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Received: 4 August 2025 | Revised: 6 November 2025 | Accepted: 12 November 2025

DOI: 10.1111/jfb.70296

REGULAR ARTICLE

JOURNAL OF FISH BIOLOGY fsbi

# Growth and reproductive dynamics of the devil firefish, *Pterois miles* (Bennett, 1828), in the Eastern Mediterranean Sea

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**Funding information**
Scientific Research Projects Coordination Unit of Istanbul University, Grant/Award Number: FUA-2020-34578.

## Abstract

The devil firefish, *Pterois miles*, an invasive alien species, presents a growing threat to marine biodiversity due to its rapid population expansion and significant ecological impacts in the Eastern Mediterranean Sea. This study, conducted between February 2020 and April 2021, aimed to assess the growth patterns and reproductive behaviour to better understand its invasion dynamics in Turkey. Monthly sampling revealed its length–weight relationship, with positive allometric growth. The reproductive dynamics showed a prolonged spawning season from June to November, with females displaying high fecundity, averaging 20,743 oocytes per batch. Females reached first maturity at 20.1 cm total length, and its natural mortality rate was estimated at 0.8 per year. Understanding life-history characteristics of lionfish is important for understanding its invasion success and may help develop effective measures to control its invasion to protect regional marine native biodiversity.

KEYWORDS
fecundity, invasive alien species, lionfish, natural mortality, spawning season, Turkey

## 1 | INTRODUCTION

The Eastern Mediterranean Sea is experiencing a growing influx of marine alien species, primarily introduced through the manmade Suez Canal and increased amount of shipping traffic. The majority of these introductions are believed to result from ballast water transport and biofouling (Galil et al., 2015; Katsanevakis et al., 2013). Among these invasive species, the devil firefish, *Pterois miles* (Bennett, 1828), commonly referred to hereafter as lionfish, is of high regional concern. Lionfish were first recorded in the Mediterranean Sea off the coast of Israel in 1991 (Golani & Sonin, 1992), but they were not successful in establishing until 2012 when two specimens were sighted in Lebanon (Bariche et al., 2013), after which they quickly spread around the Eastern Mediterranean basin to Turkish, Cypriot, Greek and Israeli waters (Turan et al., 2014: Crocetta et al., 2015: Iglésias & Frotté, 2015). Their establishment seems localized to the warmer Eastern Mediterranean basin so far, despite some individuals being sighted in Croatia, Sardinia, Italy, Malta and Spain (Azzurro et al., 2017).

Lionfish belong to the Scorpaenidae family of teleosts native to the Indo-Pacific, characterized by their bright red colouration, striking stripes and venomous erect spines. The lionfish invasion has been extensively studied in the western Atlantic Ocean, where two Indo-Pacific species – *P. miles* and *Pterois volitans* – are abundant. There, they were first reported in 1985 (Fogg et al., 2013), under the assumption that lionfish were released from aquariums in southeast Florida (Betancur-R. et al., 2011). Their populations began to increase significantly in the late 2000s and 2010s, causing severe impacts on native species, including reduced biodiversity, reef deterioration and

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economic losses to the fishing industry (Côté et al., 2013; Henderson, 2012; Lesser & Slattery, 2011). Studies have shown a strong relationship between the increase in lionfish populations and the decline of their prey species (Green et al., 2012). Remarkably, lionfish continue to expand their range in the Western Hemisphere, now extending down the Brazilian coast (Soares et al., 2023).

Due to their rapid spread and extensive impacts, lionfish are considered the most successful marine invader to date in the western Atlantic (Morris & Akins, 2009). They disrupt local food webs through excessive prey consumption, impacting some native species (Albins & Hixon, 2013). The success of their invasion is attributed to several factors: high fecundity, lack of sufficient predators, prey naivety, a generalist diet and habitat flexibility (Anton et al., 2016; Côté et al., 2013; Galloway & Porter, 2019; Peake et al., 2018; Rojas-Vélez et al., 2019). As generalist predators, lionfish have large mouths and expandable stomachs, allowing them to consume a wide range of prey. Juveniles primarily feed on invertebrates, whereas adults shift to a more piscivorous diet (Dahl & Patterson III, 2014). This dietary flexibility has serious implications for native biodiversity, as native species often become the primary components of their diet and are generally unaware of these new predators – a term called prey naivety – the failure of prey to recognize new predators as threats (Anton et al., 2016).

Highlighting the major ecological differences between the Mediterranean Sea and the tropical western Atlantic invasions is crucial for advancing our understanding of Lessepsian invasive species. The Mediterranean Sea is a subtropical sea characterized by rocky reefs, seagrass meadows and sand patches, and is affected by seasonality (Bussotti & Guidetti, 2011; Kleitou et al., 2021; La Mesa et al., 2011). In contrast, the tropical western Atlantic is dominated by coral reefs, similar to the native habitats of lionfish with warmer and more constant temperatures (Côté & Smith, 2018; Kulbicki et al., 2012). Both regions support diverse marine biodiversity, potentially leading to different responses to invasions (Albins & Hixon, 2008; Kallianiotis et al., 2000).

In recent years, several studies have been conducted on lionfish populations in the Mediterranean Sea, particularly in the eastern basin, reflecting its rapid invasion and establishment in these waters. Dağhan (2020) in İskenderun Bay, Savva et al. (2020) and Mouchlianitis et al. (2022) in Cyprus and Kondylatos et al. (2024) in Rhodes provided valuable insights into various aspects of lionfish biology, including sex ratios, growth and reproductive behaviours. Although Rhodes (Dodecanese Islands) is near the Turkish coastline, differences in ecological conditions, anthropogenic pressures and fisheries practices may affect the population dynamics regionally. In Türkiye, there have been very few studies to date on lionfish populations despite its elevated risks to native biodiversity. Monitoring the bioecological characteristics of invasive species in newly colonized areas is essential for predicting their impact on ecosystem functions. This research contributes valuable new data on the growth and reproductive traits of lionfish in the Eastern Mediterranean Sea.

## 2 | MATERIALS AND METHODS

### 2.1 | Sampling methodology

Between February 2020 and April 2021, lionfish specimens were collected monthly from two localities from the southwestern Turkish coast: Fethiye and Kaş (Figure 1). In 2020, 338 individuals were sampled from Fethiye and 148 from Kaş; in 2021, 119 individuals were collected from Fethiye (sample sizes by month and location are provided in Table S1). Specimens were obtained from small-scale coastal gillnet fisheries operating in waters down to 60 m deep and from recreational spear fishers in shallow coastal waters down to 40 m deep. During summer, lionfish are generally most abundant between 20 and 40 m and tend to seek cooler waters in winter between 50 and 70 m. Measurements performed in the laboratory included total length (TL, to the nearest 0.1 cm), standard length (SL, to the nearest 0.1 cm), body weight (TW, to the nearest 0.1 g), gonad and liver weight (GW and LW, respectively, with an accuracy of 0.01 g). Although sex can be easily distinguished macroscopically in mature individuals based on the colour and texture of the gonads, it can be confounded in immature individuals; therefore, the gonads of all individuals were examined histologically.

The sex ratio was calculated as a percentage using the formula (number of individuals of a given sex/total number of fish) × 100. The significance of the sex ratio was evaluated with a $\chi^2$ test. Differences in total length between male and female lionfish were assessed using a Mann–Whitney *U* test, as the length data departed from normality and therefore required a non-parametric procedure.

### 2.2 | Growth parameters

The length–weight relationship (LWR), $W = a * TL^b$ was converted into its logarithmic expression: $\log a + b^*\log TL$. The parameters *a* and *b* were calculated using least-squares regression, as was the coefficient of determination ($R^2$). The *b* value of the species was tested by a *t*-test ($\alpha = 0.05$) to verify whether it was significantly different from 3. The length–length relationships (LLR) between TL and SL were also established using linear regression analysis: $TL = a + b\ SL$.

The growth pattern was determined using the von Bertalanffy growth function (VBGF) expressed as: $L_t = L_\infty \left[1 - e^{-k(t-t_0)}\right]$, where $L_t$ is the mean length (cm) at age t, $L_\infty$ is the asymptotic length, *k* is the growth coefficient and $t_0$ is the theoretical age when $L_t = 0$. Monthly length–frequency distributions (LFDs – Table S1) were analysed to estimate growth parameters using the ELEFAN I routine implemented in the TropFishR package (Mildenberger et al., 2017) within the R environment (R Core Team, 2024). ELEFAN contains both simulated annealing (ELEFAN-SA) and a genetic algorithm (ELEFAN-GA) to help assess the uncertainties around the growth estimates according to Schwamborn et al. (2019). Finally, these methods enable estimating $L_\infty$ and *k* simultaneously to generate a growth curve that best fits the observed length–frequency data.

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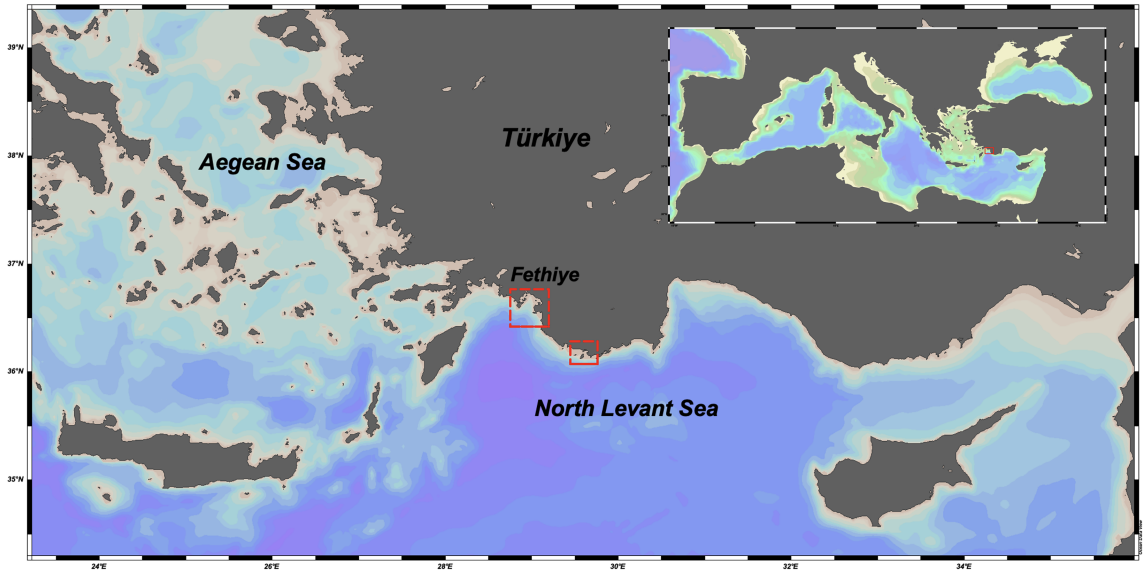



**FIGURE 1** Study area in the Eastern Mediterranean showing the sampling locations.

## 2.3 | Spawning season, size at first maturity and fecundity

The spawning season was identified by analysing development stages of the gonads, the monthly variation of the changes in gonadosomatic index (GSI), condition factor (K) and hepatosomatic index (HSI) for each sex. The GSI, HSI and K were calculated based on the following equations: $GSI = (GW/TW) \times 100$; $HSI = (LW/TW) \times 100$; $K = (TW/L^3) \times 100$. The relative condition factor ($Kn = w/W$), defined as the ratio of observed weight ($w$) of a fish at a given length to the expected weight ($W$) of a fish of the same length as calculated from the length–weight regression (Le Cren, 1951), has been calculated separately for males and females. All gonads were preserved and sampled for reproductive analysis. Gonadal development stages of females were identified based on histological analyses. Gonads were fixed in a 10% neutral buffered formalin solution before dehydration and embedding in paraffin. After this processing, 5-μm-thickness sections were cut, placed on glass slides, stained using a haematoxylin-eosin staining procedure and examined using a light microscope (Galimany et al., 2015). During the first maturity stage, the immature ovaries consisted of primary growth (PG) oocytes and a thin ovarian wall (Figure 2-I), followed by the second maturity stages with developing ovaries and the formation of cortical alveoli (Figure 2-II). The spawning-capable phase was characterized by the appearance of tertiary vitellogenic oocytes (Vtg3; Figure 2-III), and active spawning was assigned from the observation of postovulatory follicles (POFs, Figure 2-IV). Although the regressing phase was recognized by the presence of oocyte atresia and a reduced number of vitellogenic oocytes (Figure 2-V), the regenerating phase was differentiated from the first maturity stage by (i) a thicker ovarian wall (OW; Figure 2-VI); (ii) the presence of more space, interstitial tissue, capillaries around PG oocytes; and (iii) the presence of muscle bundles (Brown-Peterson et al., 2011).

Temporal variation in GSI was analysed separately for females and males using a one-way analysis of variance (ANOVA) with month (12 levels) as the fixed factor. For females, significant main effects were followed by Tukey's honest significant difference (HSD) to identify specific pair-wise differences among months; for males, no post hoc tests were conducted when the omnibus test was non-significant. Homogeneity of variances was evaluated by visual inspection of residual-fitted plots and formally tested using Levene's test at $\alpha = 0.05$. Levene's test indicated no evidence of heteroscedasticity ($p > 0.05$). The results of the Tukey HSD test were used to assign grouping letters (e.g., a, b, ab), indicating statistical similarities or differences among months. Monthly mean GSI values (± standard error) were graphically visualized using the ggplot2 package (Wickham, 2016). Bar plots included error bars representing standard errors, and grouping letters derived from the post hoc test were superimposed above each bar to facilitate visual interpretation of significant differences.

Length at first maturity (Lm) was defined as the length at which 50% of individuals had already spawned at least once and was calculated by incorporating individuals with gonadal stages higher than stage II. Lm was estimated for both sexes using a logistic function that was fitted to the proportion of sexually mature individuals by each size class using a non-linear regression following King's (1995) formula; $P = 1/\{1 + \exp.[-r(L - Lm)]\}$, where $P$ is the proportion mature in each size class, $r$ ($-b$ slope) is a parameter controlling the slope of the curve and Lm is the size at 50% maturity. For this analysis, the sizeMat package (Torrejon-Magallanes, 2019) was used with R. Monte-Carlo was used for logistic regression (Bayes GLM) that generates a sample from the posterior distribution of a logistic regression model using a random-walk Metropolis algorithm.

Monthly mean sea-surface temperature (SST) for the study area (February 2020–April 2021) was obtained from the My NASA Data Earth System Data Explorer (Reynolds et al., 2002). For descriptive

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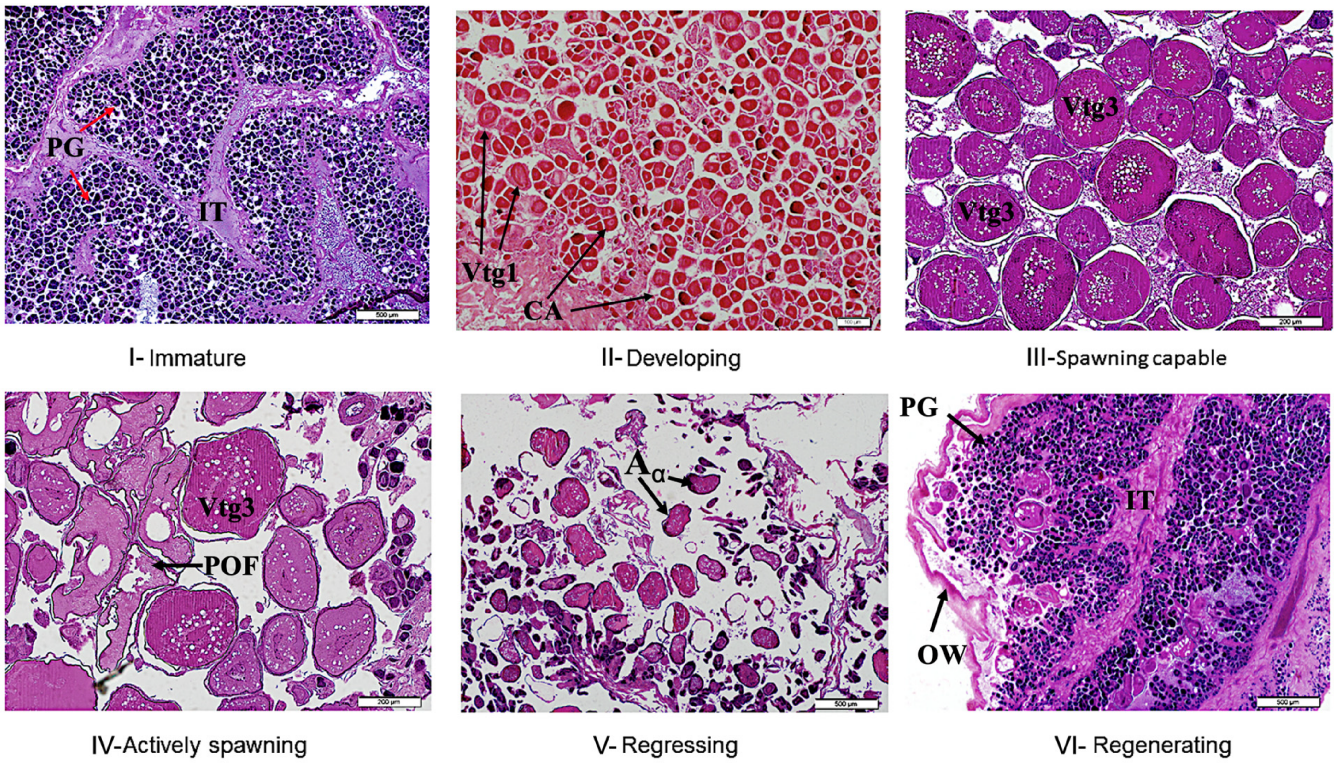



**FIGURE 2** Ovarian histological sections of female *Pterois miles* in different reproductive phases, from immature to regenerating, which also show oocyte size development.

comparison, the monthly SST time series was overlaid on (i) monthly mean GSI and (ii) the monthly distribution of gonadal developmental stages (Figure 8) to illustrate seasonal co-variation. This visualization was used for descriptive purposes only; no inferential tests relating SST to GSI or to stage composition were conducted in this study.

A total of 39 active ovaries collected between June 2020 and April 2021 (excluding December, January and February) were analysed to estimate batch fecundity (BF). BF is the number of eggs released per fish during a single spawning event. Murua et al. (2003) proposed that BF can be estimated via the highly advanced oocyte (usually ≥500 μm). Three subsamples, weighing between 20 and 40 mg, were taken from the anterior, middle and posterior parts of the ovaries. BF was estimated using $BF = (GW/GWi) \times n$ (Bagenal, 1978), where $n$ = mean number of eggs in the subsample, GWi = average weight of subsample (g) and GW = gonad weight (g). Relative batch fecundity (RBF) is the number of eggs per gram of gonad free body weight (GFBW), which was calculated as RBF = BF/(TW − GW) (Hunter & Macewicz, 1980). The relationships between BF and TL, and between BF and GFBW, were determined using simple linear regression.

## 2.4 | Natural mortality

We estimated M with the 'Composite M: method weighting' routine of *The Barefoot Ecologist's Toolbox* (online interface-http://barefootecologist.com.au/shiny_m.html), which (i) computes method-specific point estimates of M from user-supplied life-history inputs and (ii) prevents double-counting of the same predictor by partitioning contributions among estimators that share a predictor class (e.g., longevity-based estimators using $t_{max}$). Concretely, the tool first evaluates a set of empirical M estimators using the inputs provided ($L_\infty$, $k$, $t_{max}$ and the mean temperature T). Within any predictor class, estimators receive equal shares; these shares are then normalized so that all contributions sum to one. The resulting ensemble of method-specific values is aggregated into a composite empirical distribution (via the empirical cumulative distribution of point estimates). We report the composite point estimate as the median and uncertainty as the 2.5%–97.5% empirical quantiles. This procedure is conceptually aligned with the Natural Mortality Tool (NMT) framework, which pools multiple empirical estimators into a method-weighted density and propagates estimator disagreement as uncertainty in M (Cope & Hamel, 2022). $L_\infty$ and $k$ were obtained from ELEFAN I (TropFishR) fits to monthly length–frequency data; $t_{max}$ was taken from validated age/length information for the study area. Detailed equations and further information about the composite M method are available on the toolbox's website. All statistical analyses were performed using R version 4.3.1 (R Core Team, 2024).

# 3 | RESULTS

A total of 605 lionfish were sampled in this study, including 277 males, 302 females and 26 unidentified. The sex ratio was M:F: 1:1.09. The

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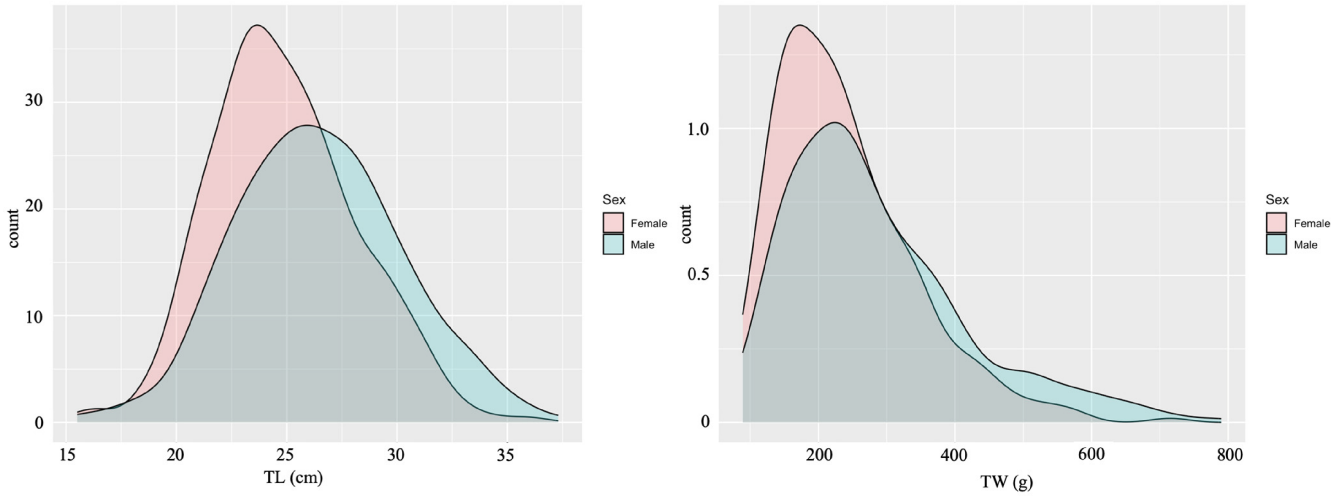



**FIGURE 3** Sex-specific total length (TL, left) and total weight (TW, right) distribution of *Pterois miles* in the Eastern Mediterranean from February 2020 to April 2021. Density plots illustrate the frequency distribution for males (blue) and females (pink), showing sex-related differences in size structure.

peak of the female distribution occurred between 20 and 30 cm TL, indicating that the majority of the sampled female (265) lionfish fell within this size range (Figure 3, left). The distribution analysis revealed that female lionfish were predominantly found in smaller size classes, with a peak between 20 and 25 cm TL (Figure 3). In contrast, male lionfish peaked between 25 and 30 cm TL, indicating that males generally attain larger sizes than females. The broader size distribution observed in males also suggests greater size variability within the male population. Although there was an overlap in the size distributions of males and females, a higher proportion of larger individuals among males was evident. A Mann–Whitney *U* test confirmed that male lionfish reached significantly larger TLs than females ($W = 52{,}396$, $p < 0.001$).

## 3.1 | Length–length relationships and length–weight relationships

LLR was very strong and positive between TL and SL. High coefficient of determination ($r^2 = 0.97$) indicates that 97.18% of the variance in SL can be explained by TL (Figure 4). This high $r^2$ value suggests a very strong fit of the linear model to the data. The slope of the regression line (0.7574) indicates that for every 1 cm increase in TL, the SL increases by approximately 0.7574 cm. The relationship is SL = 0.8*TL – 0.05. LWR was estimated as $TW = 0.0079 \times TL^{3.179}$ ($r^2 = 0.95$; Table 1 and Figure S1) for pooled data. LWRs for male and females were not significantly different ($p < 0.05$; Table 1). All calculated *b* values were found to be different from 3.

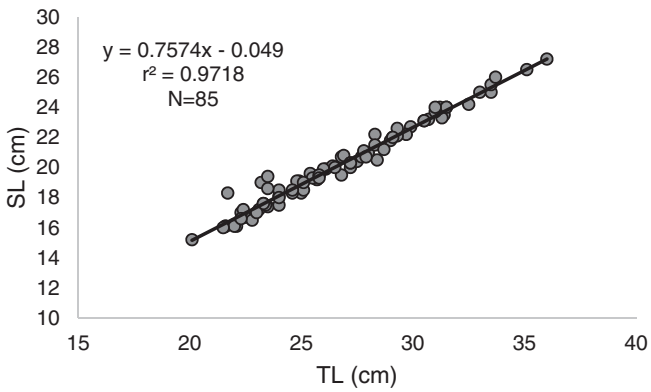



**FIGURE 4** Linear relationship between standard length (SL) and total length (TL) of *Pterois miles* in the Eastern Mediterranean during the study period.

**TABLE 1** Length–weight relationship parameters of *Pterois miles* by sex in the Eastern Mediterranean from February 2020 to April 2021.

| Sex | *N* | *a* | *b* | CI% of *b* | $R^2$ |
|---|---|---|---|---|---|
| Female | 303 | 0.0069 | 3.224 | 3.111–3.340 | 0.92 |
| Male | 278 | 0.0076 | 3.183 | 3.070–3.301 | 0.91 |
| Pooled | 581 | 0.0079 | 3.179 | 3.055–3.295 | 0.92 |

Abbreviation: CI, confidence interval.

## 3.2 | Growth parameters (vGBF)

The distribution of the ELEFAN_GA algorithm showed the most likely values of $L_\infty$, with a median around 47.31 cm. The median K value was around 0.46, indicating a moderate growth rate. C (oscillation amplitude) has a median value of around 0.58, indicating moderate seasonal growth variation. The ts value, around 0.51, suggested that the slowest growth (Winter Point) occurs mid-year, potentially aligning with the reproductive activities or other environmental factors (Figure 5 – upper). The median value of approximately 3.01 represents the overall growth performance

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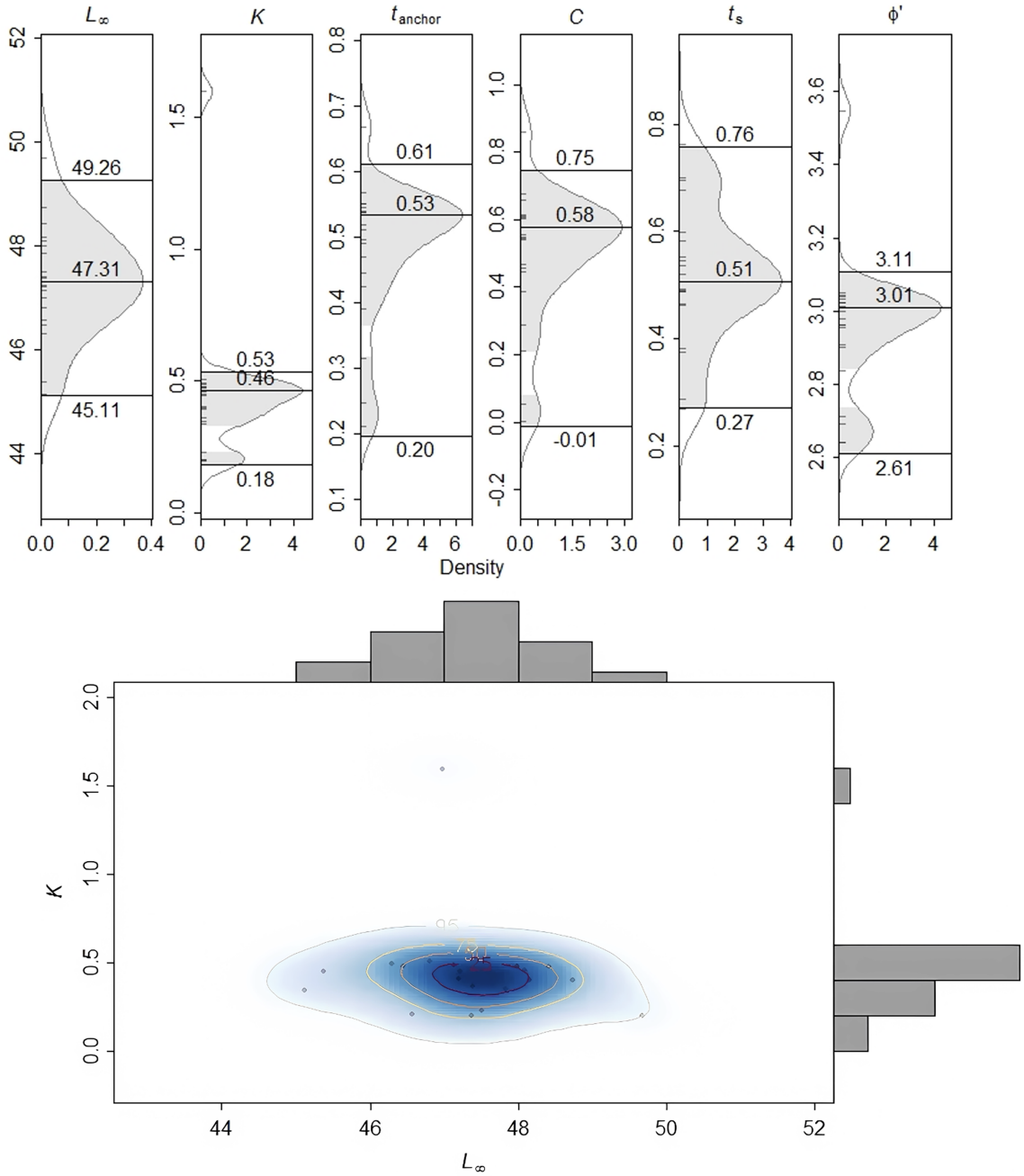



**FIGURE 5** Estimation of growth parameters for *Pterois miles* using the ELEFAN_GA routine. Upper panel: univariate kernel densities for $L_\infty$ [cm total length (TL)], K (year$^{-1}$) and related parameters derived from the GA ensemble. Numbers above each density denote the distribution median; values in brackets (if shown) give the empirical 95% interval (2.5%–97.5%) from the GA solutions/bootstraps. Vertical dashed lines mark the medians. Lower panel: bivariate density of $L_\infty$ versus K; filled contours indicate 50%/75%/95% highest-density regions; the cross marks the joint median. (Data: this study; method: TropFishR ELEFAN_GA.)

of lionfish, combining growth performance index $L_\infty$ and K values to give a holistic measure of growth efficiency. The Figure 5 (lower) plot shows the relationship between the growth coefficient (K) and the asymptotic length ($L_\infty$). The highest density region (dark blue) indicates the most likely combination of these parameters for the lionfish population. This suggests that most fish are expected to have moderate K values, with $L_\infty$ approximately in the mid-40 cm range. Figure S2 shows the growth curve superimposed onto the restructured monthly length frequency.

### 3.3 | Spawning aspects

The GSI results for female lionfish showed elevated activity from April to November (Figure 6 – upper). To identify the active spawning season in our study area, an ANOVA test was used. From this, it is clear that female GSI values were significantly different by month (ANOVA, $F_{11,289} = 11.14$, $p < 0.001$), and a Tukey post hoc test determined five homogeneous subsets for females (Figure S3). This analysis was

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determined that the peak active spawning season for female lionfish is from June to November. No significant differences were observed in the GSI values of male individuals across months (ANOVA, $p = 0.354$). The $L_{50}$ graph suggests that female lionfish typically reach sexual maturity at around 20.1 cm. (Figure 7).

The development stages of the gonads (Figure 8) suggest a strong seasonal pattern in reproductive activity, with the majority of female fish moving into the developing, spawning-capable and active stages during the warmer months (April to August). This period aligns with the peak in SST. As the SST declines towards the end of the year, the population shifts towards regressing and regenerating stages, indicating a recovery period after the peak reproductive season. The increase in immature and regenerating fish during these cooler months suggests that the population is preparing for the next reproductive cycle, which likely commences as temperatures begin to increase again in spring.

A total of 39 female gonads were analysed for fecundity (Table 2). Average BF was calculated at 20,743 oocytes for an average female with 24.2 cm TL and 288 g TW. The lowest and highest BF ranged between 1513 and 66,255 oocytes, respectively. The smallest size lionfish was 19 cm and 129 g, whereas the largest was 33 cm and 536 g. RBF was calculated as 77 oocytes per gram of female, ranging from 7 to 190 oocytes per gram. The relationship of BF and GFBW was moderate and significant ($r^2 = 0.26$, $p = 0.002$), and the regression equation was BF = 0.65GFBW + 8603 (Figure 9). However, the BF and TL relationship was weak and insignificant ($r^2 = 0.080$, $p = 1.23$).

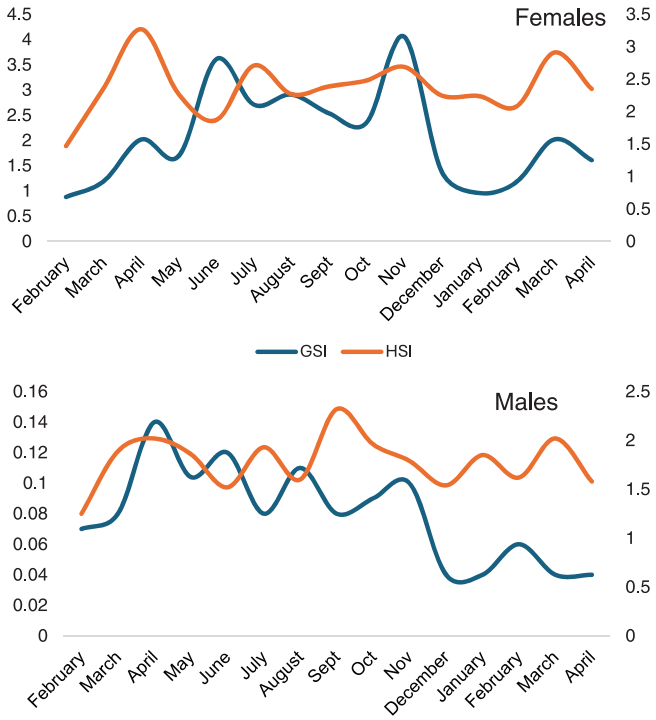



**FIGURE 6** Monthly variation in gonadosomatic index (GSI) and hepatosomatic index (HSI) in female and male *Pterois miles* in the Eastern Mediterranean.

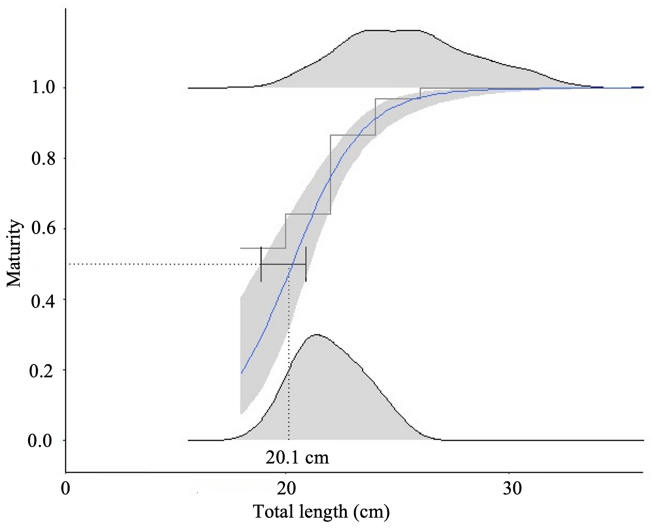



**FIGURE 7** Length at first maturity for females.

## 3.4 | Condition (Kn)

In female lionfish, the monthly and seasonal changes in HSI and overall condition (Kn) started to increase in spring and reached the highest point in summer, with noticeable peaks in April and November. In the late summer and fall, Kn values increase even as HSI starts to stabilize or decline, indicating that energy demands had decreased, and the fish were replenishing their overall body condition. Monthly changes in HSI and Kn values for male lionfish exhibited a different pattern with moderate increase and less-pronounced seasonal peaks. Kn values in males tended to remain relatively stable, with slight increases during the late summer and early fall.

The relationship between TL and Kn, modelled by a smoothed spline function, indicated a decreasing trend, with the steepest decline occurring as TL increased from 15 cm to approximately 20 cm (Figure 10). The relationship between TL and Kn weakened around 20 cm, followed by a slight increase around 25 cm and ended by stabilizing at around 35 cm.

## 3.5 | Natural mortality (M)

Across all empirical estimators considered, method-specific values of natural mortality for lionfish spanned 0.60–1.25 $years^{-1}$. When pooled via the method-weighted composite, the estimates formed a unimodal and fairly concentrated distribution with a pronounced central mass between ~0.8 and 1.0 $years^{-1}$ and a visible mode near 0.9 $year^{-1}$ (Figure S4). Measures of central tendency were closely aligned – the composite median was 0.83 $year^{-1}$ and the mean 0.81 $year^{-1}$ – indicating limited skewness and broad agreement among predictor classes. We therefore adopt the composite median (0.83 $year^{-1}$) as the working value of M for downstream calculations, as it is robust to the thin tails contributed by a small number of lower and higher estimator values; using the mean instead would change M by only 0.02 $year^{-1}$ (<3%), leaving all qualitative conclusions unchanged.

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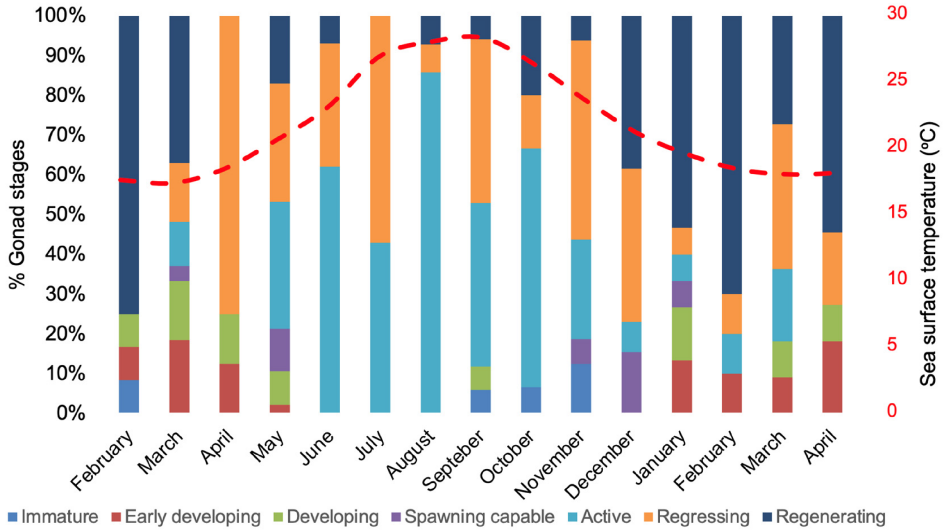



**FIGURE 8** Monthly variation in gonad development stages of female *Pterois miles* and the corresponding sea surface temperature in the study area.

**TABLE 2** Fecundity results and information on analysed individuals.

| Months | *n* | TL (cm) | TW (g) | GW (g) | GSI (%) | Batch fecundity | Relative batch fecundity |
|---|---|---|---|---|---|---|---|
| Jun | 4 | 24.5 | 227 | 5.9 | 2.7 | 10,615 | 51 |
| Jul | 5 | 24.6 | 247 | 5.6 | 2.3 | 25,256 | 77 |
| Aug | 5 | 23.7 | 193 | 6.1 | 3.3 | 20,574 | 107 |
| Sep | 5 | 21.0 | 316 | 12.0 | 3.9 | 19,014 | 61 |
| Oct | 6 | 19.9 | 275 | 13.4 | 5.1 | 28,070 | 112 |
| Mar | 8 | 29.2 | 362 | 10.2 | 2.9 | 18,536 | 63 |
| Apr | 6 | 28.3 | 383 | 9.8 | 2.6 | 13,004 | 44 |
| Overall | 39 | 24.2 | 288 | 9.4 | 3.3 | 20,743 | 77 |

Abbreviations: GSI, gonadosomatic index; GW, gonad weight; TL, total length; TW, total body weight.

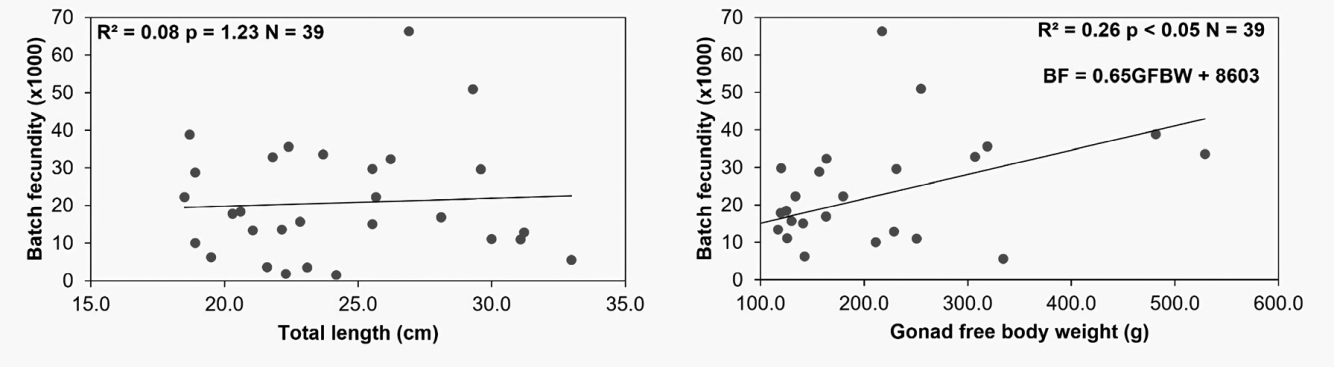



**FIGURE 9** Simple linear regression between lionfish batch fecundity and total length, and gonad free body weight.

## 4 | DISCUSSION

The results of this study provide crucial insights into the growth and reproductive biology of the invasive lionfish in the Eastern Mediterranean. The observed LWR supports the existing data, indicating that lionfish exhibit positive allometric growth in this region. In southwestern Türkiye, the spawning season extended from June to November (~6 months), coinciding with the warmest period of the year; however, causality cannot be inferred, as multiple environmental cues can modulate reproductive timing. This prolonged ongoing reproductive period, coupled with the species' high fecundity and adaptability, underscores the urgent need for effective management measures to control their spread and mitigate their impact on native marine biodiversity.

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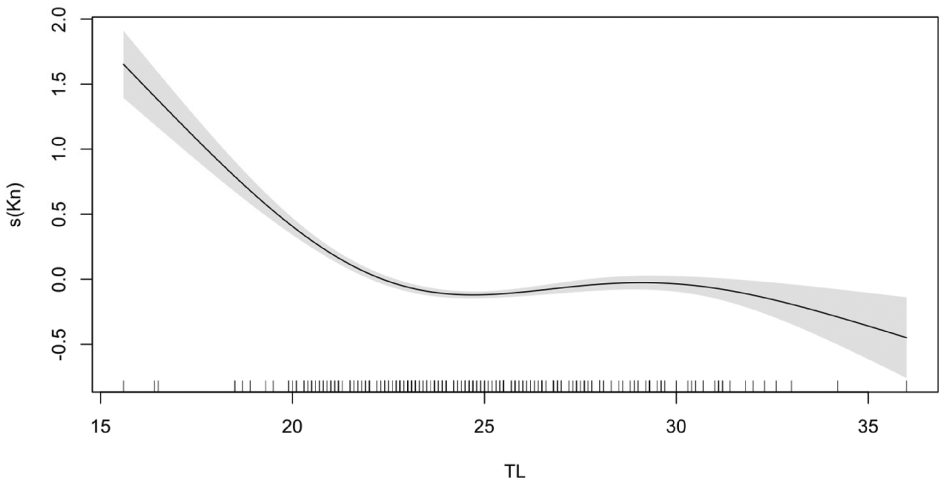



**FIGURE 10** Non-linear relationship between fish total length and condition factor.

**TABLE 3** Comparison of length–weight relationship parameters of *Pterois miles* across different studies in the Eastern Mediterranean.

| Sex | *a* | *b* | $R^2$ | *N* | Reference |
|---|---|---|---|---|---|
| Male | 0.0079 | 3.171 | 0.94 | 106 | Dağhan (2020) |
| | | 3.125 | | 75 | Savva et al. (2020) |
| | 0.0045 | 3.326 | | 179 | Kondylatos et al. (2024) |
| | 0.0076 | 3.183 | 0.91 | 278 | Present study |
| Female | 0.0067 | 3.220 | 0.93 | 71 | Dağhan (2020) |
| | | 3.164 | | 119 | Savva et al. (2020) |
| | 0.0072 | 3.199 | | 184 | Kondylatos et al. (2024) |
| | 0.0069 | 3.224 | 0.92 | 303 | Present study |
| Pooled | 0.0076 | 3.181 | 0.95 | 179 | Dağhan (2020) |
| | 0.0085 | 3.154 | | 249 | Savva et al. (2020) |
| | 0.0063 | 3.232 | | 363 | Kondylatos et al. (2024) |
| | 0.0079 | 3.179 | 0.92 | 580 | Present study |

The findings from various studies on the sex ratio of lionfish in the Eastern Mediterranean revealed some interesting patterns and differences. Dağhan and Demirhan (2020) reported a predominance of males, with a male to female ratio of approximately 1.5:1 (106 males to 71 females). Kondylatos et al. (2024) found a nearly balanced sex ratio with a slight female bias (1:1.03), not significantly different from 1:1 as we found in this study. Savva et al. (2020) observed a significant female dominance with a sex ratio of 1:1.54 overall, which was even more skewed in certain size classes, such as a 1:3.25 ratio in the 20–25 cm size class. Our sex ratio found here varied across different size classes, with a higher proportion of females in the 20–25 cm class and more males in the larger size classes. These different sex ratios may be attributable to different collection methodologies, environmental factors or actual population dynamics. The significant female dominance observed in certain size classes, particularly in Savva et al. (2020) and in this study, might indicate differential mortality rates between sexes, or different selective pressures acting on both sexes. These findings highlight the complexity and variability of sex ratios in lionfish populations. Understanding these size distributions by sex is important for assessing population dynamics and reproductive biology of lionfish and could be applied in their targeted control strategies by spear fishers.

Both males and females exhibit positive allometric growth, with no significant differences in LWRs between sexes. This suggests that the growth patterns are consistent regardless of sex, implying a standard formula for predicting weight from length across the population. Across studies, the length–weight exponent *b* clustered at or slightly above 3, indicating isometric to mildly positive allometry. In practical terms, lionfish become relatively stouter with size when $b>3$; $b = 3$ implies geometric similarity (isometry), whereas $b < 3$ would indicate increasing slenderness. This uniformity suggests that lionfish in this region grow proportionally in a similar manner regardless of location or sex (Table 3). This information is crucial for fisheries management, as it provides a reliable basis for estimating biomass and assessing population health.

In this study, the active spawning season for lionfish in southwestern Turkey lasted 6 months from June to November, but spawning-capable females were found between March and

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November. Other studies in the Eastern Mediterranean found spawning-capable lionfish year-round; however, lionfish are only actively spawning during the warmer summer months in Cyprus, Rhodes (Greece) and İskenderun (southeastern Turkey) (Dağhan, 2020; Kondylatos et al., 2024; Mouchlianitis et al., 2022; Savva et al., 2020). In southwestern Turkey (Fethiye), the GSI values began to spike in synch with warming SST in June, which averaged 22.6°C. Similarly, Kondylatos et al. (2024) reported the highest reproductive intensity in Rhodes during the summer, followed by a smaller peak in autumn. Interestingly, Mouchlianitis et al. (2022) noted a much shorter spawning season from Cyprus in June and July. Savva et al. (2020) also highlighted that lionfish in Cyprus peak in spawning during summer at a critical temperature threshold around 28.4°C. Dağhan (2020) found elevated GSI values during the warmest period in July and August. Although this spawning-capable duration is relatively long compared to native marine fish species in the Mediterranean, lionfish actively spawn year-round in tropical regions (Fogg et al., 2017; Morris et al., 2008), indicating a shorter and more defined season in the invaded Mediterranean Sea, which is affected by seasonality.

Seasonal changes in female HSI values indicate that the liver stores lipids and glycogen for periods of high-energy demand, such as reproduction and/or rapid growth. During HSI peaks, Kn values, which reflect overall fish condition, tend to decrease slightly, suggesting that energy is stored in the live, whereas other reserves are used for physiological needs. Male HSI values show less variation, indicating stable energy storage, which is consistent year-round. The Kn and TL relationship suggests that smaller fish are in better condition, but as they grow, their condition declines before it stabilizes in larger fish, possibly due to shifts in energy allocation during growth or maturity.

According to well-documented reproductive dynamics of lionfish from the western Atlantic, this species is a multiple spawner (Brown-Peterson & Hendon, 2013; Morris et al., 2011), with a spawning frequency ranging from 2 to 4 days (Fogg et al., 2017; Morris Jr., 2009). Gardner et al. (2015) also indicated that lionfish females with mature oocytes were found in every month except December in the Cayman Islands, with macroscopic analyses confirming their year-round spawning there. In the Mediterranean, multiple spawning events were also reported by Mouchlianitis et al. (2022), highlighting a prolonged spawning season in peak summer months. Our GSI results and histological observations indicate a more prolonged spawning season, lasting from June to November, than neighbouring studies from the Turkish Mediterranean coast. Additionally, histological examinations confirmed this by observing terminally positioned oocytes near the ovary wall during this period. Morris et al. (2008) highlighted that lionfish exhibit cystovarian-type ovaries (Hoar, 1957), with oocytes developing on stalks or peduncles. Mouchlianitis et al. (2022) reported that lionfish have an indeterminate fecundity type, with an estimated BF of 21,140 and ranging from 3225 to 63,149 oocytes. We also estimated a BF value of 20,743 oocytes, which is similar to the Mouchlianitis et al. (2022) study in western Mediterranean. Our RFB result was slightly lower (RFB = 77) compared to the result (RFB = 92) from western Atlantic, another major lionfish invasion area (Fogg et al., 2017). However, BF results were remarkably different and not compatible with a study from their native Indian Ocean (75,547 oocytes; Priyadharsini et al., 2013). Such differences in reproductive traits across regions are consistent with expectations for invasive alien species adapting to new environments. Invasive species often exhibit high phenotypic plasticity in key life-history traits, including reproductive timing, batch fecundity and spawning strategies, allowing them to optimize fitness in novel or fluctuating habitats (Kolar & Lodge, 2001; Llopis-Belenguer et al., 2023). For lionfish specifically, reproductive traits such as fecundity, spawning duration and frequency have shown notable plasticity across both native and invaded ranges, often influenced by local environmental conditions such as temperature, food availability and habitat type (Morris et al., 2011; Priyadharsini et al., 2013). Therefore, although methodological factors may contribute to observed variation, it is equally plausible that the elevated fecundity and prolonged spawning season documented here reflect adaptive responses to regional environmental conditions and ongoing establishment processes of lionfish in the Mediterranean Sea.

This study provides the first estimates of natural mortality for lionfish in Turkey. Despite the presence of lionfish fishing practices in the country, there are no existing studies on catches and fishing effort that could help to infer fishing mortality rates. The natural mortality rates calculated here, ranging between 0.6 and 1.25 years$^{-1}$, are higher than the 0.43 year$^{-1}$ reported by Kondylatos et al. (2024) and are still relatively high compared to many other fish species. Mortality is influenced by factors such as $k$, $L_\infty$ and temperature, with higher and consistent temperatures in tropical environments accelerating biological processes (Pauly, 1980). Kondylatos et al. (2024) used the updated Hoenig's estimator according to Then et al. (2015) and calculated the natural mortality (M) for lionfish as 0.43. They also reported total mortality (Z) as 0.83, fishing mortality (F) as 0.41 and an exploitation ratio (E) of 0.48, suggesting that the population is underexploited. In contrast, the natural mortality rate calculated for lionfish in the PNAA by Rodriguez-Cortes et al. (2015) was 1.46 years$^{-1}$, which is considered high compared to typical values for short-lived fish species, which range from 0.2 to 0.5 (Froese & Pauly, 2014). No directed commercial fishery for lionfish currently operates in Türkiye; however, opportunistic removals occur in mixed-species set-net fisheries and by recreational spearfishing, particularly during summer. These removals constitute fishing mortality (F) and are distinct from the natural mortality (M) estimated here. Because standardized catch-and-effort data are unavailable, we did not quantify F or total mortality Z (where $Z = M + F$). Diver observations and local price signals are anecdotal and were not used in estimating M.

In conclusion, lionfish have demonstrated a formidable capacity for adaptation and population expansion in the Eastern Mediterranean region, driven by their high reproductive potential and extended spawning season, including prey naivety (Anton et al., 2016). The findings from this study, including the high fecundity and positive allometric growth, underline the urgency for effective management strategies to mitigate the ecological impacts of this invasive species. The prolonged reproductive period, combined with having few natural predators in the region, suggests that lionfish populations could continue to grow if left unchecked, potentially leading to further declines

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in native biodiversity. To successfully tackle this invasion, it is advised that regional co-ordination for research and control efforts are initiated, including permitting the use of scuba gear for targeted removals and/or organizing lionfish culling events (Ulman et al., 2022), in addition to improved public awareness campaigns and commercialization activities.

## AUTHOR CONTRIBUTIONS

Taner Yildiz: project administration, conceptualization, lab work, data curation, software, resources, formal analysis, validation, visualization, writing – original draft, writing – review and editing. Nazlı Demirel: formal analysis, visualization, writing – original draft, writing – review and editing. Aylin Ulman: fieldwork, writing – original draft, writing – review and editing. Özgür Çanak: lab work, writing – review and editing. Mert Kesiktaş: lab work. Lütfiye Eryılmaz: lab work. Hilal Buyuran: lab work. Utkuhan Şahinoğlu: lab work. Nurdan Cömert: software, formal analysis, visualization, writing – original draft, writing – review and editing. Emre Yemişken: project administration, lab work, conceptualization, writing – original draft, writing – review and editing.

## ACKNOWLEDGEMENTS

The sea surface temperature data were obtained from the NASA Langley Research Center Atmospheric Science Data Center. We thank Alex Fogg for checking the reproduction season results found in this study.

## FUNDING INFORMATION

This study was funded by Scientific Research Projects Coordination Unit of Istanbul University. Project number: FUA-2020-34578.

## CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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## REFERENCES

Albins, M. A., & Hixon, M. A. (2008). Invasive Indo-Pacific lionfish *Pterois volitans* reduce recruitment of Atlantic coral-reef fishes. *Marine Ecology Progress Series*, *367*, 233–238. https://doi.org/10.3354/meps07620

Albins, M. A., & Hixon, M. A. (2013). Worst case scenario: Potential long-term effects of invasive predatory lionfish (*Pterois volitans*) on Atlantic and Caribbean coral-reef communities. *Environmental Biology of Fishes*, *96*, 1151–1157. https://doi.org/10.1007/s10641-011-9795-1

Anton, A., Cure, K., Layman, C., Puntila, R., Simpson, M. S., & Bruno, J. (2016). Prey naiveté to invasive lionfish *Pterois volitans* on Caribbean coral reefs. *Marine Ecology Progress Series*, *544*, 257–269. https://doi.org/10.3354/meps11553

Azzurro, E., Stancanelli, B., Di Martino, V., & Bariche, M. (2017). Range expansion of the common lionfish *Pterois miles* (Bennett, 1828) in the Mediterranean Sea: An unwanted new guest for Italian waters. *BioInvasions Records*, *6*, 95–98. https://doi.org/10.3391/bir.2017.6.2.01

Bagenal, T. (1978). Methods for assessment of fish production in fresh waters-3. In *IBP Handbook* (Vol. 3). Blackwell Scientific Publications.

Bariche, M., Torres, M., & Azzurro, E. (2013). The presence of the invasive lionfish Pterois miles in the Mediterranean Sea. *Mediterranean Marine Science*, *14*, 292–294. https://doi.org/10.12681/mms.428

Betancur-R, R., Hines, A., Acero, A., Ortí, G., Wilbur, A. E., & Freshwater, D. W. (2011). Reconstructing the lionfish invasion: Insights into greater Caribbean biogeography. *Journal of Biogeography*, *38*, 1281–1293. https://doi.org/10.1111/j.1365-2699.2011.02496.x

Brown-Peterson, N. J., & Hendon, J. R. (2013). Notes on the biology of invasive lionfish (Pterois sp.) from the northcentral Gulf of Mexico. *Gulf and Caribbean Research*, *25*, 117–120. https://doi.org/10.18785/gcr.2501.09

Brown-Peterson, N. J., Wyanski, D. M., Saborido-Rey, F., Macewicz, B. J., & Lowerre-Barbieri, S. K. (2011). A standardized terminology for describing reproductive development in fishes. *Marine and Coastal Fisheries*, *3*(1), 52–70. https://doi.org/10.1080/19425120.2011.555724

Bussotti, S., & Guidetti, P. (2011). Timing and habitat preferences for settlement of juvenile fishes in the marine protected area of Torre Guaceto (south-eastern Italy, Adriatic Sea). *Italian Journal of Zoology*, *78*, 243–254. https://doi.org/10.1080/11250001003774652

Cope, J. M., & Hamel, O. S. (2022). Upgrading from M version 0.2: An application-based method for practical estimation, evaluation and uncertainty characterization of natural mortality. *Fisheries Research*, *256*, 106493. https://doi.org/10.1016/j.fishres.2022.106493

Côté, I. M., & Smith, N. S. (2018). The lionfish Pterois sp. invasion: Has the worst-case scenario come to pass? *Journal of Fish Biology*, *92*, 660–689. https://doi.org/10.1111/jfb.13544

Côté, I. M., Green, S. J., & Hixon, M. A. (2013). Predatory fish invaders: Insights from Indo-Pacific lionfish in the western Atlantic and Caribbean. *Biological Conservation*, *164*, 50–61. https://doi.org/10.1016/j.biocon.2013.04.014

Crocetta, F., Agius, D., Balistreri, P., Bariche, M., Bayhan, Y. K., Çakir, M., Ciriaco, S., Corsini-Foka, M., Deidun, A., El Zrelli, R., Ergüden, D., Evans, J., Ghelia, M., Giavasi, M., Kleitou, P., Kondylatos, G., Lipej, L., Mifsud, C., Özvarol, Y., … Zenetos, A. (2015). New Mediterranean biodiversity records (October 2015). *Mediterranean Marine Science*, *16*, 682–702. https://doi.org/10.12681/mms.1477

Dağhan, H., & Demirhan, S. A. (2020). Some bio-ecological characteristics of lionfish *Pterois miles* (Bennett, 1828) in Iskenderun Bay. *Mar. Life Sci*, *2*, 28–40.

Dağhan, H., 2020. İskenderun Körfezi'nde dağılım gösteren aslan balığı *Pterois miles* (Bennett, 1828)'in bazı biyoekolojik özellikleri. M.Sc. Thesis, İskenderun Teknik Üniversitesi, Mühendislik ve Fen Bilimleri Enstitüsü, Su Ürünleri Anabilim Dalı, İskenderun, Türkiye, 60p. (in Turkish)

Dahl, K. A., & Patterson, W. F., III. (2014). Habitat-specific density and diet of rapidly expanding invasive red lionfish, Pterois volitans, populations in the northern Gulf of Mexico. *PLoS One*, *9*, e105852. https://doi.org/10.1371/journal.pone.0105852

Fogg, A. Q., Brown-Peterson, N. J., & Peterson, M. S. (2017). Reproductive life history characteristics of invasive red lionfish (*Pterois volitans*) in the northern Gulf of Mexico. *Bulletin of Marine Science*, *93*, 791–813. https://doi.org/10.5343/bms.2016.1095

Fogg, A. Q., Hoffmayer, E. R., Driggers, W. B., III, Campbell, M. D., Pellegrin, G. J., & Stein, W. (2013). Distribution and length frequency of invasive lionfish (Pterois sp.) in the northern Gulf of Mexico. *Gulf and Caribbean Research*, *25*, 111–115. https://doi.org/10.18785/gcr.2501.08

Froese, R., & Pauly, D. (Eds.). (2014). FishBase. [version 06/2014]. http://www.fishbase.org

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Galil, B. S., Boero, F., Campbell, M. L., Carlton, J. T., Cook, E., Fraschetti, S., Gollasch, S., Hewitt, C. L., Jelmert, A., Macpherson, E., Marchini, A., McKenzie, C., Minchin, D., Occhipinti-Ambrogi, A., Ojaveer, H., Olenin, S., Piraino, S., & Ruiz, G. M. (2015). 'Double trouble': The expansion of the Suez Canal and marine bioinvasions in the Mediterranean Sea. *Biological Invasions*, *17*, 973–976. https://doi.org/10.1007/s10530-014-0778-y

Galimany, E., Baeta, M., Durfort, M., Lleonart, J., & Ramón, M. (2015). Reproduction and size at first maturity in a Mediterranean exploited Callista chione bivalve bed. *Scientia Marina*, *79*, 233–242. https://doi.org/10.3989/scimar.04155.13A.

Galloway, K. A., & Porter, M. E. (2019). Mechanical properties of the venomous spines of *Pterois volitans* and morphology among lionfish species. *Journal of Experimental Biology*, *222*, jeb197905. https://doi.org/10.1242/jeb.197905

Gardner, P. G., Frazer, T. K., Jacoby, C. A., & Yanong, R. P. (2015). Reproductive biology of invasive lionfish (Pterois spp.). *Frontiers in Marine Science*, *2*, 7. https://doi.org/10.3389/fmars.2015.00007

Golani, D., & Sonin, O. (1992). New records of the Red Sea fishes, *Pterois miles* (Scorpaenidae) and *Pteragogus pelycus* (Labridae) from the eastern Mediterranean Sea. *Japanese Journal of Ichthyology*, *39*, 167–169. https://doi.org/10.11369/jji1950.39.167

Green, S. J., Akins, J. L., Maljković, A., & Côté, I. M. (2012). Invasive lionfish drive Atlantic coral reef fish declines. *PLoS One*, *7*, e32596. https://doi.org/10.1371/journal.pone.0032596

Henderson, M. J. (2012). *Movements, growth, and mortality of Chesapeake Bay summer flounder based on multiple tagging technologies*. M.Sc. Thesis, College of William and Mary.

Hoar, W. S. (1957). The gonads and reproduction. In *The physiology of fishes: Metabolism, vol. 1* (pp. 287–324). Academic Press.

Hunter, J. R., & Macewicz, B. J. (1980). Sexual maturity, batch fecundity, spawning frequency, and temporal pattern of spawning for the northern anchovy, Engraulis mordax, during the 1979 spawning season. *California Cooperative Oceanic Fisheries Investigations Reports*, *21*, 139–149.

Iglésias, S. P., & Frotté, L. (2015). Alien marine fishes in Cyprus: Update and new records. *Aquatic Invasions*, *10*, 425–438. https://doi.org/10.3391/ai.2015.10.4.06

Kallianiotis, A., Sophronidis, K., Vidoris, P., & Tselepides, A. (2000). Demersal fish and megafaunal assemblages on the Cretan continental shelf and slope (NE Mediterranean): Seasonal variation in species density, biomass and diversity. *Progress in Oceanography*, *46*, 429–455. https://doi.org/10.1016/S0079-6611(00)00028-8

Katsanevakis, S., Zenetos, A., Belchior, C., & Cardoso, A. C. (2013). Invading European seas: Assessing pathways of introduction of marine aliens. *Ocean and Coastal Management*, *76*, 64–74. https://doi.org/10.1016/j.ocecoaman.2013.02.024

King, M. (1995). *Fisheries biology, assessment and management*. Fishing News Books, Blackwell Science Ltd..

Kleitou, P., Crocetta, F., Giakoumi, S., Giovos, I., Hall-Spencer, J. M., Kalogirou, S., Kletou, D., Moutopoulos, D. K., & Rees, S. (2021). Fishery reforms for the management of non-indigenous species. *Journal of Environmental Management*, *280*, 111690. https://doi.org/10.1016/j.jenvman.2020.111690

Kolar, C. S., & Lodge, D. M. (2001). Progress in invasion biology: Predicting invaders. *Trends in Ecology & Evolution*, *16*(4), 199–204. https://doi.org/10.1016/S0169-5347(01)02101-2

Kondylatos, G., Theocharis, A., Mandalakis, M., Avgoustinaki, M., Karagyaurova, T., Koulocheri, Z., Vardali, S., & Klaoudatos, D. (2024). The devil Firefish *Pterois miles* (Bennett, 1828): Life history traits of a potential fishing resource in Rhodes (eastern Mediterranean). *Hydrobiology*, *3*, 31–50. https://doi.org/10.3390/hydrobiology3010003

Kulbicki, M., Beets, J., Chabanet, P., Cure, K., Darling, E., Floeter, S. R., Galzin, R., Green, A., Harmelin-Vivien, M., Hixon, M., Letourneur, Y., de Loma, T. L., McClanahan, T., McIlwain, J., MouTham, G., Myers, R., O'Leary, J. K., Planes, S., Vigliola, L., & Wantiez, L. (2012). Distributions of Indo-Pacific lionfishes Pterois spp. in their native ranges: Implications for the Atlantic invasion. *Marine Ecology Progress Series*, *446*, 189–205. https://doi.org/10.3354/meps09442

La Mesa, G., Molinari, A., Gambaccini, S., & Tunesi, L. (2011). Spatial pattern of coastal fish assemblages in different habitats in north-western Mediterranean. *Marine Ecology*, *32*, 104–114. https://doi.org/10.1111/j.1439-0485.2010.00404.x

Le Cren, E. D. (1951). The length-weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). *Journal of Animal Ecology*, *20*, 201–219. https://doi.org/10.2307/1540

Lesser, M. P., & Slattery, M. (2011). Phase shift to algal dominated communities at mesophotic depths associated with lionfish (*Pterois volitans*) invasion on a Bahamian coral reef. *Biological Invasions*, *13*, 1855–1868. https://doi.org/10.1007/s10530-011-0005-z

Llopis-Belenguer, C., Balbuena, J. A., Blasco-Costa, I., Karvonen, A., Sarabeev, V., & Jokela, J. (2023). Sensitivity of bipartite network analyses to incomplete sampling and taxonomic uncertainty. *Ecology*, *104*(4), e3974. https://doi.org/10.1002/ecy.3974

Mildenberger, T. K., Taylor, M. H., & Wolff, A. M. (2017). TropFishR: An R package for fisheries analysis with length-frequency data. *Methods in Ecology and Evolution*, *8*, 1520–1527. https://doi.org/10.1111/2041-210X.12791

Morris, J. A., & Akins, J. L. (2009). Feeding ecology of invasive lionfish (*Pterois volitans*) in the Bahamian archipelago. *Environmental Biology of Fishes*, *86*, 389–398. https://doi.org/10.1007/s10641-009-9538-8

Morris, J. A., Akins, J. L., Barse, A., Cerino, D., Freshwater, D. W., Green, S. J., Muñoz, R. C., Paris, C., & Whitfield, P. E. (2008). Biology and ecology of the invasive lionfishes, *Pterois miles* and *Pterois volitans*. *Gulf and Caribbean Fisheries Institute*, *61*, 409–414.

Morris, J. A., Jr. (2009). *The biology and ecology of invasive Indo-Pacific lionfish*. Ph.D. Dissertation, (p. 168p). North Carolina State University.

Morris, J. A., Shertzer, K. W., & Rice, J. A. (2011). A stage-based matrix population model of invasive lionfish with implications for control. *Biological Invasions*, *13*, 7–12. https://doi.org/10.1007/s10530-010-9786-8

Mouchlianitis, F. A., Kalaitzi, G., Kleitou, P., Savva, I., Kletou, D., & Ganias, K. (2022). Reproductive dynamics of the invasive lionfish (*Pterois miles*) in the eastern Mediterranean Sea. *Journal of Fish Biology*, *100*, 574–581. https://doi.org/10.1111/jfb.14971

Murua, H., Kraus, G., Saborido-Rey, F., Witthames, P. R., Thorsen, A., & Junquera, S. (2003). Procedures to estimate fecundity of marine fish species in relation to their reproductive strategy. *Journal of Northwest Atlantic Fishery Science*, *33*, 33–54. https://doi.org/10.2960/J.v33.a3

Pauly, D. (1980). On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *ICES Journal of Marine Science*, *39*, 175–192. https://doi.org/10.1093/icesjms/39.2.175

Peake, J., Bogdanoff, A. K., Layman, C. A., Castillo, B., Reale-Munroe, K., Chapman, J., Dahl, K., Patterson, W. F., III, Eddy, C., Ellis, R. D., Faletti, M., Higgs, N., Johnston, M. A., Muñoz, R. C., Sandel, V., Villasenor-Derbez, J. C., & Morris, J. A., Jr. (2018). Feeding ecology of invasive lionfish (*Pterois volitans* and *Pterois miles*) in the temperate and tropical western Atlantic. *Biological Invasions*, *20*, 2567–2597. https://doi.org/10.1007/s10530-018-1720-5

Priyadharsini, S., Manoharan, J., Varadharajan, D., & Subramaniyan, A. (2013). Reproductive biology and histological study of red lionfish Pterois volitans from Cuddalore, South East Coast of India. *Journal of Aquaculture Research and Development*, *4*, 201.

R Core Team. (2024). *R: A language and environment for statistical computing (version 4.3.1)*. R Foundation for Statistical Computing. URL: https://www.R-project.org/

Reynolds, R. W., Rayner, N. A., Smith, T. M., Stokes, D. C., & Wang, W. (2002). An improved in situ and satellite SST analysis for climate. *Journal of climate*, *15*, 1609–1625.

Rodriguez-Cortes, K. D., Aguilar-Perera, A., & Bonilla-Gomez, J. L. (2015). Growth and mortality of red lionfish, Pterois volitans (Actinopterygii:

10958649, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/jfb.70296 by Nazli Demirel - Istanbul University , Wiley Online Library on [02/12/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Scorpaeniformes: Scorpaenidae), in the Parque Nacional Arrecife Alacranes, southern Gulf of Mexico, as determined by size-frequency analysis. *Acta Ichthyologica et Piscatoria*, *45*, 175–179. https://doi.org/10.3750/AIP2015.45.2.07

Rojas-Vélez, S., Tavera, J., & Acero, A. (2019). Unraveling lionfish invasion: Is *Pterois volitans* truly a morphologically novel predator in the Caribbean? *Biological Invasions*, *21*, 1921–1931. https://doi.org/10.1007/s10530-019-01946-6

Savva, I., Chartosia, N., Antoniou, C., Kleitou, P., Georgiou, A., Stern, N., Hadjioannou, L., Jimenez, C., Andreou, V., Hall-Spencer, J. M., & Kletou, D. (2020). They are here to stay: The biology and ecology of lionfish (*Pterois miles*) in the Mediterranean Sea. *Journal of Fish Biology*, *97*, 148–162. https://doi.org/10.1111/jfb.14340

Schwamborn, R., Mildenberger, T. K., & Taylor, M. H. (2019). Assessing sources of uncertainty in length-based estimates of body growth in populations of fishes and macroinvertebrates with bootstrapped ELEFAN. *Ecological Modelling*, *393*, 37–51. https://doi.org/10.1016/j.ecolmodel.2018.12.001

Soares, M. O., Pereira, P. H., Feitosa, C. V., Maggioni, R., Rocha, R. S., Bezerra, L. E. A., Pereira, P. H. C., Duarte, O. S., Paiva, S. V., Noleto-Filho, E., Silva, M. Q. M., Csapo-Thomaz, M., Garcia, T. M., Arruda Júnior, J. P. V., Cottens, K. F., Vinicius, B., Araújo, R., Eirado, C. B. D., Santos, L. P. S., … Giarrizzo, T. (2023). Lessons from the invasion front: Integration of research and management of the lionfish invasion in Brazil. *Journal of Environmental Management*, *340*, 117954. https://doi.org/10.1016/j.jenvman.2023.117954

Then, A. Y., Hoenig, J. M., Hall, N. G., & Hewitt, D. A. (2015). Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. *ICES Journal of Marine Science*, *72*, 82–92. https://doi.org/10.1093/icesjms/fsu136

Torrejon-Magallanes, J. (2019). sizeMat: an R package to estimate size at sexual maturity. R Package Version 1.0. https://cran.r-project.org/package=sizeMat (accessed 11 April 2025)

Turan, C., Ergüden, D., Gürlek, M., Yağlıoğlu, D., Uyan, A., & Uygur, N. (2014). First record of the Indo-Pacific lionfish Pterois miles for the Turkish marine waters. *Journal of Black Sea/Mediterranean Environment*, *20*, 158–163.

Ulman, A., Ali, F. Z., Harris, H. E., Adel, M., Mabruk, S. A. A. A., Bariche, M., Candelmo, A. C., Chapman, J. K., Çiçek, B. A., Clements, K. R., Fogg, A. Q., Frank, S., Gittings, S. R., Green, S. J., Hall-Spencer, J. M., Hart, J., Huber, S., Karp, P. E., Kyne, F. C., … Yildiz, T. (2022). Lessons from the Western Atlantic lionfish invasion to inform Management in the Mediterranean. *Frontiers in Marine Science*, *9*, 865162. https://doi.org/10.3389/fmars.2022.865162

Wickham, H. (2016). Getting started with ggplot2. In *ggplot2: Elegant graphics for data analysis* (pp. 11–31). Springer International Publishing.

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**How to cite this article:** Yıldız, T., Demirel, N., Ulman, A., Çanak, Ö., Kesiktaş, M., Buyuran, H., Şahinoğlu, U., Cömert, N., Eryılmaz, L., & Yemişken, E. (2025). Growth and reproductive dynamics of the devil firefish, *Pterois miles* (Bennett, 1828), in the Eastern Mediterranean Sea. *Journal of Fish Biology*, 1–13. https://doi.org/10.1111/jfb.70296

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