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Research Article

Progress of the dispersal of the alien goatfish *Parupeneus forsskali* (Fourmanoir & Guézé, 1976) in the Mediterranean, with preliminary information on its diet composition in Cyprus

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Abstract

Parupeneus forsskali has been the latest Indo-Pacific goatfish species to expand its range into the Mediterranean. It is the least studied alien mullid in the Eastern Mediterranean, and specific information on its diet is generally lacking in the literature. The objectives of this paper are (1) to comprehensively document the progress of its invasion in the Mediterranean through a systematic literature review to retrieve all published records of the species in the region, and (2) to present preliminary quantitative information on its diet in its non-native range. *Parupeneus forsskali,* first recorded in Cyprus in 2014, has established self-sustaining, reproducing, commercially important populations in the nearshore waters of Cyprus at least since 2017. Significant *P. forsskali* catches by artisanal fisheries in Cyprus began in late 2017 and have been increasing since. Its particularly successful establishment and spread across Cyprus occurred after a time lag of several years since its introduction in the Mediterranean, possibly during the 1990s or earlier. As the westernmost records of the species along both the southern and the northern Mediterranean coastlines were made in recent years, it is assumed that *P. forsskali* is currently expanding its range in the Mediterranean. The prey items identified in the stomach contents analysis, ranked by their frequency of occurrence, belonged to the following taxonomic groups: Crustacea (67%), Mollusca (37%), Polychaeta (19%), Foraminifera (12%), Actinopterygii (5%).

Key words: alien species, marine biological invasions, time lags, stomach contents analysis, mullids, Eastern Mediterranean

Introduction

The goatfish of the family Mullidae are marine carnivorous species that are rarely found also in brackish waters. They are important components of the demersal communities across the Atlantic, Indian and Pacific Oceans, and are considered among the most important commercial fish globally (Whitehead et al. 1986; Nelson et al. 2016). Six goatfishes have been confirmed to be present in the Mediterranean (Capapé et al. 2018). *Mullus surmuletus* Linnaeus, 1758 (surmullet) and *Mullus barbatus* Linnaeus, 1758

(red mullet) are native species, distributed throughout its extent (Whitehead et al. 1986). *M. barbatus* in particular constitutes a significant part of demersal fisheries' catches (Martin et al. 1999; Tsikliras et al. 2013; Mahmoud et al. 2017). *Pseudupeneus prayensis* (Cuvier, 1829) (West African goatfish) is a species of Atlantic origin, frequent along Mauritanian coasts (Whitehead et al. 1986). It is a recent immigrant in the Western and Central Mediterranean (Reina-Hervás 1987; Azzouz et al. 2011), and lately also in the Eastern Mediterranean (Crocetta and Bariche 2017), and should thus be considered a neonative species in the Mediterranean (*sensu* Essl et al. 2019). The other three goatfishes are alien, introduced through the Suez Canal (Lessepsian migrants): *Upeneus moluccensis* Bleeker, 1855 (goldband goatfish), *Upeneus pori* Ben-Tuvia & Golani, 1989 (Por's goatfish) and *P. forsskali* (Fourmanoir & Guézé, 1976) (Red Sea goatfish). *U. moluccensis* was first reported from Israel by Haas and Steinitz (1947), who misidentified it as "*Mulloides auriflamma* (non Forsskål, 1775)". *Upeneus pori* was first reported from Iskenderun Bay (Turkey) by Kosswig (1950) as *Upeneoides* (= *Upeneus*) *tragula* (Richardson, 1846). The two *Upeneus* species are now common in the Eastern Mediterranean and exploited by local fisheries (EastMed 2010; Avşar et al. 2016). *Parupeneus forsskali* has been the latest Indo-Pacific goatfish species to expand its range into the Mediterranean (Bariche et al. 2015). It was first recorded in 2004 and, until recently, it was generally considered a rare species without commercial significance (Bariche et al. 2013; Avşar et al. 2016; but see Ali 2018; DFMR 2018). *Parupeneus forsskali* is the least studied of the alien mullids in the Mediterranean, and a comprehensive review of the records of the occurrence of the species in this sub-region would assist in tracking the progress of its dispersal.

According to GBIF (2019), *P. forsskali* is distributed across the Indo-Pacific Ocean. However, Bogorodsky and Randall (2019) included the species among the endemic fishes of the Red Sea, also present in the Gulf of Aden, where it is particularly abundant at depths < 30 m (Ben-Tuvia and Kissil 1988). It is one of the most exploited goatfishes in the Red Sea, mainly by artisanal fisheries using gill and trammel nets (Farrag et al. 2018). In its native range, *P. forsskali* reaches a maximum total length of 28 cm (Sabrah 2015), a maximum longevity of 5 years (Mehanna et al. 2018) and a length at maturity of 16 cm (Farrag et al. 2018). It inhabits sandy bottoms and coral reefs (Golani 1999; Al-Rousan et al. 2005), and, like other goatfish species, probes sand with its sensory organs-carrying hyoid barbels for its prey. The prey of *Parupeneus* species in their native ranges mainly consist of benthic invertebrates (Hobson 1974; Wahbeh and Ajiad 1985). However, higher resolution, quantitative information on the diet of *P. forsskali* in its native range or the Mediterranean is lacking in the literature.

The objectives of this paper are (1) to comprehensively document the progress of *P. forsskali*'s invasion in the Mediterranean through a systematic literature review to retrieve all published records of the species in the

region, and (2) to present preliminary quantitative information on its diet in its non-native range.

Materials and methods

In order to document the progress of the dispersal of *P. forsskali* in the Mediterranean, we conducted a systematic review of the literature based on the "PRISMA" (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) approach (Moher et al. 2009). The bibliographic search was performed on the Google Scholar database (https://scholar.google.gr/) on all published literature, searching for "*Parupeneus forsskali*" anywhere in the text. This process resulted in 191 publication records (9 April 2019). Thirty four publications were then selected by screening the full text, using as the main selection criteria that the publications needed to give information on occurences of the species in the Mediterranean or on its diet. Two more publications that were available to the authors were also added to the review. Additionally, updated information on the distribution and abundance of the species and its importance for small-scale coastal fisheries in Cyprus based on unpublished data of the Department of Fisheries and Marine Research of Cyprus (DFMR) and the personal observations of the authors is also presented. All of the 36 selected publications dealt with the distribution of the species in the Mediterranean, while none was found on its diet composition, with the exception of the study of Uiblein (1991) on its feeding behavior in the Red Sea. Data collected from the selected publications included the country, location, geographic coordinates, date, number of specimens/density, habitat, depth, sampling methodology and bibliographic information on the source. The results of the systematic review were tabulated and the occurrence records locations were mapped with ArcGIS Desktop 10.5.

For the analysis of its diet, 73 specimens of *P. forsskali* were bought from the local fishermen at Potamos Liopetriou in southeastern Cyprus. The fish were caught with trammel nets (36 mm mesh size), at a depth of 15–40 m, during the summer of 2018. Nineteen specimens were fished in June, 18 in July, and 36 in August 2018. The fishing grounds are located between Cape Pyla and Agia Napa, at the southeastern coast of Cyprus (Figure 1). They consist mostly of rocky bottoms, while at greater depths soft substrate and *Posidonia oceanica* (Linnaeus) Delile, 1813 vegetation also occur. All specimens were frozen and transferred for laboratory analysis to the Department of Marine Sciences, University of the Aegean, Greece.

The thawed specimens' lengths (total lengths) were measured in the lab with a digital caliber to the nearest mm and weights with a scale to the nearest 0.01 g. Sex was determined by macroscopic examination of the gonads. Stomach contents analysis was carried out by stomach dissection and examination of the contents under a stereomicroscope.

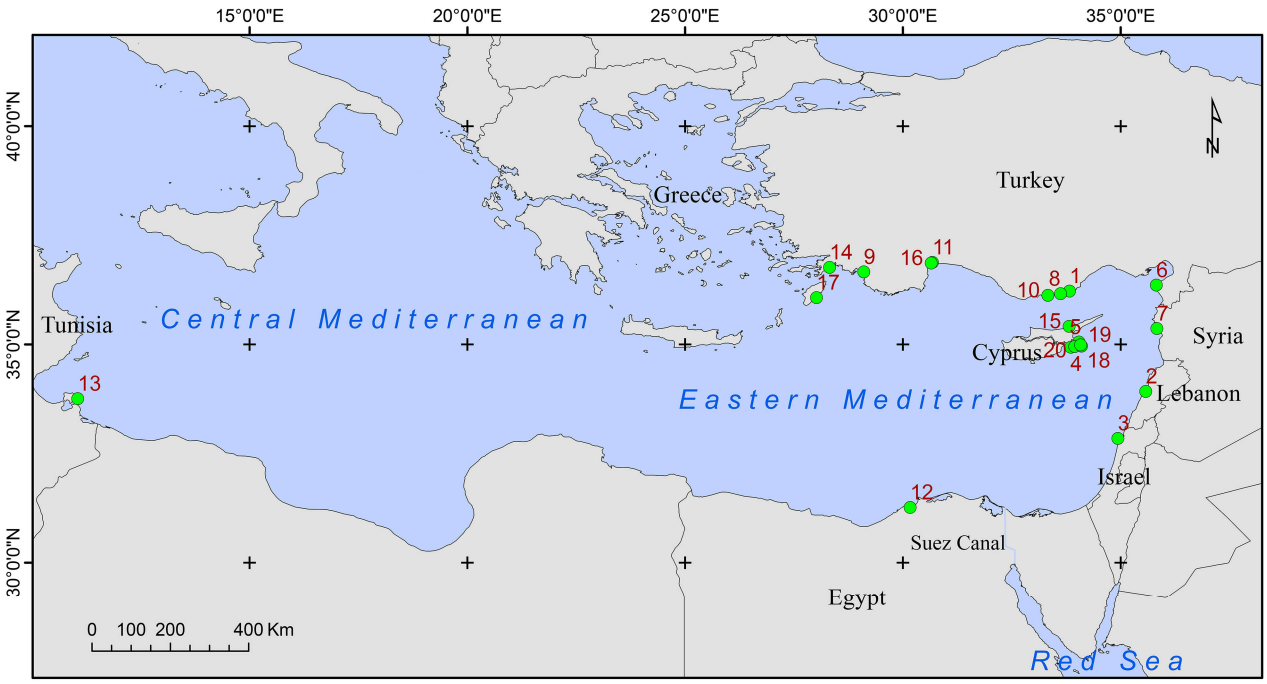

Figure 1. Map indicating the study area (#20), as well as the published records of occurrence of *Parupeneus forsskali* in the Mediterranean. The numbers in parentheses correspond to the bibliographic source numbers as given in Table 1 and Supplementary material Table S1.

Dietary composition and the relative importance of different food items were determined by the frequency of occurrence method (Hyslop 1980):

$$\%O_i = \frac{P_i}{N} \times 100$$

where $\%O_i$ is the % frequency of occurrence of prey item i,
P_i is the number of stomachs where prey item i was found, and
N is the number of stomachs examined

Although this method does not estimate the actual bulk of each group of prey in the stomachs, it has been considered as the one providing the most robust and interpretable measure of diet composition (Baker et al. 2014; Buckland et al. 2017).

The Fullness Index of Blegvad (1917) was calculated as follows: (stomach contents weight / body weight) × 10000.

To evaluate whether the number of fish stomachs examined was adequate for a valid description of the diet of the species, accumulation prey curves (Ferry and Cailliet 1996; Tiralongo et al. 2018) were computed with the vegan R package (Oksanen et al. 2019). The estimated (mean) number of prey groups and associated CI were plotted against the cumulative number of stomachs examined. Stomach order was randomised, as suggested by Ferry and Cailliet (1996).

A six-stage maturity scale based on external appearance (Nikolsky 1963) was used to classify the maturity of gonads.

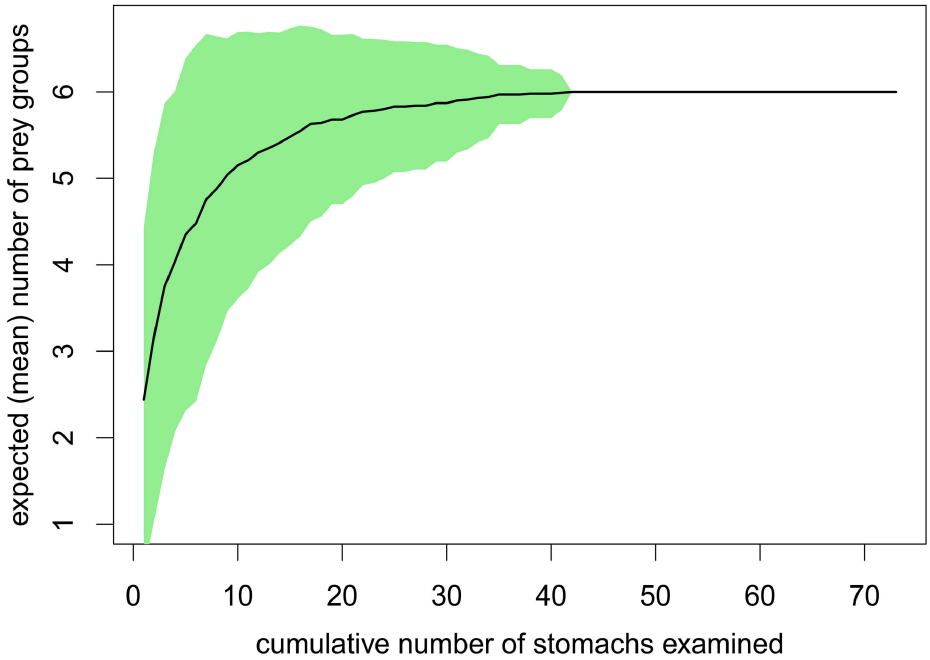

Figure 2. Prey groups accumulation curve with associated 95% confidence intervals. Stomach order was randomized.

Results

All specimens in the sample (29 females and 44 males) corresponded to the diagnostic morphological characters of *Parupeneus forsskali* (Randall 2004; Bariche et al. 2013). Fish total lengths (TL) ranged from 12.2 to 20.4 cm, with a mean value of 16.3 cm. The assessment of the maturity of the gonads revealed that 29 individuals in the sample were reproductively mature (5 males and 20 females at stage IV and 4 females at stage V).

The results of the stomach contents analysis showed the presence of five main taxonomic groups: Crustacea (67%), Mollusca (37%), Polychaeta (19%), Foraminifera (12%), Actinopterygii (5%). Fourteen stomachs out of 73 (19.18%) were found empty. It was not possible to identify the prey items to a lower taxonomic level due to the generally high degree of digestion. The fullness index ranged from 0 to 670.3, with a mean value of 57.1. The computation of the accumulation prey curve showed that the number of sampled *P. forsskali* stomachs was sufficient to describe their diet (Figure 2).

The systematic review of the literature resulted in the documentation of 19 published records of the occurrence of *P. forsskali* in the Mediterranean, presented in Tables 1 and S1 and mapped in Figure 1. The first documented record of the species in the Mediterranean was its observation at Tasucu, Mersin Bay, Turkey, made during an underwater survey in 2004 (Çinar et al. 2006). However, Çinar et al. (2006) reported that the species had been observed at the same location before, in 2000. The next published record of the species in the Mediterranean is a specimen caught by fishing gear in Lebanon in 2012, the first that was taxonomically verified (Bariche et al. 2013). Since then, it has been recorded by underwater observation or specimens

Table 1. List of the published records of occurrence of *Parupeneus forsskali* in the Mediterranean Sea and associated data. n.d. = no data given in the bibliographic source.

No	Country	Location	Record date	No of specimens/ Density	Habitat	Depth (m)	Sampling methodology	Source
1	Turkey	Tasucu, Mersin Bay	2004*	1	rocky bottom	0–5	underwater observation	Çinar et al. 2006
2	Lebanon	North of Beirut	2012	1	rocky bottom	40	trammel nets	Bariche et al. 2013
3	Israel	Southern edge of Haifa Bay	2013	1	n.d.	45	bottom trawl	Sonin et al. 2013
4	Cyprus	Area of Cape Pyla	2014	1	rocky bottom/*Posidonia oceanica*	24	trammel nets	Chartosia and Michailidis 2016
5	Cyprus	off Agia Triada	2014	1	n.d.	15	nets	Iglésias and Frotté 2016
6	Turkey	Iskenderun Bay	2015	1	n.d.	30	trammel nets	Gürlek et al. 2016
7	Syria	Northwest of Jableh	2015	1	sandy bottom	30	bottom trawl	Ali et al. 2016
8	Turkey	Yeşilovacık Bay	2015	n.d.	n.d.	100–110	bottom trawl	Yağlioğlu and Ayas 2016
9	Turkey	Fethiye Bay	2016	1	n.d.	12	underwater observation	Ergüden et al. 2018
10	Turkey	Aydıncık Bay	2016	2	n.d.	18	bottom trawl	Ergüden et al. 2018
11	Turkey	Konyaalti beach, Gulf of Antalya	2016	1	sandy-gravelly bottom	8–10	underwater observation	Gökoğlu and Teker 2016
12	Egypt	Alexandria	2016	1	rocky bottom	40	trammel nets	Mehanna et al. 2016
13	Tunisia	Jerba Island, Gulf of Gabès	2016	1	sandy-muddy bottom/seagrass and algae	7	underwater observation	Capapé et al. 2018
14	Turkey	off Turunç, Muğla province	2016	1	rocky bottom/*Posidonia oceanica*	10	underwater observation	Yapici and Filiz 2017
15	Cyprus	Gazimağusa	2017	7	sandy bottom	18	trammel nets	Özvarol and Tatlises 2018
16	Turkey	Gulf of Antalya	2017	1	sandy bottom	11	spearfishing	Özvarol and Tatlises 2018
17	Greece	off Lardos beach, SE Rodos Isl.	2017	2	fine sand/*Cymodocea nodosa*/rocky bottom	5–30	bottom seine	Kondylatos and Corsini-Foka 2017
18	Cyprus	Cavo Greko	2017, 2018	61**	highest population density in rocky habitats	< 30	underwater observation	DFMR 2018
19	Cyprus	Nisia	2017, 2018	114**	highest population density in rocky habitats	< 30	underwater observation	DFMR 2018
20	Cyprus	between Cape Pyla and Agia Napa	2018	73	rocky bottom/soft substrate/*Posidonia oceanica*	15–40	trammel nets	this study

* In Cinar et al. (2006) it is reported that the first observation of *Parupeneus forsskali* along the Turkish coast was made off Mersin, near Tasucu, in 2000.
** Maximum seasonal value of mean density (ind./1000 m^2).

were caught with trammel nets or bottom trawl in Israel, several locations in Turkey (Levantine and South Aegean coasts), Cyprus, Egypt, Tunisia and, recently, in 2017, in Greece (Table 1).

Cilia (1979) reported a record of the goatfish *Pseudupeneus barberinus* (Lacepède) (= *Parupeneus barberinus*) from the Maltese island of Gozo. However, according to Golani et al. (2004), the records of *P. barberinus* in the Mediterranean as an alien species should be considered erroneous, since it does not occur in the Red Sea. Sciberras and Schembri (2007) included the record from Gozo by Cilia (1979) in their alien marine species list from the Maltese islands as *Parupeneus* sp., arguing that the description given by Cilia (1979) showed some resemblance to *P. forsskali*. Since that possible sighting of *P. forsskali* from Gozo has not been confirmed yet with further, more reliable records, we decided not to include it in our list.

The species occurred at depths ranging from 0 to 110 m: There is only one record of the species from depths > 50 m (Yağlioğlu and Ayas 2016), and 75% of the existing records are from depths < 40 m (Table 1). *Parupeneus*

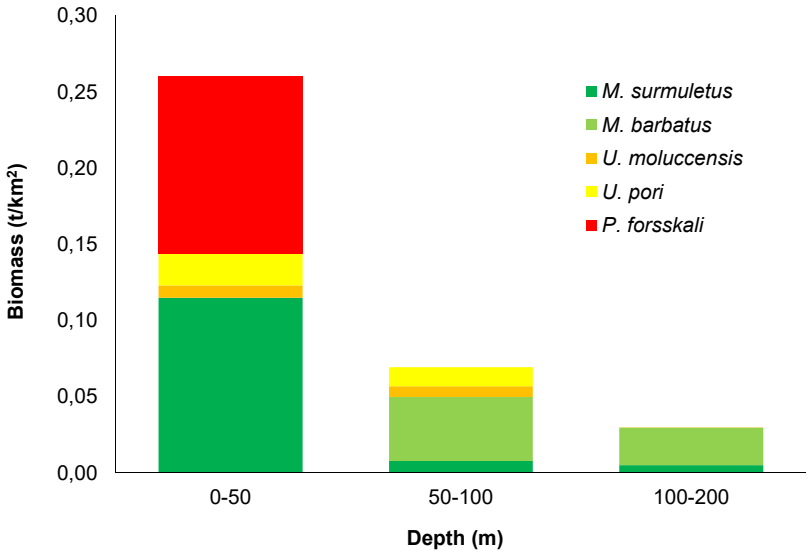

Figure 3. Biomass (t/km^2) by depth zone of the native *Mullus surmuletus* and *Mullus barbatus* and alien *Upeneus moluccensis*, *Upeneus pori* and *Parupeneus forsskali* in Cyprus, in late 2017. The estimates for 0–50 m are based on visual survey data (DFMR 2018), after summing biomasses in different habitat types, weighted by habitat surface area. The estimates for 50–100 and 100–200 m are based on raw data of MEDITS trawl surveys (Bertrand et al. 2002).

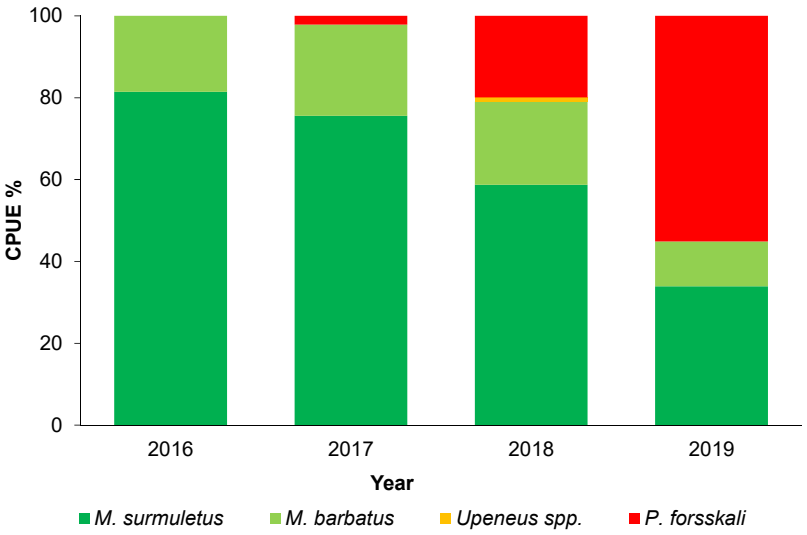

Figure 4. Mullidae annual CPUE (kg/trip) percentages in all sampled artisanal fisheries trips from 2016 to 2019 (all during sunrise).

forsskali was observed or caught mainly on rocky bottoms, but also on soft substrate, often in the vicinity of seagrass vegetation (*P. oceanica*, *Cymodocea nodosa* (Ucria) Ascherson, 1870).

In Cyprus, since its first record in August 2014, *P. forsskali* has spread in shallow waters < 50 m deep throughout the coast and today is possibly the most abundant mullid in the area (Figure 3). In addition, *P. forsskali* has already become as commercially important as it is in its native range (Al-Absy 1988; Khalaf and Disi 1997), as predicted by several authors (e.g. Golani 1994; Çinar et al. 2006). Based on unpublished DFMR data from samplings at landing sites, significant *P. forsskali* catches began in late 2017 and have been increasing since (Figure 4), but, as the species is mixed and

traded along other mullids, catch figures are absent in the official reports which are mainly based on sales documents. *Parupeneus forsskali* is mostly targeted by the artisanal fleet with bottom-set trammel nets at depths of usually less than 50 m. Fish are targeted during both sunrise and sunset hours, with the biggest quantities being caught during sunset. An average targeted catch contains around 4–5 kg of individuals of this species, although catches of 15 kg or more are not rare. Total annual catches can be preliminarily estimated to be as high as 20 t, although this needs to be confirmed. Currently the species is being sold in fish markets and restaurants alongside other mullids at relatively high prices (Nikolas Michailidis *pers. obs.*).

Discussion

According to the results of the systematic review of the literature, *Parupeneus forsskali,* a Lessepsian migrant species first recorded in Cyprus in 2014, has established self-sustaining, reproducing populations in the nearshore waters of Cyprus at least since 2017. *P. forsskali* catches by artisanal fisheries in Cyprus began in late 2017 and have been increasing since. Success in establishment and spread across Cyprus occurred only after a time lag of several years since its introduction in the Mediterranean, estimated to have happened during the 1990s or earlier. Moreover, the species has lately been expanding its range in the Mediterranean, currently occurring as far west as the Dodecanese, Greece and Tunisia. The first, preliminary quantitative information on food preferences of the species in Cyprus presented in this paper—representing the first published quantitative diet information for its global distribution—indicated that, similar to what is known about the diets of the *Mullus* and *Upeneus* species (Hobson 1974; Wahbeh and Ajiad 1985; Golani and Galil 1991; Vassilopoulou et al. 2001; Mahmoud et al. 2017), *P. forsskali* feeds predominantly on crustaceans and to a lesser degree on other invertebrates, fish and foraminiferans.

The main objective of this study was a comprehensive documentation of the dispersal pattern of *P. forsskali* in its non-native range in the Mediterranean: The first observations of the species in the Mediterranean were made at the Levantine coast of Turkey during the early 2000s (Çinar et al. 2006), while subsequent recordings were made several years later, in Lebanon (2012) and Israel (2013). Since 2014 recordings have increased in frequency and the species has been found in Cyprus, Egypt, further westwards along the Turkish coastline, and lately in Tunisia (2016) and Greece (2017). Based on the information collected, it can be assumed that the species entered the Mediterranean from the Suez Canal some time during the 1990s or earlier. Its first observation in the Mediterranean taking place in Turkey, far from the vicinity of the Suez Canal, and its second recording in 2012 in Lebanon occurring only after several years, could be attributed to a combination of a sustained rarity in its non-native

range and a low resolution of observations. Importantly, the fact that the westernmost records of the species along both the southern and the northern coastlines were made in recent years indicate that *P. forsskali* has been lately expanding its range in the Mediterranean.

Parupeneus forsskali evidently belongs to those species that have persisted in their non-native range at low numbers for several years, presenting time lags between introduction and strong population growth and high spread rates (Crooks and Soulé 1999; Crooks 2005; see also Bariche et al. 2013): Until recently, almost all occurrence reports for *P. forsskali* in the Mediterranean were based on single individuals observed or caught with fishing gear, while slightly larger numbers of specimens (2–7) were reported rarely. The establishment of self-sustaining local populations of the species was often assumed but based only on anecdotal evidence: Sonin et al. (2013) reported that there have been numerous observations of this species by underwater divers off the coast of Israel. Likewise, Kondylatos and Corsini-Foka (2017) reported that local fishermen reported the presence of numerous individuals of the species around the fishing grounds of Rhodes. However, DFMR (2018) recorded by visual census in 2017 and 2018 the presence of large populations of the species at both the Cavo Greco and Nisia Natura 2000 sites in Cyprus in all seasonal expeditions. Moreover, the presence of young as well as reproductively mature specimens in the catch sample of this study are evidence of an established, reproducing population of the species in the study area that is exploited by local artisanal fisheries. Based on the results of the analysis of the catch sample and of the systematic review of the literature, *P. forsskali*, first recorded in Cyprus in 2014, has established self-sustaining, reproducing, commercially important populations in the nearshore waters of Cyprus at least since 2017. To our knowledge, there is currently no published information on large populations of the species in other locations in the Eastern Mediterranean, except for the report by Ali (2018) that the species is now considered very common and of commercial importance in Syria.

As there are as yet no reports that *P. forsskali* "threatens or adversely impacts upon biodiversity and related ecosystem services" (EU 2014), it is currently not designated as "invasive" in Cyprus. However, the apparent replacement of native mullids by *P. forskalli* in the Cypriot artisanal fisheries catches in recent years (Figure 4) may be an indication of significant negative impact by the latter on *Mullus* spp. through competition for space and resources. Competitive exclusion of native mullids, as a result of interspecific competition by the Lessepsian *Upeneus* spp. due to a high overlap in co-occurrence and traits, has been previously shown to possibly occur in the eastern Mediterranean (Arndt et al. 2018). Moreover, if we choose to adopt the alternative perspective that the use of the term "invasive" shouldn't connote negative environmental impacts (Ricciardi and Cohen 2007; see also Lockwood et al. 2013), its recent great success in establishing

self-sustaining, reproducing, commercially important populations across the nearshore waters of Cyprus, and reportedly also in Syria, may mean that the species has overcome all barriers to invasion success and, regarding the aforementioned populations, it can now be designated as a "fully invasive species" (*sensu* Blackburn et al. 2011).

It is not clear which processes triggered the end of the time lag since the introduction of *P. forsskali* in the Mediterranean and the onset of the current success in establishment and spread of its populations across Cyprus and reportedly also in Syria. It seems that a significantly enhanced growth rate is not implicated in Cyprus as the total length of 16.3 cm for age group I estimated in this study (see also Sabrah 2015) is comparable to that of the coexisting *M. surmuletus* (GFCM/FAO 2017). The effects of Climate Change on the physical environment and marine biodiversity of the Eastern Mediterranean are now well-documented and considered a major driver of the range expansions and invasions by Lessepsian migrant species (Ben Rais Lasram et al. 2010; Raitsos et al. 2010), and might also be influencing the spread of *P. forsskali* (see also Bariche et al. 2013). Although high genetic variability was not found to contribute to colonization success of the *Upeneus* species in the Eastern Mediterranean (Golani and Ritte 1999), to our knowledge no current similar study also involving *P. forsskali* exists in the literature.

Filling the identified knowledge gaps on the mechanisms underlying the successful spread of *P. forsskali* in the Eastern Mediterranean is a challenge that could be pursued using a number of complementary contemporary approaches: Seasonal samplings, a more representative sample regarding the length range, and a higher taxonomic resolution of stomach contents would aid in a more precise determination of the dimensions of the trophic niches of coexisting mullids in Cyprus, whereas DNA metabarcoding analysis (Berry et al. 2015) could also be applied for speed and resolution in diet analysis. A compilation of comprehensive diet information and time series of biomass and catch data would allow hindcasting and predictive modeling of the cumulative effects of this species, local fisheries and Climate Change on native food webs using ecosystem modeling tools within the Ecosystem Based Management Approach (e.g. Corrales et al. 2017, 2018; Michailidis et al. 2019). Furthermore, studies of the populations of the species across its non-native range using current molecular genetics methods (e.g. Golani and Ritte 1999; Turan 2006; Stern et al. 2019), would permit important insights into the mechanisms and evolution of the on-going spread of *P. forsskali* in the Mediterranean.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Geo-location data of the published records of occurrence of *Parupeneus forsskali* in the Mediterranean.

This material is available as part of online article from:
http://www.reabic.net/journals/bir/2020/Supplements/BIR_2020_Evagelopoulos_etal_Table_S1.xlsx