at first sexual maturity include feeding rate, gonadal development, season, population density and hydrographic conditions (Muchlisin *et al.*, 2010; Hossain *et al.*, 2012). The fecundity observed for *L. lentjan* differs from the findings of Toor (1964) and Mrombo *et al.* (2019), who reported 12,146-77,922 eggs per female in Indian

Ocean waters and 89,573 eggs per female on the Kenyan coast, respectively. The disparities in results might probably be attributed to environmental variables and the habitat ecology persisting between interregional stocks besides the anthropogenic fishing pressures (Alam and Pathak, 2010). All these factors influence progeny size, ultimately affecting recruitment and productivity, thus decreasing stock replenishment.

The study shows that *L. lentjan* and *L. nebulosus* from the Gulf of Mannar region face moderate to high fishing pressure, with a high capture rate of juveniles and subadults. Both species have multiple spawning peaks, and adults are more common in reef habitats, while juveniles thrive in seagrass areas to feed and avoid predators. As they grow, juveniles move to reefs to optimise feeding. Fish in the 15-30 cm size range that undergo transition to adulthood and spawning are particularly vulnerable to exploitation. Overfishing and the removal of these fish can jeopardise wild stock sustainability. To protect this fragile ecosystem, it is essential to implement management measures like reducing fishing efforts, enforcing gear restrictions and limiting fishing in critical habitats.

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References

- Abdallah, M., Flamerzi, M., Al-Banali, A. R. and Al-Khalaf, K. 2010. *Stock assessment and management of commercial fish resources in Qatar, Part 1: Current status of ten fish stocks. Technical Report*, Ministry of Environment, Fish Department, Doha, Qatar, 48 p.
- Adams, A. J., Dahlgren, C. P., Kellison, G. T., Kendall, M. S., Layman, C. A., Ley, J. A., Nagelkerken, I. and Serafy, J. E. 2006. Nursery function of tropical back-reef systems. *Mar. Ecol. Prog. Ser.*, 318: 287-301. <https://doi.org/10.3354/meps318287>.
- Alam, M. and Pathak, J. K. 2010. Rapid assessment of water quality index of Ramganga River, Western Uttar Pradesh (India) using a computer programme. *Nat. Sci.*, 8: 1-8.
- Aldonov, V. K. and Druzhinin, A. D. 1979. Some data on scavengers (Family Lethrinidae) from the Gulf of Aden region. *J. Ichthyol.*, 18: 527-535.
- Allsop, D. J. and West, S. A. 2003. Constant relative age and size at sex change for sequentially hermaphroditic fish. *J. Evol. Biol.*, 16: 921-929. <https://doi.org/10.1046/j.1420-9101.2003.00590.x>.
- Bean, K., Mapstone, B. D., Davies, C. R., Murchie, C. D. and Williams, A. J. 2003. Gonad development and evidence of protogyny in the red-throat emperor on the Great Barrier Reef. *J. Fish. Biol.*, 62: 299-310. <https://doi.org/10.1046/j.1095-8649.2003.00021.x>.
- Bellido, J., Santos, M., Pennino, M., Valeiras, J. and Pierce G. 2011. Fishery discards and bycatch: Solutions for an ecosystem approach to fisheries management. *Hydrobiologia*, 670: 317-333. <https://doi.org/10.1007/s10750-011-0721-5>.

- Beverton, R. J. H. and Holt, S. J. 1957. On the dynamics of exploited fish populations. *Fish. Invest.*, 19: 1-533.
- Beverton, R. J. H. and Holt, S. J. 1966. Manual of methods for Fish Stock Assessment, Part II Tables of Yield Function. *FAO Fishery Biology Technical Paper, No 38, Version 1*. Food and Agriculture Organisation of the United Nations, Rome, Italy.
- Blaber, S. J. M., Dichmont, C. M., Buckworth, R. C., Badrudin, S. B., Nurhakim, S., Iskandar, B., Fegan, B., Ramm, D. C. and Salini, J. P. 2005. Shared stocks of snappers (Lutjanidae) in Australia and Indonesia: Integrating biology, population dynamics and socio-economics to examine management scenarios. *Rev. Fish. Biol. Fish.*, 15: 111-127. <https://doi.org/10.1007/s11160-005-3887-y>.
- Carpenter, K. E. and Allen, G. R. 1989. *FAO Species Catalogue Vol 9, Emperor fishes and large-eye breams of the world (Family Lethrinidae) - An annotated and illustrated catalogue of lethrinid species known to date, FAO Fisheries Synopsis*, Food and Agriculture Organisation of the United Nations, Rome, Italy. 118 p.
- Carpenter, K. E. and Niem, V. H. 2001. *The living marine resources of the Western Central Pacific Vol 6, Bony fishes - Part 4 (Labridae to Latimeriidae), estuarine crocodiles, sea turtles, sea snakes and marine mammals, FAO species identification guide for fishery purposes*, Food and Agriculture Organisation of the United Nations, Rome, Italy, pp. 3381-4218.
- Charnov, E. L. 2008. Fish growth: Bertalanffy k is proportional to reproductive effort. *Environ. Biol. Fishes*, 83: 185-187.
- Dulvy, N. K., Jennings, S. J., Goodwin, N. B., Grant, A. and Reynolds, J. D. 2005. Comparison of threat and exploitation status in Northeast Atlantic marine populations. *J. Appl. Ecol.*, 42: 883-891. <https://doi.org/10.1111/j.1365-2664.2005.01063.x>.
- El-Gammal, F. I. 1988. Age, growth, and mortality of the rabbitfish *Siganus rivulatus* (Forsk, 1775) from the Red Sea. *Bull. Inst. Oceanogr. Fish.*, 14: 13-21.
- Elsayed, M. Y., Abdel-Wahab, A. A., Nasser, A. A., Mohamed, H. G. and Fozi, S. S. 2020. Demographic structure and stock status of *Lethrinus lentjan* in Saudi coastal waters of the Red Sea. *Saudi J. Biol. Sci.*, 27: 2293-2298. <https://doi.org/10.1016/j.sjbs.2020.06.003>.
- Froese, R. and Binohlan, C. 2000. Empirical relationships to estimate asymptotic length, length at first maturity and length at maximum yield per recruit in fishes, with a simple method to evaluate length frequency data. *J. Fish Biol.*, 56(4): 758-773. <https://doi.org/10.1111/j.1095-8649.2000.tb00870.x>.
- Gayanilo, F. C., Sparre, P. and Pauly, D. 2005. *FAO-ICLARM Stock assessment tools II: User's guide (Vol 8)*, Food and Agriculture Organisation of the United Nations, Rome, Italy
- Grandcourt, E., Al Abdessalaam, T. Z., Al Shamsi, A. and Francis, F. 2006. Biology and assessment of the painted sweetlips (*Diagramma pictum* (Thunberg, 1792) and the spangled emperor (*Lethrinus nebulosus* (Forsskal, 1775) in the southern Arabian Gulf. *Fish Bull.*, 104: 75-88.
- Grandcourt, E., Al Abdessalaam, T. Z., Francis, F. and Al Shamsi, A. 2011. Demographic parameters and status assessments of *Lutjanus ehrenbergii*, *Lethrinus lentjan*, *Plectorhinchus sordidus* and *Rhabdosargus sarba* in the southern Arabian Gulf. *J. Appl. Ichthyol.*, 27: 1203-1211. <https://doi.org/10.1111/j.1439-0426.2011.01776.x>.
- Grandcourt, E., Francis, F., Al-Shamsi, A., Al-Ali, K. and Al Ali, S. 2003. Stock assessment and biology of key species in the demersal of the Emirate of Abu Dhabi (Project no 02-23-0001). *Mar. Environ. Res. Wildl. Develop. Agen.*, Environmental Research and Wildlife Development Agency (ERWDA), Abu Dhabi, United Arab Emirates, pp. 51-61.
- Grandcourt, E. M., Al Shamsi, A. T. and Francis, F. 2002. *Annual fisheries statistics for Abu Dhabi Emirate 2002*, Environmental Research and Wildlife Development Agency (ERWDA), Abu Dhabi, United Arab Emirates, 91 pp.
- Grier, H. J. 1981. Cellular organisation of the testis and spermatogenesis in fishes. *American Zoologist*, 21: 345-347
- Gulland, J. A. 1971. *The fish resources of the ocean. Revised edition of FAO Fisheries Technical Paper 97*, Fishing News (Books), Ltd., London, UK, 425 p.
- Hicks, C. C. and McClanahan, T. R. 2012. Assessing gear modifications needed to optimize yields in a heavily exploited multi-species seagrass and coral reef fishery. *PLoS ONE*, 7: 5.
- Hoening, J. M. 1983. Empirical use of longevity data to estimate mortality rates. *Fish Bull.*, 82: 898-905.
- Hossain, M. Y., Rahman, M. M., Miranda, R., Leunda, P. M., Oscoz, J., Jewel, M. A. S., Naif, A. and Ohtomi, J. 2012. Size at first sexual maturity, fecundity, length-weight and length-length relationships of *Puntius sophore* (Cyprinidae) in Bangladeshi waters. *J. Appl. Ichthyol.*, 28: 818-822. <https://doi.org/10.1111/j.1439-0426.2012.02020.x>.
- Chédia, J. 2021. Biological parameters of *Lethrinus nebulosus* in the Arabian Gulf on the Saudi Arabian Coasts. *Asian J. Fish. Aquat. Res.*, 11: 23-31. <https://doi.org/10.9734/ajfar/2021/v11i1430210>.
- Jennings, S., John, K. P., Nicholas, V. C. P. and Karema, J. W. 2001. Impacts of trawling disturbance on the trophic structure of benthic invertebrate communities. *Mar. Ecol. Progr. Ser.*, 213: 127-142.
- Karuppusamy, K. K., Jawahar, P., Venkataramani, V., Kingston, S. and Vidhya, V. 2019. *Demographic characters and stock assessment of Pink ear emperor, Lethrinus lentjan (Lacepede, 1802) from the Wadge Bank, South India*. <https://doi.org/10.6024/jmbai20186022079-0x>.
- Kimirei, I., Nagelkerken, I., Griffioen, B., Wagner, C. and Mgaya, Y. 2011. Ontogenetic habitat use by mangrove/seagrass-associated coral reef fishes shows flexibility in time and space. *Estuar. Coast. Shelf Sci.*, 92: 47-58. <https://doi.org/10.1016/j.ecss.2010.12.016>.
- Kimirei, I. A., Nagelkerken, I., Trommelen, M., Blankers, P., Van Hoytema, N., Hoeijmakers, D., Huijbers, C. M., Mgaya, Y. D. and Rypel, A. L. 2013. What drives ontogenetic niche shifts of fishes in coral reef ecosystems? *Ecosystems*, 16: 783-796.
- Kuo, C. L. and Lee, S. S. 1986. Age and growth of common porgy, *Lethrinus nebulosus* (Forsskal) in shelf waters off northwest Australia. *J. Fish. Soc. Taiwan*, 3: 39-57.
- Kuparinen A., Cano J., Loehr J., Herczeg G., Gonda A. and Merilä J. 2011. Fish age at maturation is influenced by temperature independently of growth. *Oecologia*, 167: 435-43.
- Lester, N. P., Shuter, B. and Abrams, P. 2004. Interpreting the von Bertalanffy model of somatic growth in fishes: The cost of reproduction. *Proc. Royal Soc. B: Biol. Sci.*, 271: 1625-1631. <https://doi.org/10.1098/rspb.2004.2778>.
- Mapstone, B. D., Davies, C. R., Little, L. R., Punt, A. E., Smith, A. D. M., Pantus, F., Lou, D. C., Williams, A. J., Jones, A., Ayling, A. M., Russ, G. R. and MacDonald, A. D. 2004. *The effects of line fishing on the Great Barrier Reef and evaluations of alternative potential management strategies. Technical Report No 52*. CRC Reef Research Centre, Townsville, Australia.
- Marriott, R. J., Jarvis, N. D. C., Adams, D. J., Gallash, A. E., Norriss, J. and Newman, S. J. 2010. Maturation and sexual ontogeny in the spangled emperor *Lethrinus nebulosus*. *J. Fish Biol.*, 76: 1396-1414. <https://doi.org/10.1111/j.1095-8649.2010.02571.x>.
- Mehanna, S., Zaki, S., Al-kiyumi, F., Al-Kharusi, L., Al-Bimani, S. and Al-Senaidi, R. 2012. Biology and fisheries management of spangled emperor

- Lethrinus nebulosus* from the Arabian Sea Coast of Oman. *INOC-CNRS, International Conference on Land-Sea Interactions in the Coastal Zone*, 06-08 November 2012. Jounieh, Lebanon.
- Motlagh, S. A. T., Vahabnezhad, A. and Seyfabadi, S. J. 2010. Growth, mortality and spawning season of the spangled emperor (*Lethrinus nebulosus* Forsskal, 1775) in coastal waters of Hormozgan Province in the Persian Gulf and Oman Sea. *Iranian J. Fish. Sci.*, 9: 161-172.
- Muchlisin, Z. A., Musman, M. and Azizah, M. N. S. 2010. Length-weight relationships and condition factors of two threatened fishes, *Rasbora tawarensis* and *Poropuntius tawarensis*, endemic to Lake Laut Tawar, Aceh province, Indonesia. *J. Appl. Ichthyol.*, 26: 949-953. <https://doi.org/10.1111/j.1439-0426.2010.01524.x>.
- Nathan M., Chrisestom M., Cosmas M. and Julius M. 2019. Stock status and some biological aspects of *Lethrinus lentjan* (Lacapede, 1802) from the south coast of Kenya. *WIO J. Mar. Sci.*, 18: 69-76. <https://doi.org/10.4314/wiojms.v18i2>.
- Nzioka, R. M. 1979. Observations on the spawning seasons of East African reef fishes. *J. Fish Biol.*, 14: 329-342. <https://doi.org/10.1111/j.1095-8649.1979.tb03528.x>.
- Parrish, R. H. 1989. The South Pacific oceanic horse mackerel (*Trachurus picturatus murphyi*) fishery. In: Pauly, D., Muck, P., Mendo, J. and Tsukayama, I. (Eds.), *The Peruvian upwelling ecosystem: Dynamics and interactions*. ICLARM Conference Proceedings, 18: 321-331.
- Pauly, D. 1980. A new methodology for rapidly acquiring basic information on tropical fish stocks: growth, mortality and stock-recruitment relationships. In: Saila, S. and Roedel, P. (Eds.), *Proceedings of the International Workshop on Stock assessment for tropical small-scale fisheries*, 19-21 September 1979, University of Rhode Island International Center for Marine Research and Development, pp. 154-172.
- Pauly, D. 1983. Length-converted catch curves: A powerful tool for fisheries research in the tropics (Part 1). *Fishbyte*, 1: 9-13.
- Pauly, D. 1986. A simple method for estimating the food consumption of fish populations from growth data and food conversion experiments. *Fish Bull.*, 84: 827-840.
- Rathacharen S., Venkatasami A. and Degambur D. 1999 Growth parameters and mortality rates of *Epinephelus fasciatus*, *Lethrinus nebulosus*, *Siganus sutor*, *Naso unicornis* and *Mugil cephalus* from the coastal areas of Mauritius as estimated from analyses of length frequencies. In: *AMAS Food and Agricultural Research Council*, Réduit, Mauritius, pp. 217-228.
- Sadovy, Y. and Liu, M. 2008. Functional hermaphroditism in teleosts. *Fish Fish.*, 9: 1-43. <https://doi.org/10.1111/j.1467-2979.2007.00266.x>.
- Sadovy, Y. J. 1996. Reproduction of reef fishery species In: Polunin, N. V. C. and Roberts, C. M. (Eds.). *Reef Fisheries*, Chapman and Hall, Vol 20, Springer, Dordrecht, The Netherlands, pp. 15-59.
- Toor, H. S. 1964. Biology and fishery of the pig-face bream, *Lethrinus lentjan* Lacapede, II - Maturation and spawning. *Indian J. Fish.*, 11: 581-596.
- Vasantharajan, M., Jawahar, P., Francis, T., Venkatasamy, M. and Santhoshkumar, S. 2012. Age, growth and mortality characteristics of *Lethrinus nebulosus* (Forsskal, 1775) in Thoothukudi Coast of Tamil Nadu, India. *SKUAST J. Res.*, 13: 6-13.
- Vasantharajan, M., Jawahar, P., Shanmugam, S. and Ramyalakshmi, P. 2017. Age, growth and mortality characteristics of *Lethrinus lentjan* exploited off Thoothukudi coast, Tamil Nadu, India. *Indian J. Mar. Sci.*, 46: 2367-2371.
- Von Bertalanffy, L. 1938. A quantitative theory of organic growth (inquiries on growth laws II). *Human Biol.*, 10: 181-213.
- Welch, D. W., Rechisky, E. L., Melnychuk, M. C., Porter, A. D., Walters, C. J., Shaun, C., Benjamin, J. C., Scott McKinley, R. and Carl, S. 2008. Correction: Survival of migrating salmon smolts in large rivers with and without dams. *PLoS BIOL.*, 6: e314. <https://doi.org/10.1371/journal.pbio.0060314>.
- West, G. 1990. Methods of assessing ovarian development in fishes: A review. *Aust. J. Mar. Freshwat. Res.*, 41: 199-222. <https://doi.org/10.1071/MF9900199>.
- Zaahkour, S. A., Khalaf-Allah, H. M., Mehanna, S. F., El-Gammal, F. I. and Makkey, A. F. 2017. Studies on age, growth, and mortality rates for management of the redspot emperor, *Lethrinus lentjan* (Lacapede, 1802) in the Egyptian sector of Red Sea. *Egypt. J. Aquat. Biol. Fish.*, 21: 63-72. <https://doi.org/10.21608/EJABF.2017.2384>.