



A Preliminary Study on Seasonal Changes in the Feeding Ecology and Growth Patterns of the Lessepsian Red Sea Goatfish *Parupeneus forsskali* Fourmanoir & Guézé, 1976 in the Gulf of Antalya, Eastern Mediterranean

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Abstract: The Red Sea goatfish, *Parupeneus forsskali* Fourmanoir & Guézé, 1976, is endemic to the Red Sea and the Gulf of Aden and is a Lessepsian species that entered the East Mediterranean through the Suez Canal in the early 2000s. This study aimed to determine the changes in the feeding ecology and growth characteristics of *P. forsskali* distributed in the Gulf of Antalya during two seasons. Statistical analyses revealed that individuals caught in the winter season were heavier and longer than those caught in the autumn season. In autumn, they exhibited high condition with negative allometric growth, whereas in winter, they showed low condition with positive allometric growth. The dietary habits of the species were analyzed through stomach content analysis (F%, N%, W%, and IRI), which revealed a strong preference for crustaceans, particularly Mysida and Euphausiacea. Additionally, seasonal variations were observed in diet proportions and diversity. The contribution of crustaceans to the diet decreased in winter compared to autumn, while diet diversity increased. This preliminary study provides initial insights into the feeding ecology and growth patterns of *P. forsskali*, laying the groundwork for future comprehensive research that will further support stock management and ecosystem conservation efforts.

Keywords: Condition factor, feeding ecology, lessepsian species, *Parupeneus forsskali*, stomach content analysis.

Doğu Akdeniz, Antalya Körfezi'nde Lessepsiye Kızıldeniz Keçi Balığı *Parupeneus forsskali*'nin Beslenme Ekolojisi ve Büyüme Özelliklerindeki Mevsimsel Değişimler Üzerine Ön Çalışma

Öz: Kızıldeniz keçi balığı, *Parupeneus forsskali* Fourmanoir & Guézé, 1976, Kızıldeniz ve Aden Körfezi'ne endemik olup, Suez Kanalı aracılığıyla 2000'li yılların başında Doğu Akdeniz'e giren bir Lessepsian türüdür. Bu çalışma, Antalya Körfezi'nde dağılan *P. forsskali*'nin beslenme ekolojisi ve büyüme özelliklerindeki değişiklikleri iki sezon boyunca belirlemeyi amaçlamıştır. İstatistiksel analizler, kış sezonunda yakalanan bireylerin, sonbahar sezonunda yakalananlardan daha ağır ve uzun olduğunu ortaya koymuştur. Sonbaharda, negatif allometrik büyüme ile yüksek kondüsyon sergilerken, kışın, pozitif allometrik büyüme ile düşük kondüsyon gösterdikleri gözlemlenmiştir. Türün beslenme alışkanlıkları, mide içeriği analizi (F%, N%, W% ve IRI) yoluyla incelenmiş ve karideslere, özellikle Mysida ve Euphausiacea'ya güçlü bir tercih gösterdiği belirlenmiştir. Ayrıca, diyet oranları ve çeşitliliğinde mevsimsel değişiklikler gözlemlenmiştir. Karideslerin diyet katkısı, sonbahara kıyasla kışın azalmış, diyet çeşitliliği ise artmıştır. Bu ön çalışma, *P. forsskali*'nin beslenme ekolojisi ve büyüme kalıpları hakkında ilk bilgileri sunmakta olup, stok yönetimi ve ekosistem koruma çabalarını daha da destekleyecek ileri düzey araştırmalar için bir temel oluşturmaktadır.

Anahtar Kelimeler: Beslenme ekolojisi, kondüsyon faktörü, lessepsian türler, mide içeriği analizi, *Parupeneus forsskali*.

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INTRODUCTION

The Mediterranean Basin is a semi-enclosed system with highly complex ecosystems (Tsadok et al., 2023). In 1869, the construction of the Suez Canal allowed many alien fish species to enter the Mediterranean waters and establish populations (Turan et al., 2016; Zenetos & Galanidi, 2020). So far, researchers have recorded 150 alien fish species that have settled and established populations in the Mediterranean Sea, over 100 of which originate from the Red Sea (Gilaad et al., 2017). Introducing alien species into a new ecosystem has been reported to negatively affect existing biodiversity and ecosystem health (Yılmaz & Demirhan, 2020). In addition, they also alter the food web dynamics, reshape the community structure, and impact the ecosystem functions of the system they invade (Gilaad et al., 2017; Goren et al., 2016). The Red Sea goatfish *P. forsskali* Fourmanoir & Guézé, 1976, is endemic to the Red Sea and Gulf of Aden (Randall, 2004). *P. forsskali* is a species of the Mullidae family that entered the Mediterranean waters through the Suez Canal (Turan et al., 2016; Zenetos & Galanidi, 2020). *P. forsskali* is a relatively large species within the goatfish family, capable of growing up to 28 cm in length, and is one of the most common goatfish species in the Red Sea; it inhabits sandy areas between coral reefs (Hüseyinoğlu et al., 2023). In local populations of *P. forsskali*, individuals have been reported to live up to five years, reach a total length of 28.5 cm, and attain sexual maturity at 14.2 cm for males and 11.8 cm for females (Saemundsson et al., 2023). The Mullidae family includes about 99 species with a cosmopolitan distribution in the Atlantic, Pacific, and Indian Oceans, and most of these species have commercial value in the fish market (Froese & Pauly, 2022). Currently, there are two native (*Mullus surmuletus* - red mullet; *M. barbatus* - red mullet) and three alien goatfish species (*Parupeneus forsskali* - Red Sea goatfish; *Upeneus moluccensis* - goldbanded goatfish; *Upeneus pori* - Por goatfish) in the Mediterranean (Özvarol & Tatlıses, 2018). Especially in the shelf area of Antalya Gulf, a distinct depth segregation was observed in the distribution of species belonging to the genera *Mullus* and *Upeneus*. Furthermore, morphometric parameters (length-based measurements and growth parameters) of these species increased from the eastern to the western Mediterranean (Mutlu et al., 2022). Although the first confirmed record of *P. forsskali* in the Mediterranean was from Beirut, it has also been observed visually along the southeastern coast of Turkey (Bariche et al., 2013). This species has replaced native goatfish species in many areas and has become an important commercial fish in the eastern basin (Evagelopoulou et al., 2020). *P. forsskali* was first reported from Taşucu-Mersin in 2000 (Çınar et al., 2006), followed by Iskenderun Bay (Gürlek et al., 2016), Antalya

Bay (Gokoglu & Teker, 2016), and Muğla coast (Ergüden et al., 2018; Yapici & Filiz, 2017). Researchers have reported that this Lessepsian species spreads continuously and quickly establishes new populations along the Mediterranean coast of Turkey (Ergüden et al., 2018). Lessepsian species can often spread rapidly in new habitats like the Mediterranean and compete with native species. Data on the dietary characteristics of these species allows us to understand which native species they compete with, their place in the food chain, and, indirectly, their impact on other species. We also need to know their growth characteristics to predict how fast their populations can increase and their long-term environmental impacts. Some previous studies have reported morphometric and meristic characteristics (Gürlek et al., 2016), age and growth characteristics (Turan et al., 2021), biological (Vagenas et al. 2023) and feeding characteristics (Evagelopoulou et al., 2020; Michail et al., 2024) and reproductive characteristics (Saemundsson et al., 2023) of *P. forsskali* populations in Iskenderun Bay. However, based on the available biological and ecological information, researchers do not categorize *P. forsskali* as an "invasive species" but only as an "alien species." They have not recorded it causing detrimental changes to the organisms it coexists with or the marine habitat (Vagenas et al., 2023). However, more extensive studies may change this information, so continued monitoring and research on the biological and ecological characteristics of the species is needed. Unfortunately, there is no data on the feeding ecology and growth characteristics of the populations of *P. forsskali* distributed in the Gulf of Antalya. Therefore, this study aimed to determine the changes in the condition, growth, and feeding characteristics of *P. forsskali* populations in the Gulf of Antalya during two seasons.

MATERIAL AND METHOD

The Red Sea goatfish *P. forsskali* samples were caught by commercial fishing vessels around Sican Island in the Gulf of Antalya during the autumn (n=8) and winter (n=26) seasons. The fish samples were obtained as dead specimens from local commercial fishermen and brought to the Akdeniz University Biology Department, Hydrobiology Laboratory. In the laboratory, fish were fixed in 10% formaldehyde solution. Fish weights (W) and standard lengths (SL) were measured to the nearest 0.01 g and 1.0 mm, respectively. The relationships between total length and body weight were calculated for two seasons using a least squares linear model (LWR Ricker, 1975; Froese, 2006). The equation parameters $W = aL^b$ were estimated based on logarithmically transformed data: $\log W = \log a + b \log TL$, where W is the total body weight (g), TL is the total length (cm), a is the intercept, and b is the regression coefficient; the regression parameters a and b's 95% confidence intervals

(CI) and the regression coefficient (r^2) were determined using Past 4.03 software. Whether the b value in LWR was statistically different from "3" was tested with the Chi-Square test. Relative condition factor (CF, Le Cren, 1951) of the individuals in the fish population were compared seasonally: $CF = W_t / W_t'$, where W_t represents body weight, W_t' is the weight estimated based on the standard length and weight relationship ($W_t' = aL^b$) from the linear regression model. The stomach and intestine of each individual were removed from the abdominal cavity to analyze the fish's stomach contents. The weight (GW, g) and length (GL, cm) of the digestive tract of each individual were measured. The Relative Gut Length ($RGL = GL/SL$) index was calculated to reveal the fish individuals' feeding habits and dietary diversity. In general, $RGL < 1$ is considered Carnivore, $RGL > 3$ Herbivore, $1 < RGL < 3$ Omnivore (Karachle & Stergiou, 2010). The stomach contents of all individuals were determined under a stereo microscope using a gravimetric method. For this purpose, stomachs were dissected from fish, excess water was removed with absorbent paper, and then taxonomically classified. The gut contents were analyzed using the Index of Relative Importance (IRI), as proposed by Hyslop (1980), to quantify the dietary significance of different prey categories. The IRI was calculated using the

following formula: $IRI = F\% (W\% + N\%)$. $F\%$ is the frequency of occurrence of a prey item in the total number of stomachs examined, $N\%$ is the numerical percentage of the prey item relative to the total number of prey items, and $W\%$ is the gravimetric percentage (by weight) of the prey item relative to the total weight of all prey items. To facilitate comparison among prey categories, the IRI values were subsequently standardized to percentages (IRI%) using the formula: $(IRI_j / \sum_{j=1}^n IRI_j) \times 100$, where IRI_j is the IRI value of prey item j . This index combines frequency, number, and weight to give a more integrated measure of prey importance. Since the fish data did not meet the assumptions of normal distribution (Shapiro-Wilk test) and homogeneity of variances (Levene's test), the Chi-Square Test was applied to assess seasonal differences in the data.

RESULTS

In this study, a total of 34 *P. forsskali* individuals were sampled from the Gulf of Antalya during two seasons. Ranges of standard length and weight of *P. forsskali* along two seasons were 9-12 cm and 15-45 g, respectively (Figure 1).

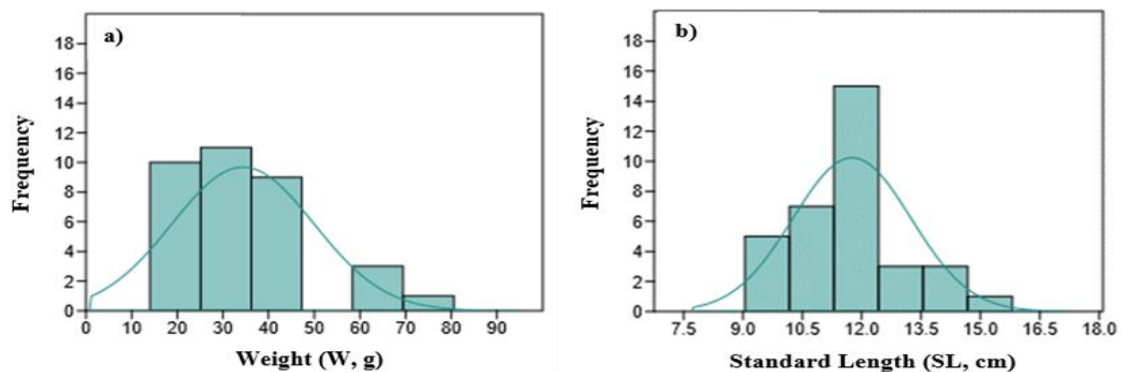


Figure 1. a) Weight and b) Standard length distributions of *P. forsskali* in the Gulf of Antalya.

There were significant differences between the length and weight of fish in the autumn and winter (SL , $\chi^2 = 11.88$; $df = 1.33$; $P = 0.002$; W , $\chi^2 = 15.29$; $df = 1.33$; $P = 0.0001$, respectively). Individuals from the winter season had higher weights and longer lengths than individuals from the autumn (Figure 2).

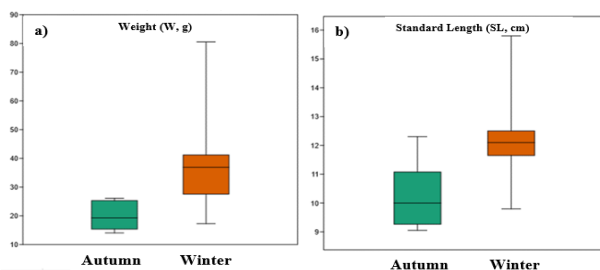


Figure 2. Seasonal distribution of standard length (a) and body weight (b) of *P. forsskali* (horizontal lines and long vertical bars in the colored box represent mean values and standard deviations, respectively).

Although the sample size for autumn ($n = 8$) was limited, the data are presented separately to reflect the seasonal framework of the study. These results should be interpreted with caution and seen as preliminary. According to the results of statistical analysis, individuals from the winter season showed positive allometric growth ($b > 3$, $p < 0.001$, $R^2 = 0.92$), and the "a" value was 0.03. In contrast, individuals from the autumn season showed negative allometric growth ($b < 3$, $p < 0.001$, $R^2 = 0.93$), and the "a" value was 0.007 (Figure 3). The chi-square test also revealed significant differences in the relative condition factors (CF) of fish between autumn and winter seasons ($\chi^2 = 72.31$; $df = 1.33$; $P < 0.0001$). The mean condition factor (CF: 1.03) of individuals from the autumn season was higher than that from the winter season (CF: 0.75).

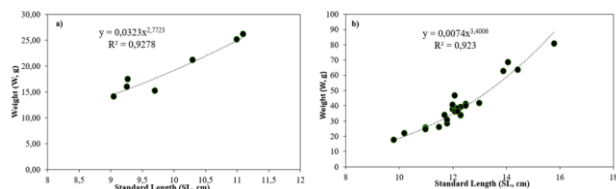


Figure 3. Length-weight relationship (LWR) parameters of *P. forsskali* individuals sampled in (a) autumn (n=8) and (b) winter (n=26) seasons.

The mean gut length of *P. forsskali* was 0.72 ± 0.08 cm in autumn and 0.98 ± 0.17 cm in winter. The mean relative gut length index of *P. forsskali* showed seasonal variation and was higher in the winter than in the autumn ($\chi^2 = 17.06$; $df = 1.33$; $P = 0.0002$). There is a linear relationship between SL and gut length (GL) ($r^2 = 0.68$, $n = 34$, $P < 0.001$). The stomach content analysis revealed that Mysida and Euphausiacea were the main prey taxa of *P. forsskali* in the autumn season, appearing in high numbers and frequencies in the stomach contents (Table 1). In the winter season, the prey diversity of the fish was higher (11) than in the autumn season (5), and the most important prey taxa based on the IRI% were Euphausiacea, Mysida, Gastropoda, Amphipoda, and Copepoda (Table 1).

Table 1. Percentage distribution of prey organisms in the diet of *P. forsskali* in the Gulf of Antalya.

Prey Group	%W		%F		%N		%IRI	
	Autumn	Winter	Autumn	Winter	Autumn	Winter	Autumn	Winter
Euphausiacea	35.88	30.07	50.00	38.46	36.36	90.91	38.93	32.37
Amphipoda	4.33	24.63	25.00	23.08	18.18	54.55	6.07	12.71
Mysida	49.08	18.01	50.00	38.46	36.36	90.91	46.05	29.15
Decapoda	0.39	3.41	12.50	3.85	9.09	9.09	1.28	0.33
Gastropoda	10.31	2.39	25.00	26.92	18.18	63.64	7.68	12.37
Copepoda	0.00	11.42	0.00	19.23	0.00	45.45	0.00	7.61
Ostracoda	0.00	0.07	0.00	11.54	0.00	27.27	0.00	2.20
Fish larvae	0.00	5.93	0.00	11.54	0.00	27.27	0.00	2.67
Coleoptera	0.00	3.41	0.00	3.85	0.00	9.09	0.00	0.33
Macroalgae	0.00	0.59	0.00	3.85	0.00	9.09	0.00	0.26

DISCUSSION AND CONCLUSION

With the opening of the Suez Canal, many alien species have entered the Mediterranean waters from the Red Sea and established populations (Turan et al., 2016; Turan et al., 2021; Zenetos & Galanidi, 2020). *Parupeneus forsskali* is one of the Lessepsian migratory species that crossed from the Red Sea to the Mediterranean following the opening of the Suez Canal. This process has accelerated, especially in recent years, with the increase in seawater temperatures (Golani, 1998). This species is considered economically important due to its high market value as a food fish in both the Red and Mediterranean Seas (Evangelopoulos et al., 2020; Sabrah, 2015). However, studies on the commercial value of *P. forsskali* are lacking in the coastal waters of Turkey. The use of this species as a potential commercial fish depends on population dynamics. Additionally, Golani (1998) stated that, besides genetic variation, trophic niche breadth (diet diversity) and life history traits play a significant role in the successful establishment of populations of species, particularly those belonging to the Mullidae family, in new environments. At this point, deciphering a species' growth parameters and

feeding ecology is crucial for determining the species biology, ecology, population success, and stock management (Turan et al., 2021). As a result, this study revealed the fitness, growth characteristics, and feeding ecology of the *P. forsskali* population distributed in the Gulf of Antalya. The length-weight relationship constant "b" value of *P. forsskali* was determined as negative allometric growth with $b < 3$ in the winter season. If fish grow allometrically, fish weight will increase either slower ($b < 3$) in proportion to the length increase (Saha et al., 2009). Positive allometric growth ($b > 3$) indicates that the fish's body weight is growing faster than its length, which can result in the fish having a larger and more robust structure. In negative allometric growth, the fish's length may increase rapidly, while body mass (fat or muscle accumulation) grows more slowly, resulting in a longer but thinner body. This pattern suggests that fish in the autumn season are shorter and leaner, whereas those in the winter season are longer and heavier. Previous studies, for example, Vagenas et al. (2024), did not detect any differences in body growth regressions between sexes in the Aegean Sea populations of this species. Ergüden et al. (2015) found that the populations in Iskenderun Bay have a negative allometric growth type ($b < 3$) for both sexes. Turan et al. (2021) determined the b value for *P. forsskali* populations in Iskenderun Bay as $b > 3$ for both sexes. Similarly, Saemundsson et al. (2023) reported that both male and female of *P. forsskali* caught off the coast of Cyprus exhibited positive allometric growth ($b > 3$). In this study, we did not perform sex determination, but other studies have emphasized that the sexes do not affect the b value. These variations in the relationship constant "b" may result from differences in environmental parameters of the ecosystem where the populations exist, individual body size, and the quantity and quality of available food in the region during the sampling season (Tsoumani et al., 2006).

Farrag et al. (2018) reported that the total lengths (TL) of *P. forsskali* individuals ranged from 11 to 27 cm, with the highest frequency (14.93%) observed in the 18–18.9 cm length group. Similarly, a specimen recorded from the Egyptian Mediterranean coast by Mehanna & Hassanien (2020) had a TL of 26.5 cm, fork length of 23.0 cm, standard length (SL) of 21.5 cm, and a total weight of 228.4 g, representing a large, likely mature individual. In contrast, the present study reported a narrower size range, with SL values between 9 and 12 cm and body weights ranging from 15 to 45 g. Considering that SL typically constitutes 75–85% of TL, the individuals sampled in our study likely represent younger age classes or subadults. These discrepancies in size structure may result from differences in sampling season, habitat conditions, fishing gear selectivity, or local population dynamics. Furthermore, the current data were obtained during autumn

and winter, which may also reflect seasonal growth variation. These results suggest that while larger individuals of *P. forsskali* are present and well-established in parts of the eastern Mediterranean, including Egypt and Cyprus, our findings provide preliminary insight into the presence of smaller size classes and potential recruitment in the Gulf of Antalya. Broader and year-round sampling efforts are needed to determine the full population structure and growth characteristics of this species in the region.

In general, the condition factor indicates fish populations' health (physiological condition and yield). It reflects lipid content and growth rates as affected by biotic and abiotic factors (Karuppiyah et al., 2022). The condition factor, $CF > 1$, may indicate a better condition than the average condition of other individuals of the same length, while $CF < 1$ may indicate a worse condition (Uzunova et al., 2017). In this study, the mean condition factor of the fish in the autumn season (1.03 ± 0.12) was higher than in the winter season (0.75 ± 0.08). Compared to the length-weight relationship, it was found that *P. forsskali* exhibited positive allometric growth during the winter season, with lower condition factors than in the autumn season. Although positive allometric growth occurs in the winter season, the decrease in temperature in the Eastern Mediterranean waters, along with reductions in food availability and the population's feeding activities, may lead to a decline in the fish's condition.

A species' feeding ecology is interrelated with its population dynamics. Therefore, gaining insight into the feeding ecology of a species, population, or community can provide important information on resource allocation, prey preference, predation strategy, energy transfer, and many other aspects (Braga et al., 2012). Regarding Lessepsian fish species, dietary characteristics are critical in understanding whether a species is invasive. A wide dietary range or high adaptability may indicate invasive characteristics (Golani, 1998; Katsanevakis et al., 2014). Researchers can determine whether it threatens the habitats and resources of native species. In this context, although *P. forsskali* is a relatively recent migrant to the Eastern Mediterranean basin, studies have shown that it is a strong competitor for resources and space, demonstrating notable habitat flexibility in the newly invaded areas (Arndt et al., 2018; Evagelopoulou et al., 2020). Within the scope of stable carbon isotope ($\delta^{13}C$) analyses, Tsadok et al. (2023) revealed a clear and significant isotopic difference between *P. forsskali* populations from the Mediterranean coast of Israel and the Gulf of Aqaba in the Red Sea. These findings indicate notable differences in dietary sources between native (Red Sea) and non-native (Eastern Mediterranean) populations. In this study, the RGL index indicated that this fish is carnivorous, with its diet primarily consisting of the Crustacea taxa, namely Euphausiacea, Mysida,

Amphipoda, and Copepoda. Therefore, the findings of this study align with those of other studies conducted in the Mediterranean and Aegean Seas (Evagelopoulou et al., 2020; Tüzün & Gücü, 2024; Vagenas et al., 2024). This species exhibits a constant feeding profile in each new region of its distribution. In this study, we detected seasonal variation in the diet composition of *P. forsskali*. In the autumn season, Mysida and Euphausiacea comprised 85% of the species' diet (%IRI). However, this proportion decreased to 61.5% in the winter season as different prey groups were added to the diet. Michail et al. (2024) found that *P. forsskali* individuals sampled from the Cypriot coast preferred different Crustacea groups each season: Copepoda and Decapoda in the autumn and Isopoda and Decapoda in the winter. Besides, the gut length of *P. forsskali* varied between 7.34 (autumn) and 12.08 cm (winter), the RGL index did not show seasonal differences (0.72-0.98) in this study. This phenotypic flexibility in gut morphology may be due to changes in gut length to utilize food resources more efficiently (Akin et al., 2016).

In conclusion, this study aimed to elucidate the feeding ecology and growth characteristics of *P. forsskali* populations in the Gulf of Antalya. Although based on a limited number of specimens, the findings provide preliminary insights into the species' feeding flexibility and growth dynamics, which appear to play a significant role in its successful adaptation to new environments. These initial observations underscore the need for further research involving larger sample sizes, and broader spatial and temporal scales to more comprehensively evaluate the ecological implications of this Lessepsian migrant. Nevertheless, the present results serve as a valuable foundation for stock management, ecosystem conservation efforts, and the assessment of interactions between native and non-native species in the Eastern Mediterranean.

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Declaration of interest statement

The authors report there are no competing interests to declare.

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