NORTH-WESTERN JOURNAL OF ZOOLOGY 17 (2): 180-186
Article No.: e211402

http://biozoojournals.ro/nwjz/index.html

Reproductive biology of non-native *Nemipterus randalli* Russell, 1986 and native *Pagellus erythrinus* (Linnaeus, 1758) from the Aegean Sea

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Received: 26 November 2020 / Accepted: 29 January 2021 / Available online: 10 December 2021 / Printed: December 2021

Abstract. The present study examined reproduction biologies of 336 and 384 individuals of native *Pagellus erythrinus* and non-native *Nemipterus randalli* species captured using trammel nets in Marmaris Bay on a monthly basis from January to December 2018. Total length, weight and sex ratios in *N. randalli* obtained by trammel net were 9.2-21.2 cm (mean±SD; 16.2±2.43), 9.15-142.63 g (mean±SD; 61.23±29.12), 1:0.41, respectively. First maturity lengths for female and male individuals of *N. randalli* were 13.11 cm and 15.55 cm, respectively. Linear relationship between total length and fecundity of the species whose fecundity was 37785- 55200 (mean±SD; 46172±7450) was calculated as F=1445.1TL+34612 (R^2=0.75). For *P. erythrinus* species, total length and weight and sex ratios were 10.2-28.5 cm (mean±SD; 18.50±3.37), 10.27-307.14 g (mean±SD; 88.53±48.57) and 1:0.64, respectively. The first maturity lengths of *P. erythrinus* were 12.69 cm in females and 14.83 cm in males, respectively. The fecundity of the species was found to be 34503-125102 eggs (mean±SD; 65863±25258). Linear relationship between total length and fecundity was F=10289TL-179 788 (R^2= 0.76).

Key words: *Nemipterus randalli, Pagellus erythrinus,* fecundity, size at maturity, spawning season, Aegean Sea.

Introduction

It is of great importance to know parameters of reproduction biology of a species such as first maturity length, reproduction season and duration and fecundity in terms of efficient uses and management of fish stock (Saborido-Rey 2003). Knowledge of the spawning period of the species enables two major rules to be used such as avoidance of its capture and catching only its individuals of maturity length during this period in terms of sustainability (Samy-Kamal et al. 2015). Known to be a partially closed basin, the Mediterranean Sea is the biodiversity hotspot on the earth because it is home to 7% of the world marine species (Coll et al. 2012). In spite of the high rates of endemism, the sea has become an available marine environment for exotic species to migrate since the Suez Canal was opened in 1869. The fact that the canal was then widened and deepened to finally intensify maritime traffic has increased invasion rate of the Mediterranean by lessepsian species and caused spatial overlap between exotic and endemic ichthyofauna (Coll et al. 2012). Some lessepsian species migrating through the canal into the Mediterranean have created predatory pressure on our native species and therefore caused negative effects on ecology (Mooney 1996). Similarly, some lessepsians such as *Lagocephalus sceleratus* have negative economic impacts on fisheries whereas others such as *Saurida lessepsianus*, *Upeneus moluccensis*, *Upeneus pori*, *Siganus rivulatus*, *Siganus luridus* and *Nemipterus randalli* managed to adapt themselves to the new environment and form populations large enough to be important in commercial fisheries.

Included in the study, the species *N. randalli* is caught and sold as if it was *Pagellus erythrinus* in southern coastal regions of Turkey (Yapıcı 2017). Twenty two % of total catch by Akyaka Fisheries Cooperative engaged in catching activity in Gökova Bay has been reported to cover *N. randalli* (Uyan 2017). Some invasive fish species which are mistakenly assumed to be of economic importance variously compete with native species of commercial value to eventually affect them negatively (Gülşahin & Soykan 2017, Grabowska et al. 2019, Nyeste et al. 2017, Kati et al. 2015). The species *Nemipterus randalli* exhibits a wide geographic distribution from east and west Indian coasts to Pakistan, Persian Gulf, Red Sea, Aden Gulf, East Africa, Seychelles and Madagascar in the West Indian Ocean (Froese & Pauly 2019). Migrating from Red Sea through Suez Canal to Mediterranean Sea, the species is of lessepsian nature (Uyan 2017). It is a demersal species inhabiting depths of 22-450 m. Nemipterus species are of commercial importance across the World. Although the species has rapidly spread across the Levant Sea, it has no record on its fisheries (İnnal et al. 2015).

Categorized in Sparidae family, the species *Pagellus erythrinus* spread in a wide geographic region from east Atlantic including Cape Verde, Madeira and Canaries Islands to Norway rarely Scandinavia and Guinea-Biseau. A demersal species, *P. erythrinus* inhabits rocky, sandy and muddy sea bottoms in depths of 20-300 m in schools (Froese & Pauly 2019). One of the important species both in fisheries and aquaculture, *P. erythrinus* is categorized as the least concern species (LC) in the red list across the Mediterranean basin and the world seas as well (IUCN 2020). *P. erythrinus* is one of the most captured species in artisanal fisheries and increases its sale price and thus importance in local livelihood thanks to catching amounts in many Mediterranean countries (Hoşsucu & Türker çakır 2003) and its fisheries has been seriously performed in the related nations (Pajuelo et al. 2003).

There are some studies on population structure and growth and feeding characteristics of the species *Nemipterus randalli* in the world (Ali & Saad 2013; Al-Kiyumi et al. 2014) and in Turkey (Özvarol 2014, İnnal et al. 2015; Aydın & Akyol 2016; Uyan 2017) respectively. However, there seems to be the only study on its reproduction by Demirci et al. (2018), who determined the reproduction season and first maturity length of the species in Iskenderun bay, northeastern Mediterranean.

Studies on *P. erythrinus* are more than those on *N. randalli* (Valdés et al. 2004, Zarrad et al. 2010, Mohammed et

al. 2010, Ben Smida & Hadhri 2014, Saleh 2018, Elmajedeb et al. 2019). The studies on the two species in Turkey and in the world have been usually performed on the basis of species. However, those in which both species have been assessed together are generally on their competition for food in the Mediterranean Sea (Yapıcı 2017). The authors reported a significant competition for food between *N. randalli* and *P. erythrinus*. (Yapıcı 2017).

Although there are studies made on determining reproduction characteristics of the two species in Turkey and other countries, no study exists which assesses native *P. erythrinus* and lessepsian *N. randalli* together that are known to share the same environment and have a competitive relationship between them. Therefore, the present study will simultaneously detail reproduction characteristics such as spawning season, sex ratios, first maturity length and fecundity of the above species. Evidence to be finally obtained will be expected to contribute to the strategies likely to be developed on stock management.

Material and Methods

A total of 720 individuals (384 *N. randalli* and 336 *P. erythrinus*) were examined in this study. Samples were taken on a monthly basis between January and December 2018 using trammel nets (20 mm mesh size) at 40 m depth in the Marmaris Bay (Fig. 1).

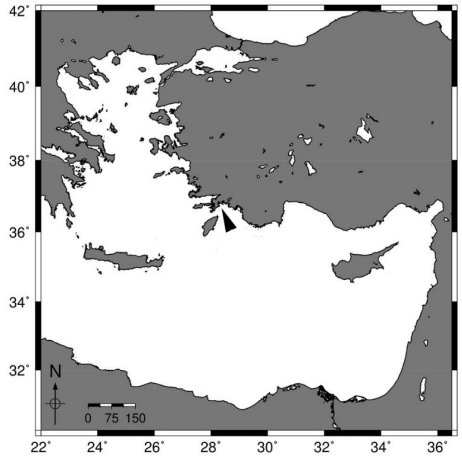

Figure 1 Sampling area

Total length (cm) and weight (g) of fishes brought to the laboratory were measured to assess their sexes by ovaries and related tests. The spawning period was identified through the analysis of the monthly variation in the gonadosomatic index (GSI). The GSI was determined as GSI = [GW/(W-GW)] ×100, where GW is the weight of the gonad (g), and W is the total weight (g) of the individual (Ricker 1975). Sexual development stages were determined macroscopically based on the morphology and colour of the gonads into five stages: I-immature, II - maturing virgin and recovering spent, III-ripening, IV-ripe, V-spent (Table 1, Pajuelo et al. 2003).

Table 1 Macroscopic scale adopted to determine stages of gonadal development of *Pagellus erythrinus* and *Nemipterus randalli* (Pajuelo et al. 2003; Mahdi et al. 2017)

Stages	Female	Male
I: Immature	Ovary small, thin filament, transparent, invisible oocytes	Testes thin, white, slightly translucent
II: maturing virgin and recovering spent	Close to the stage I, larger volume, light pink color	Close to the stage I, larger volume
III: ripening	Gonad large, light orange to dark, ovarian granular, oocytes easily visible through the membrane	Testicles soft and white, flow of a whitish liquid after incision
IV: ripe	Ovary very large, occupying almost the entire abdominal cavity, very thin ovarian membrane. Oocytes easily visible and expelled at the slightest pressure	Testes white, occupy the total abdominal cavity, sperm flows following a slight pressure
V: spent	Ovary flaccid, vascularized, pink salmon color, oocytes smaller with presence of hyaline spaces	Flaccid testes slightly vascularized

Size at first maturity (L50) was estimated by sex obtaining the percentage of adult specimens per 1 cm length class; values were afterwards fitted to a logistic regression with the maximum likelihood method.

Fecundity was assessed by using mature ovaries from the beginning, middle and end of the spawning period of each species. Anterior, median and posterior ovarian sections of ovaries at 2-5 th of ovarian weight and mature eggs were gravimetrically counted and averaged (NOAA 1985).

Chi square test was perfomed to determine whether there could be a statistical difference of sex ratios between males and females in both species. The values presented for length, weight, fecundity and diameter of the eggs are expressed as mean ± standard deviation (mean±SD) in text. All of the *P. erythrinus* individuals was found to be excluded from the length group which was seen as hermaphrodites and no hermaphrodite individuals were determined.

Results

For calculating fecundity, mature ovaries of a total of 15 *N. randalli* individuals of 15- 20 cm length in April- August and those of 15 *P. erythrinus* individuals of 16-27.9 cm in April-May were assessed.

Reproductive characteristics of *Nemipterus randalli*

Length and weight values of *N. randalli* samples are 9.2- 21.2 cm (16.2±2.43), 9.15-142.63 g (61.23±29.12), respectively. Of 384 individuals, 273 are female and 111 male. Sex ratio of female: male is 1:0.41. According to Chi square results, $\chi^2_{34.17} > \chi^2_{0.05=} 3.84$, $p<0.05$ with a significant difference in sex ratios between females and males.

Considering spawning seasons based on GSI results of the species, GSI values of *N. randalli*, in females in particular began to increase by April to reach to maximum in August, while those of males are similar around the year with a peak in April and July (Fig. 2).

The perfomed study showed the first maturity length to be 13.11 and 15.55 in females and males of *N. randalli*, respectively (Fig. 3).

Fecundity of *N. randalli* was found to be 37785-55200

(46172±7450) eggs. Between its total length and fecundity, there was a linear correlation as F =1445.1TL + 34612 (R^2= 0.75) (Fig. 4).

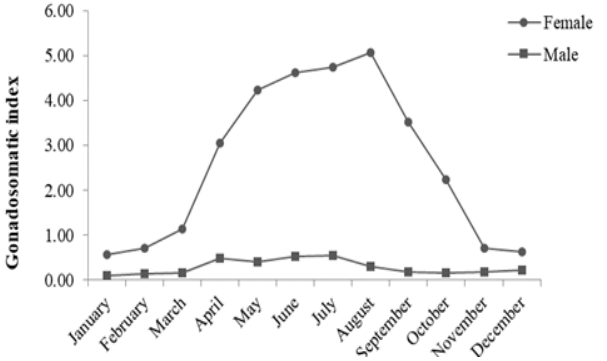

Figure 2 Monthly variation of GSI of *Nemipterus randalli* caught in Aegean Sea

Mature eggs had diameters of 0.53-0.67 (0.60±1.04) mm. During determination of the species' fecundity, hydrate eggs were observed to be present in ovaries, which indicates partial spawning unique to the species. Diameter of hidrate eggs in the ovaries was found as 0.63-0.67 (0.65±0.51) mm, in mature eggs as 0.53-0.66 (0.60±1.04) mm and in developing eggs as 0.21-0.28 (0.24±0.75) mm.

Reproductive characteristics of *Pagellus erythrinus*

Length and weight values of *P. erythrinus* are 10.02-28.5 cm (18.50±3.37), 10.27-307.14 g (88.53±48.57). Of 336 individuals examined, 205 are female and 131 males. Sex ratio of female and male is 1:0.64 with significant difference between them ($\chi^2_{8.15} > \chi^2_{0.05} = 3.84$, $p < 0.05$).On the other hand, GSI values in females of *P. erythrinus* started to rise by April with a peak in May, which also applies for males in the same month (Fig. 5). The first maturity length of females and males in *P. erythrinus* was found to be 12.69 and 14.83 cm, respectively (Fig. 6). Considering fecundity of *P.erythrinus*, the fish produced 34503-125102 (65863±25258) eggs. A linear relationship was found between its total lengths and fecundity as F=10289TL-179788 (R^2=0.76) (Fig. 7). Ovaries of the species showed presence of hydrate eggs. Diameter in hidrate eggs was 0.70-0.77 (0.74±0.78) mm, in mature eggs 0.46-0.67 (0.56±1.53) mm and in developing eggs 0.24-0.38 (0.28±1.01) mm.

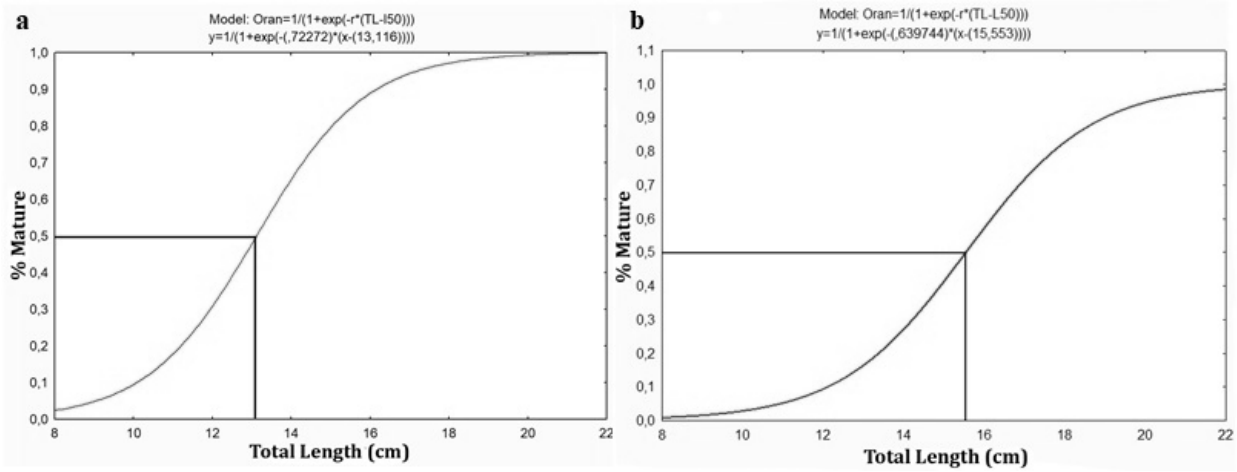

Figure 3 Length at first maturity L50 for females (a) and males of *Nemipterus randalli* (b)

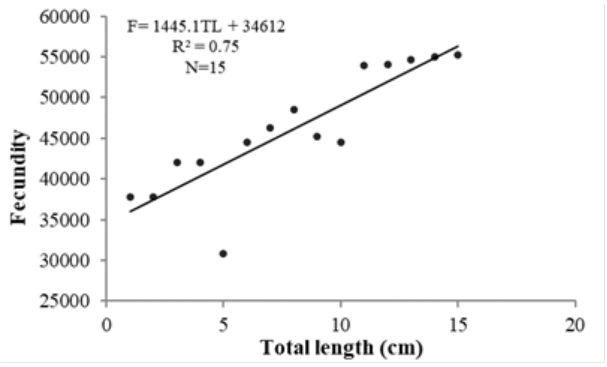

Figure 4 Total fecundity by length for *Nemipterus randalli*

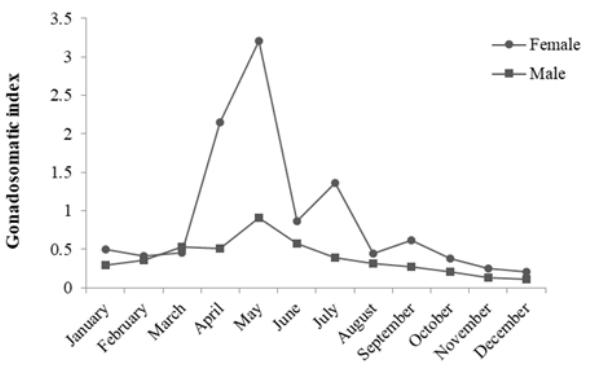

Figure 5 Monthly variation of GSI of *Pagellus erythrinus* caught in Aegean Sea

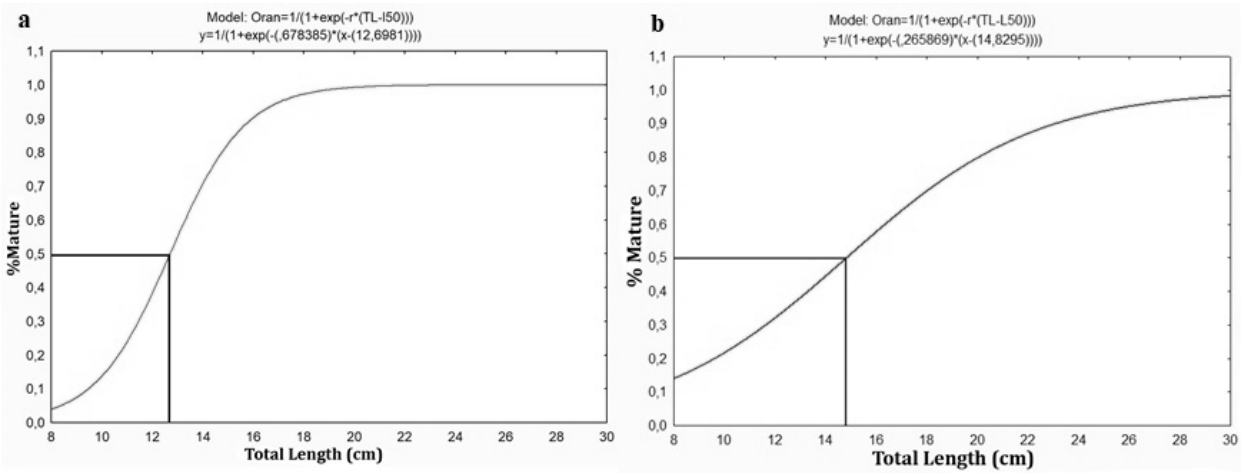

Figure 6 Length at first maturity L50 for females (a), and males of *Pagellus erythrinus* (b)

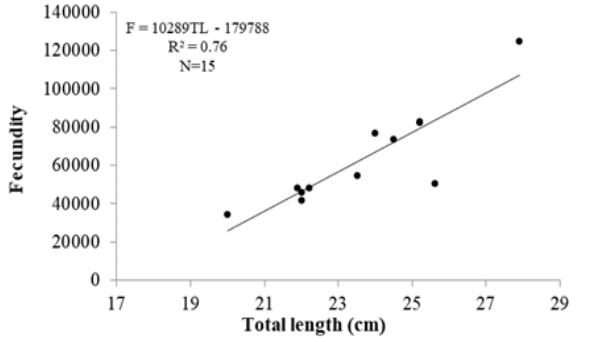

Figure 7 Total fecundity by length for *Pagellus erythrinus*

Discussion

Nemipterus randalli

Considering previous studies on the species *N. randalli*, their sex ratio according to Al Kiyumi et al. (2014) is 1:0.90 along Oman Sea, while İnnal et al. (2015) and Özen et al. (2016) found the ratios at 1:0.90 and 1:0.70 in Antalya Bay, respectively. On the other hand, Uyan (2017) and Yapıcı (2017) found sex ratio of female and male as 1:2.17 and 1:0.78 in Gökova Bay, respectively. General view of the study shows that females are slightly more dominant than males. Sex ratios of *N. randalli* range from 1:0.70 to 1:2.17 (Table 2). Our study showed that spawning seasons of *N. randalli* both females and males of *N. randalli* were reproductively active during the spring and summer, i.e. between April and August (females) and April to July (males). Moreover, the first maturity lengths in females and males are 13.11 and 15.55 cm, respectively. As the result of comparisons with studies across the Mediterranean Sea, Özen et al. (2016) found that the species' spawning period is May- September and first maturity length is 12.8 cm. Uyan (2017) showed its spawning period to be May-June and Yapıcı (2017) found that it is April- October and first maturity length is 12.86. Gonadosomatic index value of the species which Demirci et al. (2018) made to determine its reproduction period was seen to increase in February and reach to the highest value maximum in April and May. The first maturity length was found to be 11.02 cm (Demirci et al. 2018). It was clear from previous studies on reproduction period of the species that it was generally in spring and summer, which is consistent with our study. These results show that the spawning period is closely related to the ecological characteristics of the water system where the species inhabits (Nikolsky 1963). These differences could be caused by geographical variations and by the consequent differences of numerous factors, such as temperature and food availability. Those could be associated with genetic factors, catching pressure and selectivity of catching gears as well as with different methods used to determine first reproduction length (Dulčić et al. 2000).

The present study shows that reproduction seasons are similar for the two species, both of which partially spawn. Such type of spawning is aimed at increasing likelihood and success for the species to be involved in stock under unavailable environmental conditions and for migrant species to adjust themselves to the new habitats (Mañanós et al. 2009). Considering first maturity length of both species, *P. erythrinus* is seen to reach sexual maturity in younger lengths than lessepsian *N. randalli* and tend to be dominant in the habitat (Rilov 2009). However, native species do not always manage to achieve early lengths since survival of eggs spawned by young individuals is less than that of those laid by older ones (Mañanós et al. 2009). Because larvae are apt to hatch out of eggs spawned by young fish late, new individuals are supposed to participate in the stock late as well.

Table 2 Comparison of sex ratios with those in previous studies in the species *N. randalli*

Authors	Female:Male	Locality
İnnal et al. (2015)	1:0.90	Antalya Bay
Özen et al. (2016)	1:0.70	Antalya Bay
Uyan (2017)	1:2.17	Gökova Bay
Yapıcı (2017)	1:0.78	Gökova Bay
Al-Kiyumi et al. (2014)	1:0.90	Arabian Sea
Present study	1:0.41	Marmaris Bay

The present study found fecundity of *N. randalli* to be 37785-55200 (46172±7450) eggs. The fecundity of the species is yearly reported to be 12548-52158 eggs by Indian Council of Agricultural Research (CMFRI 2011-2012). Examined

individuals are 18.8 cm in average. Only fecundity was determined in the report. Now that there are not any studies made on fecundity of *N. randalli*, those of other Nemipterus species were studied. Manojkumar (2004) found fecundity of *Nemipterus japonicus* to be 14212-46369 eggs, Rajesh et al. (2013) 10472-65225 eggs in Mangolore shores and Rage (2002) 13900-58400 eggs. Sadashiv Gopal (1996) established fecundity as 5344-64369 eggs in *Nemipterus mesoprion* (Table 3).

Examination of other Nemipterus species showed values similar to those found in *N. randalli*. There was a linear correlation between its length and fecundity as F=1445.1TL+34612 (R^2=0.75). However, it was not possible to compare it with others because no previous studies were made related to the species. Relationship between total length and fecundity in some species; *N. japonicus* had F=-150511.00 +1163.58 L, r = 0.7626 (Rage 2002), Manojkumar (2004) found F = -2.45621+3.00111 LogL (r = 0.9018) (Table 4). Fecundity of the species can change based on length groups of the examined individuals and on quality and amounts of the food which they consume as well (Avşar 1998).

Table 3 Comparison of fecundity with those in previous studies

Authors	Species	Fecundity	Locality
Indian Council of Agricultural Research (CMFRI 2011-2012)	*Nemipterus randalli*	12548-52158	Indian
Manojkumar (2004)	*Nemipterus japonicus*	14212-46369	Gujarat
Rajesh et al. (2013)	*Nemipterus japonicus*	10472-65225	Mangolore Shores
Rage (2002)	*Nemipterus japonicus*	13900-58400	Veraval
Sadashiv Gopal (1996)	*Nemipterus mesoprion*	5344-64369	Veraval
Present study	*Nemipterus randalli*	37785-55200	Marmaris Bay

Table 4 Comparison of fecundity and length-fecundity relationship with those in previous studies in the species *Pagellus erythrinus*

Authors	Species	Fecundity	Fecundity relationship	Locality
Saleh (2018)	*Pagellus erythrinus*	1177.7-5818.18	F=90578-24487 TL	Libya
Elmajedeb et al. (2019)	*Pagellus erythrinus*	15504-222794	-	Libya
Farouk Mohammed et al. (2010)	*Pagellus erythrinus*	69968-139795	Fa = 10524+3866L	Libya
Present study	*Pagellus erythrinus*	34503-125102	F=10289TL-179788	Marmaris Bay

Pagellus erythrinus

The study on the species *P. erythrinus* showed the sex ratio of female and male to be 1:0.64. The previous studies were made by some authors; i.e. Mahdi et al. (2017) 1:0.43, Hoşsucu & Türker Çakır (2003) 1:0.32, Zarrad et al. (2010) 1:0.36, Metin et al. (2011) 2:0.08 and Yapıcı (2017) 1:0.43 (Table 5).

Other studies involving the Mediterranean and Atlantic populations showed the sex ratio to be significantly inequitable in favor of females (Pajuelo et al. 2003). Because *P.erythrinus* is of protogenical hermaphroditity, the phenomenon expected from current stocks is that small sized females and big sized males exist. However, it is generally seen that females are dominant, which evidently shows presence of small size males and big size females. The study by Metin et al. (2011) attributes this female dominancy to hermaphroditity and abundance of juveniles in the stock.

Reproduction season for female and male individuals of *P. erythrinus* was found to be in the spring in present study. Previous studies on the species are in Table 6 indicating that spring- summer are reproduction periods, which is generally consistent with our results as well. The present study found first maturity length to be 12.69 in females and 14.83 cm in males. Table 6 illustrates the related studies. Our study can be seen to be consistent with other works except for some differences. Such differences are believed to be attributable to variations of sea water in study locations.

The study showed the body's length as 16-27.9 cm in the samples whose fecundity was determined. Saleh (2018) found in the study of individuals with a length range of 18-27.5 cm that its fecundity was 1177.7-5818.18 eggs and length and fecundity relationship was F=90578-24487 TL (r=0.8909) in Libya. Elmajedeb et al. (2019) established fecundity to be 15504-222794 eggs on 21.73 cm individuals in Libya. Farouk Mohammed et al. (2010) found fecundity to be 69968-139795 eggs on studied samples of 15-33 cm and total length-fecundity relationship as Fa = 10524+3866L. Fecundity values of the present study can be seen to be similar to those of the study by Farouk Mohammed et al. (2010). Although there are some similarities to and differences from previously made studies, variations observed in fecundity are believed to be attributable to different length groups used for the matter involved.

Table 5 Comparison of sex ratios with those in previous studies in the species *P.erythrinus*

Authors	Female:Male	Locality
Hoşsucu & Türker Çakır (2003)	1:0.32	Edremit Bay
Zarrad et al. (2010)	1:0.36	Tunis Bay
Metin et al. (2011)	1:0.08	Central Aegean Sea
Yapıcı (2017)	1:0.43	Gökova Bay
Mahdi et al. (2017)	1:0.43	Oran Bay
Present study	1:0.64	Marmaris Bay

The fish migrations from the Red Sea to the Mediterranean through the Suez Canal have gradually increased in recent years and it is known fact that this

migration has both ecological and economic impacts on the Eastern Mediterranean fish natural populations (Yapıcı 2017). By examining in detail the reproductive biology of the sympatric *N. randalli* and *P. erythrinus* species, which share the same habitat, it has been tried to reveal whether the *N. randalli* species has any reproductive pressure on the native species.

However, risk possibility on the domestic species of the alien species migrating to the Mediterranean and their roles in the ecosystem may be understood through the detailed monitoring projects in future.

Table 6 Comparison of spawning seasons with those in previous studies in the species *Pagellus erythrinus*

Authors	Spawning season	Sexual maturity Total length (cm)		Locality
		♀	♂	
Hoşsucu & Türker Çakır (2003)	April-October	13.00	-	Edremit Bay
Zarrad et al. (2010)	April-October	14.60	15.80	Tunis Bay
Metin et al. (2011)	June-October	11.30	15.08	Central Aegean Sea
Yapıcı (2017)	April-October	11.90	14.52	Gökova Bay
Mahdi et al. (2017)	April-July	12.50	-	Oran Bay
Present study	April-June	12.69	14.83	Marmaris Bay

Acknowledgement. The authors would like to thank the anonymous reviewers for their suggestions and comments.

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