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A preliminary assessment of *Fistularia petimba* (Lacepède, 1803) migration in the Mediterranean Sea: historical and new data from Cyprus (Levantine Sea) with biological notes

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Abstract

Biological invasions may pose a serious threat to ecosystems and economies. In this study, the presence of the non-indigenous species *Fistularia petimba* in Cyprus is documented. A total of 76 individuals were collected by bottom trawls and trammel nets in June 2020, March 2021, August 2021, and September 2021. Morphometric measurements, meristic counts, sex, stomach content, and maturity stages were recorded, and notes were made on the length-weight relationship, reproduction, and diet composition. Results from the length-weight relationship indicated a positive allometric growth ($b = 3.5127$). The preliminary results indicate a prolonged reproductive season, lasting from spring to autumn. The presence of two native and highly commercial fish species, *Mullus barbatus* and *Pagellus* sp. in the stomachs of *F. petimba* highlights the need for further dietary analysis of the species and the study of its impact on local fauna. These findings may confirm the successful establishment of *F. petimba* in Cyprus and indicate that this species could have similar impacts on local ecosystems as its invasive relative *Fistularia commersonii*.

Keywords: Lessepsian migration; marine bioinvasions; non-indigenous species; red cornetfish; bottom trawl; set-nets; length-weight relationship; reproduction; diet composition; Eastern Mediterranean.

Introduction

Compared to previous years (Coll *et al.,* 2010; Edelist *et al.,* 2013; Katsanevakis *et al.,* 2013), the number of non-indigenous species (NIS) entering the Mediterranean Sea appears to be decreasing (Zenetos, 2019). Currently, the estimated rate of NIS entering the whole Mediterranean is eight species per year and the rate of NIS entering the Mediterranean through the Suez Canal is four species per year (Zenetos & Galandi, 2020), whereas the total number of validated NIS is close to 1000 taxa (Zenetos *et al.,* 2022). A study conducted in 2012 showed that the total cumulative number of non-indigenous fish species of Indo-Pacific origin, crossing the Suez Canal into the Mediterranean was approximately 126 species per year (Zenetos *et al.,* 2012). The list has been recently re-evaluated and the confirmed number of non-indigenous fish species entering via this route is now estimated at 173 per year (Zenetos & Galandi 2020; Zenetos *et al.,* 2022). The enlargement of the Suez Canal has made the marine environment in the eastern Mediterranean more susceptible to Lessepsian species (Indo-Pacific species entering the Mediterranean via the Suez Canal) (Galil *et al.,* 2015; 2017), which appear to be dominating the Levantine basin (Edelist *et al.*, 2013). Even though the impacts of NIS on biodiversity are still poorly understood, it is believed that NIS could cause shifts in the community composition of indigenous species (Katsanevakis *et al.,* 2014; Arndt *et al.,* 2018). The composition of non-indigenous fish species in the total fish biomass can be up to 90% in certain habitats of the Eastern Mediterranean (Goren & Galil, 2005; Edelist *et al.,* 2011). A recent study showed that in Cyprus the proportion of non-native fish species in the total catch fish biomass is 18% (Michailidis *et al.,* 2019).

The family Fistulariidae currently consists of four described species (WoRMS Editorial Board, 2021) worldwide and two of them are found in the Mediterranean Sea, having invaded via the Suez Canal. All species are carnivorous and mostly prey on fishes including species of economic importance, such as those of the family Sparidae and Mullidae (Corsini *et al.,* 2002; Bariche *et al.,* 2009), and on crustaceans and cephalopods (Froese & Pauly, 2023). The blue-spotted cornetfish, *Fistularia commersonii* (Rüppell, 1838) was first reported from Israel in 2000 (Golani, 2000) and now it can be found throughout the Mediterranean basin. However, Bariche *et al.,* (2013a) confirmed a previous presence back in 1975 which did not lead to a full establishment. After the recording of the species in Israel at the turn of the century, a very rapid colonization was observed throughout the Mediterranean Sea with a large increase in its population and full establishment (Karachle *et al.,* 2004).

The congeneric red cornetfish, *Fistularia petimba* (Lacepède, 1803), has a wide spatial distribution and its native range is in the Western, Eastern and South Atlantic and Indo-Pacific Oceans and the Red Sea. Its known bathymetric distribution is from 10 to 200 m depth but is usually found between 18 and 57 m depth (Froese & Pauly, 2023). It is a reef-associated, benthopelagic species that inhabits coastal areas over soft bottoms and feeds on small fishes and crustaceans (Froese & Pauly, 2023). *Fistularia petimba* was first recorded in Spanish waters in 1996 (Cárdenas *et al.,* 1997), in Israel in 2016, and from 2018 to 2021 reports on their presence emerged from various parts of the Eastern Mediterranean (Stern *et al.*, 2017; Ünlüoğlu *et al.*, 2018; Çİftçİ *et al.*, 2019; Hussein *et al.,* 2019; Ibrahim *et al.,* 2020; Crocetta *et al.,* 2021; Ragheb, 2022). In Cyprus, the species was first recorded in 2019 by a single captured individual with fishing gear at 55 m depth (Dragičević *et al.*, 2019).

The current study aims to contribute to the baseline knowledge of *F. petimba* in Cyprus' waters and to explore potential impacts on the native communities. The study provides a) notes on biological information of *F. petimba* through detailed morphometric and meristic count characteristics, length-weight relationships, and stomach content and developmental stages analyses and b) information on its spatial and bathymetric distribution from historical and new records.

Material and Methods

Specimens were collected by trained observers on bottom trawls in March 2021 and on trammel nets in September 2021 following normal fishing operation (fisheries dependent data collection) and during the Mediterranean International bottom Trawl Survey (MEDITS) in June 2020 and August 2021 (fisheries independent data collection). The sampling of the MEDITS survey was conducted by the Cypriot National Data Collection Programme, under the European Community Data Collection Framework (Regulations EC2017/1004, 665/2008 and Decisions 2019/909, 2019/910, 2019/910) following the Mediterranean International bottom Trawl Survey handbook (Anonymous, 2017). The samples were immediately deep frozen (-20° C) after capture and defrosted at the day of examination. All specimens collected were dissected in less than a month from the day of capture, sexed and analysed following standard protocols. Detailed morphometric measurements and meristic counts were recorded to the nearest mm and weighted to the nearest 0.1 g. All statistical analysis were performed using Microsoft Excel and the statistical software R (R Core Team, 2022).

Literature review

An electronic literature review with elements of a systematic review's methodology was conducted using Google Scholar to synthesise published records of the species in the Mediterranean Sea, in April 2023. Search items were '*Fistularia petimba',* and '*red cornetfish'* combined with '*Mediterranean', 'lessepsian migrant', 'non-native', 'alien, invasive', 'fisheries', 'trammel nets', 'static nets'* and *'bottom trawl'.* Inclusion criteria were only for the studied species and records in the Mediterranean region. Due to the small number of published records no other inclusion criteria were used. All retrieved articles are included in Table S4. A map of *F. petimba* records in the Mediterranean Sea was created to combine information from the current study and from published records to visualise the species' distribution throughout the years. The map was generated using the ArcGIS v.10.3 software.

Length-weight relationship

Four different length measurements were selected to estimate the length-weight relationship (LWR), to cover uncertainties that may occur on body length due to the species unusual body shape and in some cases, the lack of the tail filament. These were total length including tail filament (TLF), total length excluding tail filament (TL), standard length (SL) and fork length (FL). The LWR was calculated using the power curve equation:

$$\mathbf{W=\alpha L^{b}}$$

where W is the total weight (dependent variable), L is the length measurement (independent variable), *a* is the intercept and *b* is the slope. The equation was transformed to a linear model by applying common logarithms to both sides to minimise the differences on the data points and the straight line and is expressed as:

$$\mathbf{\log_{10}(w)=\log_{10}(\alpha)+b\log_{10}(L)}$$

One-way ANOVA tests were used to find differences between the different length measurements and total weight of both and combined sexes.

Gonad morphology and maturity stages

Gonads were weighed to the nearest 0.01 g and macroscopic identification of the maturity stages was achieved by examining the consistency, size and weight, colour and vascularisation, and presence of visible sperm or oocytes in the gonad lumen (according to MEDITS survey handbook; Anonymous, 2017).

Stomach content analysis

Ingested organisms found in the stomach were macroscopically identified to the lowest possible taxonomic level and weighed to nearest 0.01 g. The percentage of each identifiable prey item was calculated out of the total stomachs with identifiable prey items. To calculate the frequency of each prey item found in the stomachs, the percentage frequency of occurrence (Bowen, 1996) was used and calculated as:

$$\%F=(n_s/N_s)\times 100$$

where n_s is the number of stomachs including a prey item and N_s is the total number of stomachs examined.

Results

A total of 76 individuals of *F. petimba* were collected in June 2020 ($n = 21$), March 2021 ($n = 14$), August 2021 ($n = 40$), and September 2021 ($n = 1$). The species was identified by the presence of elongate bony plates along the midline of the dorsal and posterior part of the body and by the reddish or brownish-orange colour above and silvery below (Fig. 1). The congeneric and Lessepsian immigrant well-established in Cyprus, *F. commersonii*, does not have bony plates on the dorsal side and posterior part of the body and the colour is green or bluish green.

Morphometric measurements and metric characters

The mean total length (excluding tail filament) of males ($n = 35$) and females ($n = 41$) was 389 mm (SD = 34.2) and 436.9 mm (SD = 38.8), respectively. The mean total weight of males and females was 28.1 g (SD = 8.7) and 43.6 g (SD = 14.6). The mean values (SD) of all morphometric measurements and meristic counts are shown in Table S1 and Table S2, respectively.

Length-weight relationships

The plots of the length-weight relationship (LWR) of the four length measurements of combined sexes (Fig. 2) suggest that the four different length measurements and weight are positively correlated and that the relationship appears linear (ANOVA, $p < 0.01$). The correlation coefficient (r^2) for all relationships is above 0.81, indicating that there is a good degree of correlation between the variables in the sample (King, 2017). The positive r^2 values also reflects that the slopes are positive. The TLF increases 3.694 times, the TL increases 3.5127 times, the SL increases 3.515 and the FL increases 3.5673 times with every unit increase in weight. All values of *b* are greater than 3.0, indicating that the species exhibits positive allometric growth.

The large F test-statistics and correspondingly the very small *p* values for males, females, and combined sexes for all four log-transformed length measurements indicate that the linear regression models with both intercepts and log-transformed length measurements explain more of the variability in the log-transformed weight than a model with just an intercept. This explains that all four log-transformed length measurements for both sexes and for combined sexes are significant predictors of the log-transformed weight. Also, the very small *p* values (< 0.001) indicate that the slope is significantly different than zero, which shows that there are significant relationships between the log-transformed total weight and the log-transformed length measurements for both and combined sexes. The simple linear regressions and ANOVA tests of the four different log-transformed length measurements with log-transformed total weight are shown in Table S3.

Fig. 1: (A) *Fistularia petimba* specimens caught in June 2020 from the MEDITS bottom trawl survey in Cyprus; (B) Gonads of a mature/spawning female individual; (C) *Mullus barbatus* (TW = 0.77 g) inside the stomach of a female *Fistularia petimba* (TLF = 598 mm; TL = 415 mm; SL = 404 mm; FL = 411 mm; TW = 41.86 g; Stage: Mature/Spawner).

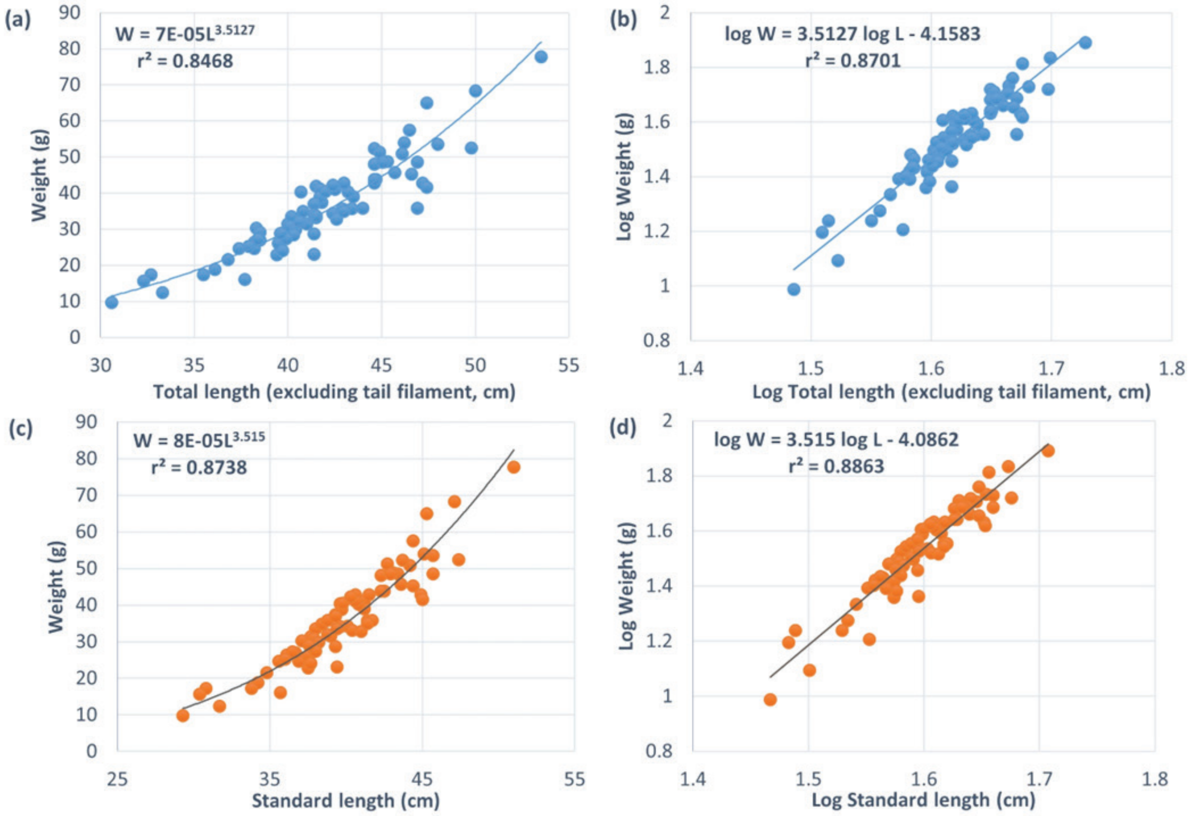

Fig. 2: Combined sex length-weight relationships of total and standard length measurements of the species *F. petimba*. Scatter plots of untransformed weight and length with power model *a* and *b* values (a, c) and $\log_{10}$ transformed weight and length with linear regression *a* and *b* values (b, d).

Maturity stages

At stage 1 (Immature) there were one female (gonad weight = 0.01 g ± 0.0 g) and 13 males (gonad weight = 0.02 ± 0.01 g), at stage 2 (Developing/Maturing) there were 28 females (gonad weight = 3.27 ± 1.10 g) and nine males (gonad weight = 0.36 ± 0.08 g), at stage 3 (Mature/Spawner), seven females (gonad weight = 5.57 ± 2.58 g) and five males (gonad weight = 0.40 ± 0.17 g) and at stage 4 (Spent), five females (gonad weight = 0.80 ± 0.41 g) and eight males (gonad weight = 0.45 ± 0.29 g). The ovarian and testes development was asynchronous. Reproductive active individuals (Maturing and Mature/Spawner) ranged between 383 to 535 mm (mean TL: 440 ± 331 mm) for females and from 377 to 472 mm (mean TL: 413 ± 254 mm) for males. Active females were recorded during June, August and September and active males were recorded during March, June, and August. In March, 16.7% of female individuals were immature and 83.3% were spent, in June 14.3% were maturing and 85.7% were mature, in August 96.3% were maturing and 3.7% were mature and in September 100% were mature.

Stomach content

Of the 76 stomachs examined, 35 were empty, 29 contained identifiable prey, and 10 contained unidentifiable prey that was fully decomposed. Among the identifiable prey items was the native *Mullus barbatus* (6.9%) (Fig.1C) *Pagellus sp.* (3.4%), Scorpaenidae (3.4%), and the remainder were unidentified fish species (86.2%). The two prey items that were identified to species level are native to the Mediterranean Sea. The *%F* for *M. barbatus* was 2.6%, for *Pagellus sp.* was 1.3%, for Scorpaenidae was 1.3%, and for unidentified fish was 32.9%.

Spatial and bathymetric distribution of* F. petimba *records in the Mediterranean Sea

The species was first documented in the Mediterranean Sea off the coast of Cadiz, Spain in 1996 and then again in 2016 off the coast of Israel. Since then, the species has been documented in other areas of the eastern Mediterranean like Egypt, Syria, Turkey, Lebanon, and Cyprus and more recently in Greece and the Marmara Sea (Fig. 3 and Table S4). The mean depth of capture of the samples collected in the current study was 57.5 m (SD = 17.2 m), with the minimum depth of 13 m and the maximum of 93 m, whereas the mean depth of the samples collected from previous studies (Table S4) is 53.8 (SD = 33.4 m), with the minimum depth of 17.5 m and the maximum of 150 m.

Since the first record in 2016 in the Eastern Mediterranean Sea, there was an increase of 233% in the number of reported records of *F. petimba*, including the records from the current study. The increasing trend in the number of sightings was more obvious since 2019.

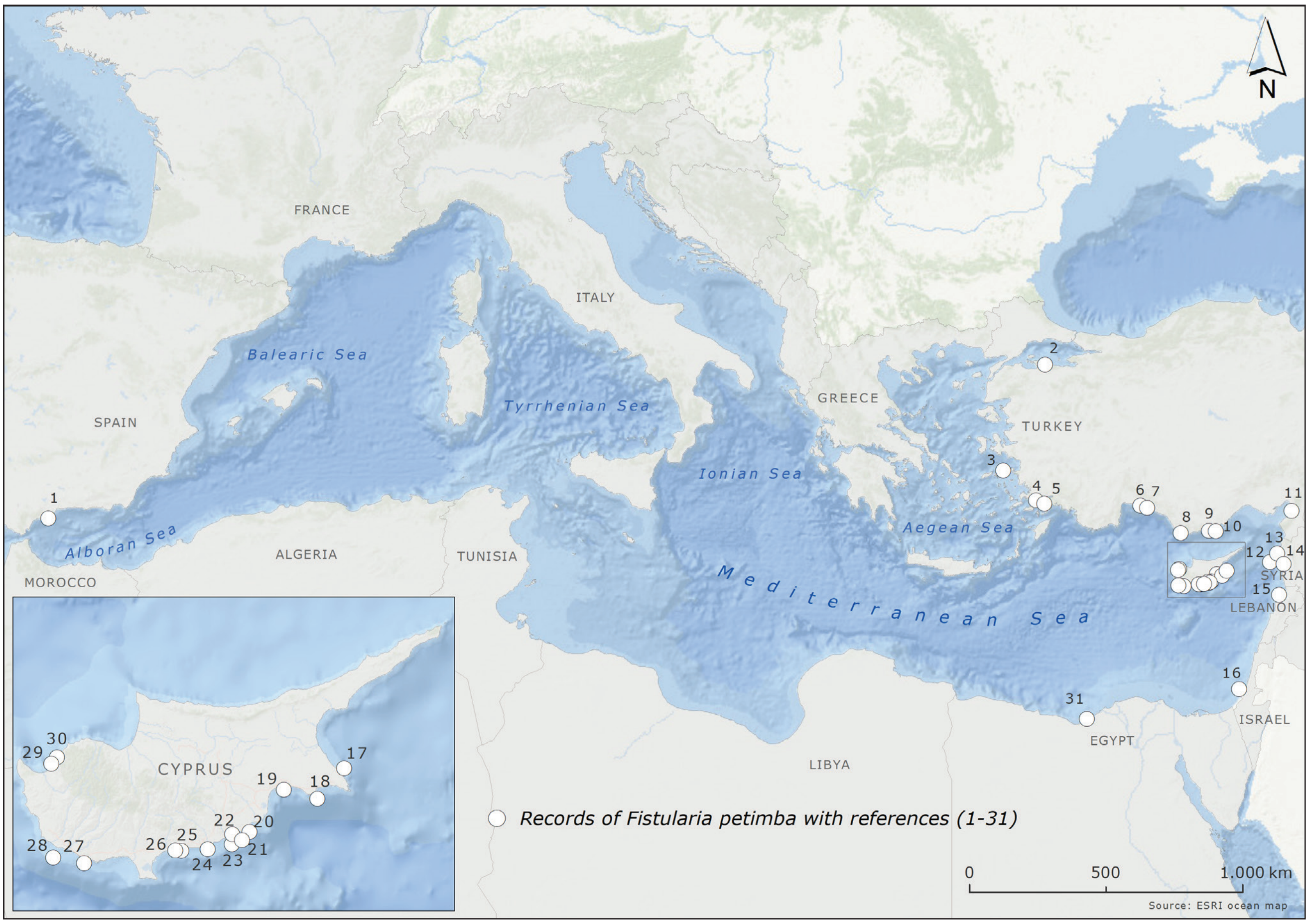

Fig. 3: Locations of present and historical records of *Fistularia petimba* in the Mediterranean Sea with information on abundance and year of capture. Numbers (1 – 31, records from current study: 17 – 29) correspond to references to the current and previous studies with information on latitude and longitude, number of individuals and date, depth, and method of capture (Table S4). The map was generated using the ArcGIS v.10.3 software.

Discussion

The current study confirms the presence of mature and spent male and female individuals, suggesting the potential successful establishment of the species in Cyprus. Zenetos and Galanidi (2020) have previously confirmed the establishment of the species in the Mediterranean Sea. Many NIS have established permanent populations in the Mediterranean which are responsible for causing significant ecological and socioeconomic impacts (Katsanevakis *et al.,* 2014), such as the *F. commersonii* (Bariche *et al.,* 2009), *Lagocephalus sceleratus* (Ulman *et al.,* 2021) and more recently *Pterois miles* (Savva *et al.,* 2020). Considering that *F. petimba* has similar feeding traits, environmental and habitat requirements as its congeneric *F. commersonii* (Froese & Pauly, 2023), the species will likely have the same or similar diet and spawning capabilities in the new environment as well as ecological impacts as its relative. Additionally, the specimens examined in the current study were immature and mature and had uniform sizes which may indicate the establishment of a new self-generated population in the area (Psomadakis *et al.,* 2009). However, survival and reproduction may not confirm the successful establishment of a species in a new environment as long-term population growth is required. In other words, the successful reproduction of adults does not guarantee the survival of the next generation (Williamson & Fitter, 1996).

F. petimba was first recorded off the coast of Spain in 1996 and then 20 years later off the coast of Israel. Since then, the species rapidly and progressively expanded along the eastern Mediterranean and more recently moved northward in the Aegean and Marmara Seas. The species was almost simultaneously recorded (over a period of five years) in different countries in the eastern Mediterranean, indicating another possible successful invasion. Non-indigenous fish species introduced in the past two decades (after 1990) are expected to expand faster compared to previous years' species introductions due to the favourable environmental conditions as a result of global warming (Azzurro & D'Amen, 2022; D'Amen *et al.,* 2022). Additionally, it seems that the faster the species' geographical expansion, the higher its ecological impact will be (Azzurro *et al.,* 2022). *Fistularia petimba* presence in the eastern Mediterranean may alone confirm that the origin of the introduction was from the Red Sea and not from the Atlantic and that the first record in Spain could be considered a failed introduction (Cerim *et al.,* 2021). It is also important to mention that the one specimen recorded in Spain had a total length of 1240 mm (common total length of *F. petimba* reported in Fishbase is 1800 mm; Froese & Pauly, 2023), whereas later records, including the records in this study (n = 101, Table S4), ranged between 415 mm and 704 mm. This shows that there might be unknown morphometric differences between the species found in the different oceans or that the species did not yet reach its optimal size. Molecular analysis on one specimen indicated that the route of introduction in the eastern Mediterranean was through the Suez Canal (Stern *et al.,* 2017). However, given that *F. petimba* is a complex and cryptic species (Stern *et al.,* 2017), future work should focus on further molecular analysis to address the question of possible multiple introductions in the Mediterranean. Additionally, the observed distribution of the species (Fig. 3) may reflect to differences across the Mediterranean countries in terms of data collection and fisheries' monitoring protocols and effort, fishing practices, and engagement of fishers in sharing information.

The morphometric measurements recorded from the specimens of the present study are aligned with the measurements documented in previous studies in the eastern Mediterranean (Table S4). The results revealed a significant difference in length and weight between male and female individuals, where females tend to be larger than males. The length-weight relationship showed a positive allometric growth (b = 3.5127) which indicates that the *F. petimba* becomes heavier as it increases in size, similar to its congeneric *F. commersonii* (b = 3.4063) (Bariche & Kajajian, 2012). However, differences in growth patterns between the two species are expected: the current study covered only limited size classes and differences might be due to the fact that the species has not yet fully adapted to the new environment and maximum growth is not yet achieved, thus the lack of larger individuals. Several small-scale fishers in Cyprus have recently reported catching *F. petimba* in static nets more frequently than in previous years but the fish lengths are always small (pers. comm. to MP, 2023). *Fistularia commersonii* as well as other Lessepsian fish species had rapid adaptation and tremendous success in the Mediterranean Sea in a very short time after their migration. This can be explained by the low direct competition with native species and by preadaptation and local selection mechanisms (Bernardi *et al.,* 2016) as well as to the suitable environmental conditions, analogous to their native range (Azzurro & D'Amen, 2022). Therefore, larger individuals of the species may be present in the future when the species has been well adapted. When the species becomes more common, future work should examine the length-weight relationship of the species covering all size classes and months of the year as well as study age and growth to enable a better understanding of the dynamics of *F. petimba* populations in the Mediterranean.

The seasonal distribution of maturity stages and the asynchronous development of ovaries and testes reported in the current study are consistent to the values and trends reported for *F. commersonii* (Bariche *et al.,* 2013b). The prolonged reproductive season and the asynchronous gonad development are common characteristics of low-latitude marine fishes which are not subjected to great temperature variations over the year (Srinivasan & Jones, 2006; King, 2017). The spawning period of *F. commersonii* in the Mediterranean Sea was estimated to last for at least six months, from May to October (Bariche *et al.,* 2013b). As discussed for *F. commersonii* (Bariche *et al.,* 2013b), *F. petimba* may have also retained its reproductive features in the newly colonised environment. It is therefore likely that *F. petimba* will have similar reproductive features and patterns to *F. commersonii* in the Mediterranean, however, further research is required to support that hypothesis as the current study examined a limited number of individuals and covered only four months of the year.

The presence of native and highly commercial fish species in the stomachs of *F. petimba* is worrisome as both species are of high economic importance for fishers and the local market. Nevertheless, it is premature at this stage to predict potential impacts on native fish communities as shown for *F. commersonii* (Kalogirou *et al.,* 2007). On the other hand, non-native species and potentially invasive species may have significant impacts on local communities and population dynamics (Katsanevakis *et al.,* 2014; Katsanevakis *et al.,* 2016; Corrales *et al.,* 2017; Arndt *et al.,* 2018). The two species identified, *M. barbatus* and *Pagellus sp.* were also recorded in the diet of *F. commersonii* in the Mediterranean (Bariche *et al.,* 2009). Bariche *et al.,* (2009) recorded 41 taxa in the diet of *F. commersonii* of which 77% were native to the Mediterranean and many were important commercial species, such as *Spicara smaris* and *Boops boops*, and concluded that the invasive cornetfish preferred to feed on schooling species living in the water column. Considering the dietary similarities between the invasive *F. commersonii* and *F. petimba*, it is urgent to further study the diet composition and feeding ecology of *F. petimba* as it continues to colonise the Mediterranean and to understand the species' impacts on native fish populations.

The findings of the current study set the foundations and questions for future research on the biology of *F. petimba* and its effects on the native biota in the Mediterranean Sea. The study also highlights the need for further research to understand the species' ecological and socioeconomic impacts. Recently introduced NIS have not yet produce their full impact and it is therefore necessary for rapid assessments and responses with management actions that could mitigate their impact before the situation is out of human control.

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Supplementary Data

The following supplementary information is available online for the article:

Table S1. Morphometric measurements (mm) and weight (g) of 76 *F. petimba* specimens collected between 2020 and 2021. TL= Total Length; SD= Standard deviation.

Table S2. Meristic characters of 76 *F. petimba* specimens collected between 2020 and 2021. SD = Standard deviation.

Table S3. Simple linear regressions and one-way ANOVA tests of four different log-transformed length measurements with log-transformed total weight. R squared (r^2), intercept (*a*) and slope (*b*) values of linear regression models and confidence intervals (*CI*; lower, upper) at 95%, *F* and *p* values of ANOVA tests.

Table S4. Number of studies from the western to eastern Mediterranean Sea where the *Fistularia petimba* has been recorded with information on coordinates, date, depth, method and number of individuals captured.