e-ISSN: 3023-7343

TETHYS ENVIRONMENTAL SCIENCE

an International Journal

Determining the Bioecological Characteristics of Invasive Lionfish Species (*Pterois* spp.) in the Northeastern Mediterranean

Hayri Ertuğrul Çete*, Serap Ergene

Mersin University, Faculty of Science, Department of Biology, 33343 Yenişehir, Mersin.

Research Article

Citation: Çete, H. E., Ergene, S. (2025). Determining the Bioecological Characteristics of Invasive Lionfish Species (*Pterois* spp.) in the Northeastern Mediterranean. *Tethys Env. Sci.* 2(4): 163-180.

DOI: 10.5281/zenodo.17900987

Received: 18 September 2025

Accepted: 02 December 2025

Available Online: 11 December 2025

Publication Date: 29 December 2025

Abstract

The present study investigated the bioecology of invasive lionfish species (*Pterois spp.*) through regular dives along the Mersin coastline, northeastern Mediterranean. The length, weight, age, stomach contents and gonads of the collected lionfish were analyzed, and the environmental parameters such as seawater temperature, depth, pH and salinity at the sampling stations were also recorded. The total lengths ranged from 6.0 to 38.0 cm and the weights ranged from 1.3 to 769.0 g. The length-weight relationships were calculated for all individuals as $W = 0.049 \times L^{3.30}$. The growth pattern was detected as positive allometric. The maximum age class was VII for all individuals. The von Bertalanffy growth parameters were L_∞ = 45.35 cm, W_∞ = 1435 g, k = 0.061 year^{-1}, t_0 = -6.282 years. The stomach contents were found to be predominantly composed of small fish, accounting for 77.5% of the total weight, while invertebrates constituted a smaller proportion (5.9%). The mean gonad weight of 191 females was 4.52 g, with a maximum of 60 g. Mean egg diameter measured 1.3 mm, and females averaged 74 eggs. Gonadosomatic index and condition factor analyses show reproduction peaks in summer. Lionfish proliferation in the eastern Mediterranean is driven by venomous spines, rapid growth, early maturation, hunting success, and opportunistic feeding. Findings highlight rapid growth, high fecundity, and dietary overlap with native predators, suggesting sustainable control requires protecting natural predators and targeted removals.

Keywords: *Lionfish, Pterois spp., invasive species, bioecological characteristics, northeastern Mediterranean, Türkiye.*

Introduction

The opening of the Suez Canal in 1869 and the completion of the Aswan Dam in 1970 eliminated natural barriers between the Red Sea and the Mediterranean, enabling the migration of numerous

Correspondence: Hayri Ertuğrul Çete
hertugrulcete@gmail.com

species (Turan et al., 2016, 2024; Stamouli et al., 2017). This biogeographic shift, particularly prominent in the eastern Mediterranean, has significantly altered regional biodiversity. Many non-native species, especially from the Red Sea, have become established and pose ecological risks by outcompeting native fauna (Poursanidis, 2015; Farrag et al., 2016). Invasive species are characterized by high reproductive rates, broad ecological tolerance, and adaptability, often leading to reduced biodiversity and altered ecosystem functions (Zenetos et al., 2012; Otero et al., 2013; Turan et al., 2018). Among these, lionfish (*Pterois miles* and *Pterois volitans*), venomous predators from the Scorpaenidae family, have rapidly expanded their range (Johnston and Purkis, 2014; Kletou et al., 2016; Turan, 2020). Their morphology, including venomous spines and camouflage coloring, along with opportunistic feeding behavior and lack of natural predators, make them highly successful invaders. Studies have shown they primarily prey on small reef fish and crustaceans, with significant impacts on local food webs (Cote et al., 2013; Andradi-Brown et al., 2017).

The devil firefish *Pterois miles* (Bennett, 1828) was first reported from the coasts of Israel (Golani and Sonin, 1992), and then northwards from Lebanese (Bariche et al., 2013) and Cypriot waters (Evripidou, 2013; Oray et al., 2015). In Turkish marine waters, *P. miles* was first reported from the Iskenderun Bay by Turan et al. (2014) and spread westwards to Mersin (Yağlıoğlu and Ayas, 2016) and Antalya Bays (Özbek et al., 2017) and the South Aegean coast of Türkiye (Turan and Öztürk, 2015; Bilge et al., 2016; Özgül, 2020; Oruç et al., 2022). Most recently, *P. miles*, recorded in 2023 by Alkan et al. (2023) from the Edremit Bay, has expanded its spread towards the the North Aegean coast of Türkiye. The red lionfish *Pterois volitans* (Linnaeus, 1758) was first reported in the Mediterranean Sea by Gürlek et al. (2016) from the Iskenderun Bay, followed by records from the Antalya Bay by Gökoğlu et al. (2017) and from the Mersin Bay by Ayas et al. (2018). In the last decade, lionfish have expanded their habitat to the Central Mediterranean and continue to spread to the Western Mediterranean, highlighting their high invasive potential (Turan, 2020; Ulman et al., 2020).

This study aimed to reveal some bioecological characteristics of lionfish species on the Mersin coast in the northeastern Mediterranean. Regular dives were made at four stations over two years, collecting data on morphometric, age, nutrition, reproduction, and environmental variables (temperature, salinity, pH, depth, and currents). Therefore, by better understanding the adaptation of *Pterois* spp. and its regional ecological impact, potential management strategies against this invasive species were evaluated.

Material and Methods

Between June 2020 and June 2022, a total of 320 lionfish specimens were collected through systematic dives along the Mersin coastline. Following several exploratory dives, Akkum, Susanoğlu, Dana Island and Aydıncık were identified as sampling areas with high lionfish density (Figure 1).

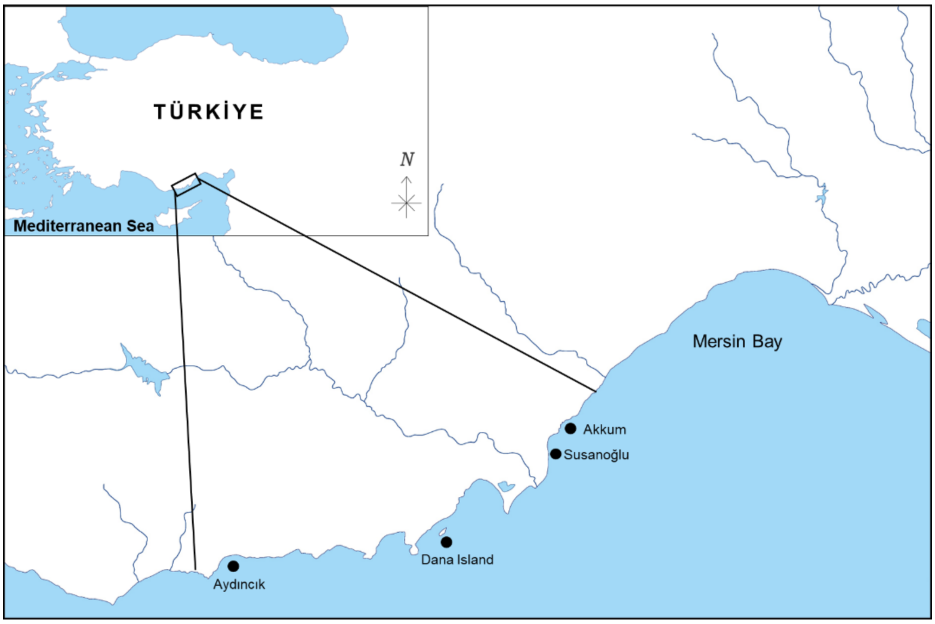

Figure 1. Map of the study area along the Mersin coastline, showing the four sampling stations: Akkum, Susanoğlu, Dana Island, and Aydıncık.

Due to its venomous spines, lionfish is challenging to harvest (Arbuatti and Lucidi, 2010). Specimens were collected using a 180 cm hand harpoon and a custom 10 L container and preserved in 70% ethanol. Environmental parameters were recorded using an Aqualung i450 dive computer (depth and temperature) and an ATC 0–100% refractometer (salinity). Dives ranged from 2 to 30 meters.

The total length and weight of 320 individuals were measured to the nearest 0.1 cm and 0.01 g. Age determination was carried out using scales, as they were preferred over otoliths and vertebrae due to their consistency and clarity. Scales were collected dorsally, near the head and pectoral fin, and then cleaned using a warm distilled water-NaOH protocol (Çete and Ergene, 2018), mounted between slides, and read independently by two observers using a stereo microscope (Figure 2).

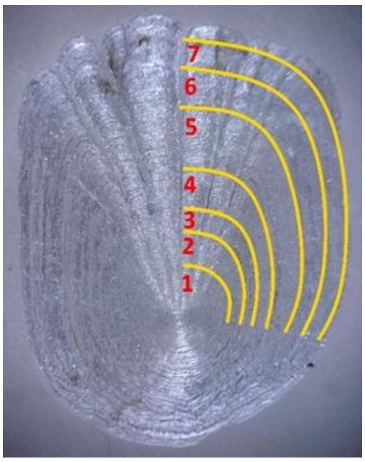

Figure 2. The scale of lionfish used for age determination.

Total length-weight relationships were calculated for all individuals with the formula $W = a \times L^b$ (Ricker, 1975). W is the fish weight (g), L is the fish length (cm), a is a coefficient relative to body form, and exponent b is the allometry coefficient of the linear regression equation expressing isometric (= 3), positive allometric (> 3) and negative allometric (< 3) growth in length.

Fulton condition factor (K) was calculated according to the formula (Le Cren, 1951) $K = \left(\frac{(BW\text{-}GW)}{L^3}\right) \times 100$, where GW is the gonad weight, BW is the body weight, and L is the fish total length.

The age-length relationship was modeled using the von Bertalanffy growth function $L_t = L_\infty [1 - e^{-k(t-t_o)}]$, where L_t is the fish length (cm) at the time t (year), L_∞ is the mean asymptotic length (cm), k is the growth coefficient (year^{-1}), and t_o (year) is the theoretical time at which the length equals to zero. On the other hand, the age-weight relationship was also calculated von Bertalanffy growth function $W_t = W_\infty [1 - e^{-k(t-t_o)}]^3$, where W_t is the weight of the fish at any age (g), W_∞ is the theoretical maximum weight (g), k is the growth coefficient (year^{-1}), t is the age (years), t_o is the theoretical age (years) at the time when fish length is assumed to be zero (von Bertalanffy, 1957).

The internal organs of a total of 320 fish were removed in the dissecting tub, the structures outside the digestive system were separated, and the stomach contents were examined. The digestive system was weighed with PL202-S model precision balance (0.01-210 g). Both full and empty weights of the digestive system were measured. The stomach and intestines were opened and the prey items in the stomach were counted and grouped as vertebrates, invertebrates and unidentified. Macro-sized organisms in the stomach content were photographed using a scale and calculated using $NOF = \frac{TNI}{N}$ formula (Lagler, 1956), where NOF is the number of organisms per fish, TNI is the total number of individuals of a given prey taxon, and N is the number of fish examined.

The weight of the gonads of the 320 fish examined was measured on a precision scale, the eggs were counted and their measurements were taken under a stereo microscope. The Gonadosomatic Index (GSI) was calculated according to the method of Render et al. (1995) $GSI = \left(\frac{GW}{BW\text{-}GW}\right) \times 100$, where GW is the gonad weight, BW is the body weight. All statistical analyses were performed using SPSS Statistics (v.25).

Result and Discussion

Lionfish typically inhabit rocky substrates, crevices, and caves, exhibiting ambush predation behavior by remaining motionless near aggregations of small fish (Golani et al., 2006; Darling et al., 2011). Although rarely observed in open waters, they are frequently encountered near Diadema setosum, a long-spined sea urchin that shelters small fish, indirectly attracting lionfish.

Sampling focused on four key areas due to habitat suitability. Lionfish abundance increased during summer and autumn, coinciding with higher prey availability and making them more detectable. In colder seasons, they retreat into deeper burrows and caves. While juveniles exhibit site fidelity (Jud et al., 2011), adults, especially those >30 cm, tend to roam freely and are often observed at greater depths. Lionfish were also found near artificial reefs and shipwrecks, such as around Dana Island, where habitat complexity supports their presence.

Over the two-year study period, the highest number of lionfish specimens was recorded at the Susanoğlu station (n = 120), followed by Dana Island (n = 93), Akkum (n = 67), and Aydıncık (n = 40). These locations are characterized by rocky substrates and complex structures, such as the shipwreck near Dana Island, which acts as an artificial reef and supports dense populations of small prey fish. Although Aydıncık also hosts a high lionfish presence, sampling was limited due to diving safety constraints, as the majority of individuals were observed at depths exceeding 30 meters. Standard diving limits restricted maximum sampling depth to 30 m.

During the two-year study period, a notable increase in sea surface and air temperatures was recorded, with 2021 being the warmest year. In coastal areas, sea temperature did not fall below 20°C even during winter, favoring thermophilic and migratory species such as lionfish. Supporting this, Poursanidis (2015) identified the eastern Mediterranean as the most suitable region for lionfish expansion, in contrast to less favorable northern basins like the Adriatic or Tyrrhenian Seas.

pH values measured at coastal stations averaged 7.9, showing no significant changes over time. Although this is slightly lower than the typical Mediterranean range (8.0–8.2), the region remains buffered against acidification due to high saturation levels of calcite and aragonite (Schneider and Erez, 2006). A slight decrease in pH was observed in surface waters during 2021, the warmest year on record.

Salinity ranged seasonally between 35‰ and 39‰, peaking in summer and decreasing in winter, likely influenced by freshwater inputs from the Taurus Mountains. Despite these fluctuations, lionfish, known for their broad salinity tolerance and resilience to environmental stressors, appeared unaffected. No signs of disease or high parasite load were detected, consistent with findings by Kindinger (2014).

Length and weight frequency distributions of 320 lionfish individuals were presented (Figure 3). The minimum total length (6.0 cm) and weight (1.3 g) were obtained from Akkum, while the maximum total length (38.0 cm) and weight (769.0 g) were obtained from Dana Island samples. The average weight of the Dana Island samples was 333.0 g, while the average weight of the Akkum samples was 157.0 g. In addition, the fact that most specimens on Dana Island (n = 242; 75.6%) were in the range of 18.0-30.0 cm and had an average total length of 27.6 cm (n = 93) may be attributed to the optimal habitat conditions created by the proximity of the region to fish farms, as well as the regional ecosystem may have provided suitable conditions for lionfish. In contrast, the lowest number of samples (n = 67) and mean length (22.0 cm) were observed from Akkum. Consistent with the study conducted by Kondylatos et al. (2024) on Rhodes Island, it showed similarity in the total length range obtained (15.7-38.8 cm).

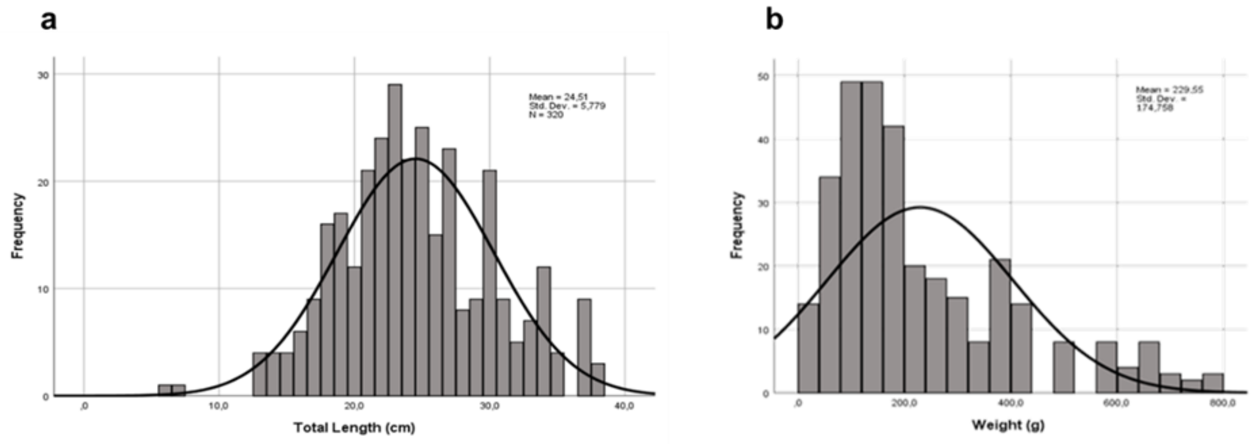

Figure 3. Length (a) and weight (b) frequency distribution of *Pterois* spp. from the Mersin coastline between June 2020 and June 2022.

The functional relationship in the fitted growth curve was determined by constructing length-weight relationship for all individuals of *Pterois* spp. (Figure 4). The constant *b* was found to be positive allometric with a value of 3.30 and was statistically significant ($P < 0.05$). This finding is consistent with Perera-Chan and Aguilar-Perera (2014), Toledo-Hernandez et al. (2014), Sabido-Itza et al. (2016), Savva et al. (2020), and Yılmaz and Demirhan (2020), but inconsistent with Barbour et al. (2011) and Zannaki et al. (2019). Perera-Chan and Aguilar-Perera (2014) calculated *b* value of *P. volitans* as positive allometric 3.30 in 455 samples from the Yucatan Peninsula (Gulf of Mexico). Toledo-Hernandez et al. (2014) found that *P. volitans* sampled across Puerto Rico exhibited positive allometric ($b = 3.32$) in 87 immature samples, isometric ($b = 2.99$) in 140 mature samples, and positive allometric ($b = 3.11$) in all individuals. Sabido-Itza et al. (2016) detected the growth pattern of *P. volitans* samples as positive allometric obtained from the coasts of Banco Chinchorro (n = 368) and Xcalak (n = 449) (Mexico) and determined the *b* constants to be 3.25 and 3.19, respectively. Savva et al. (2020) observed positive allometry in *P. miles* collected from the coasts of Cyprus, with *b* values of 3.16 for 119 female and 3.12 for 75 male specimens. Yılmaz and Demirhan (2020) reported the positive allometric growth pattern detected in 254 *P. volitans* individuals collected from Iskenderun Bay with *b* value of 3.11. Conflictingly, Barbour et al. (2011) determined negative allometry by calculating *b* value as 2.89 in 774 *P. miles* and *P. volitans* samples collected along the southeastern coast of the USA. Zannaki et al. (2019) reported an isometric growth pattern in *P. miles* sampled from Rhodes Island, with *b* value of 2.896 based on 42 specimens. The parameter *b*, which reflects the natural growth pattern of fish, typically ranges between 2 and 4. Variations in length-weight relationships across different geographic regions may arise from a combination of influences, including methodological approaches, sampling location, habitat conditions, seasonal effects, maturity stage, sex, age, dietary factors, and the length distribution of the sampled fish (Ricker, 1975; Bagenal and Tesch, 1978).

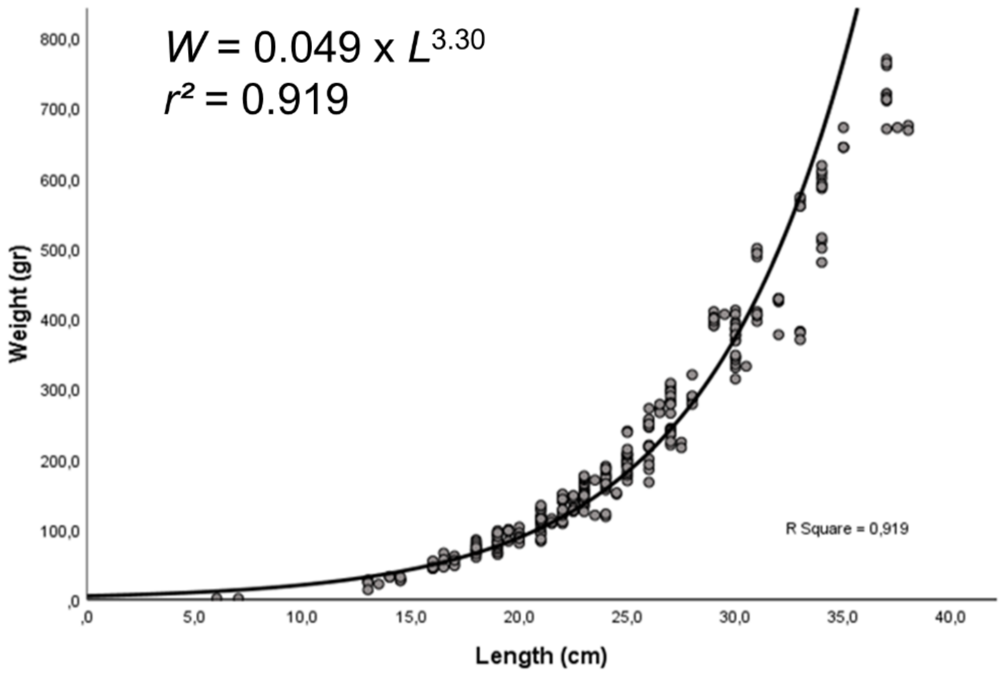

Figure 4. The length-weight relationship of lionfish (*Pterois* spp.) individuals from the Mersin coastline, northeastern Mediterranean.

Table 1 summarizes the range of length (L) and weight (W) across different age groups, along with sample sizes. A total of 320 individuals were studied, with age group contributions ranging from 3.1% (Group VII) to 24.7% (Group III). The largest sample was observed in Group III and the smallest in Group VII. Length ranges (L_{min}-L_{max}) indicate that at age 0, individuals measured 6.0-19.0 cm, with maximum length increasing steadily with age. The widest ranges were recorded in Groups VI (34.0-38.0 cm) and VII (30.0-37.0 cm). Lengths for all age groups of individuals ranged from 6.0 to 38.0 cm. Weight ranges (W_{min}-W_{max}) also increased with age. At age 0, weights were 1.3-98.0 g, while in Groups VI and VII they reached 510.0-764.0 g and 395.0-769.0 g, respectively. Weights for all age groups of individuals ranged from 1.3 to 769.0 g. Mean values (±SD) showed the same trend. Average length rose from 15.6±3.1 cm at age 0 to 35.4±1.7 cm in Group VI. Average weight increased from 50.5±26.3 g to 633.2±66.2 g in the same group, reflecting a normal growth pattern in the population.

Table 1. Distribution of sample size, total length (cm) and weight (g) ranges, and mean values by age groups of *Pterois* spp. individuals.

Age	0	I	II	III	IV	V	VI	VII	All
N	31	41	57	79	68	23	11	10	320
% coverage	9.7%	12.8%	17.8%	24.7%	21.3%	7.2%	3.4%	3.1%	100%
L_{min}-L_{max}	6.0-19.0	14.0-22.0	19.0-25.0	21.0-28.0	21.0-34.0	25.0-37.5	34.0-38.0	30.0-37.0	6.0-38.0
L_{mean}±SD	15.6±3.1	18.5±1.8	21.9±1.3	24.6±1.6	28.4±2.8	31.9±3.2	35.4±1.7	35.5±2.4	24.5±5.8
W_{min}-W_{max}	1.3-98.0	32.0-145.0	80.0-190.0	114.0-305.0	94.0-592.0	204.0-720.0	510.0-764.0	395.0-769.0	1.3-769.0
W_{mean}±SD	50.5±26.3	77.2±24.3	130.3±29.1	188.6±47.1	329.7±107.1	466.9±150.7	633.2±66.2	627.6±138.4	229.6±174.8

N, sample number; L_{min}, minimum total length; L_{max}, maximum total length; L_{mean}, mean total length; W_{min}, minimum weight; W_{max}, maximum weight; W_{mean}, mean weight; SD, standard deviation.

Lionfish are generally reported to have lifespans ranging from 0 to IX years, although individuals in the wild have been observed to live up to XV years (Green et al., 2012; Pusack et al., 2016), and those maintained in captivity have survived as long as XXX–XXXIII years (Potts et al., 2010). Field surveys across multiple regions consistently indicate that lionfish populations are dominated by younger cohorts: in the Gulf of North Carolina, 90% of 814 specimens were under II years of age (Potts et al., 2010); in the Gulf of Mexico, 93% were ≤ II years (Fogg et al., 2019); and in areas such as Little Cayman and northeast Florida, 90% were ≤ III years (Barbour et al., 2011; Edwards et al., 2014; Johnson and Swenarton, 2016).

The total lengths and calculated asymptotic length (L_∞ = 45.35 cm) of lionfish individuals assigned to each age class were shown in Figure 5. This L_∞ estimation is comparable to previous reports from Rhodes Island (Kondylatos et al., 2024) with 45.35 cm, Iskenderun Bay (Yılmaz and Demirhan, 2020) with 47.58 cm, the northeast Florida coast (Johnson and Swenarton, 2016) with 44.8 cm, southern Cyprus (Savva et al., 2020) with 44.4 cm, and North Carolina (Barbour et al., 2011) with 45.5 cm. The growth coefficient (k) was estimated at 0.061, consistent with values reported in both the Atlantic and Mediterranean. A low k value suggests slower growth and lower natural mortality rates (Sparre and Venema, 1992), which is likely due to reduced predation pressure (Andradi-Brown et al., 2017).

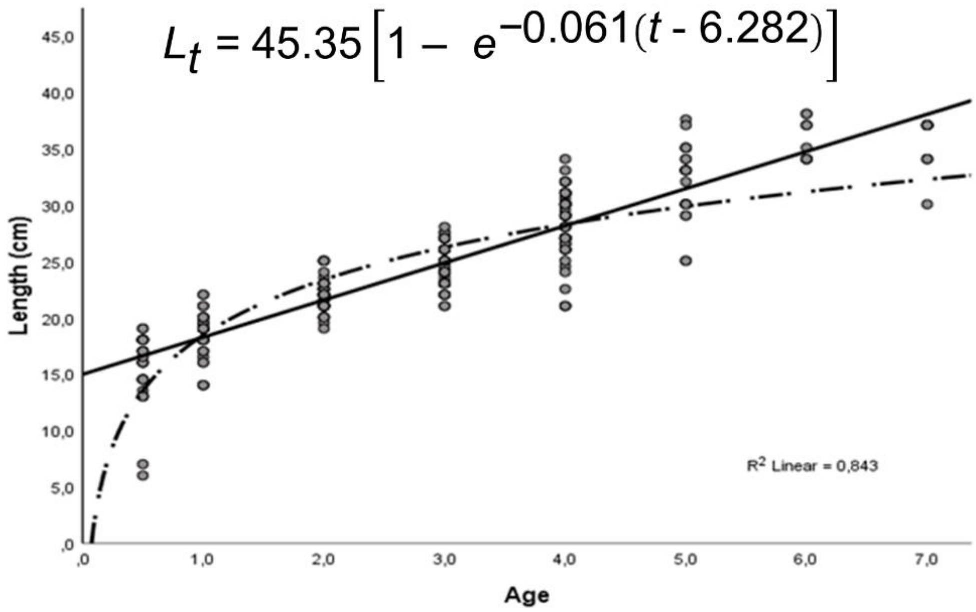

Figure 5. von Bertalanffy growth curves applied to total length-at-age data for lionfish (*Pterois* spp.) individuals from the Mersin coastline, northeastern Mediterranean.

The weights and calculated asymptotic weight (W_∞ = 1435 g) of lionfish individuals assigned to each age class were shown in Figure 6. Although a typical sigmoid curve was not observed here, growth initially proceeded rapidly and then slowed. Fish weights increased only gradually in the younger age groups, reflecting limited early development. However, the growth rate accelerates during the early age classes and eventually levels off in older individuals, a pattern consistent with the general growth trajectory commonly reported in fish populations (Avşar, 2005).

Ehemann (2017) reported lionfish measurements of 45.7 cm in total length and 1440 g in weight from Margarita Island (Venezuela). This high theoretical maximum weight (W_∞) suggests a significant potential biomass, which has important implications for both the ecosystem and potential fisheries.

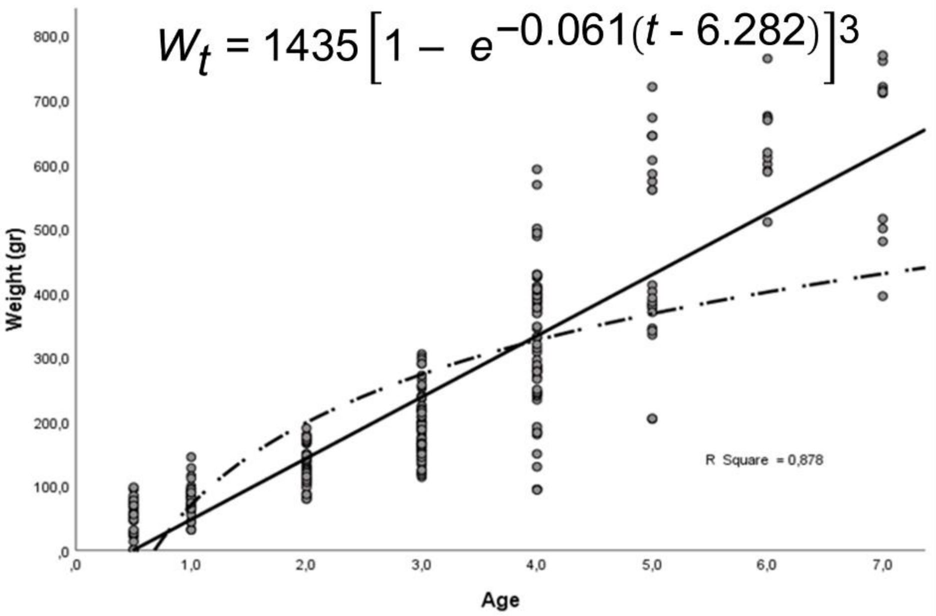

Figure 6. von Bertalanffy growth curves applied to weight-at-age data for lionfish (*Pterois* spp.) individuals from the Mersin coastline, northeastern Mediterranean.

The condition factor (*K*), a measure of nutritional status and environmental fitness, ranged from 0.83 to 1.68 in 262 individuals. According to age-related categories, it ranged from 1.14 to 1.50, with the highest mean value in the age group V (1.50). The mean *K* was 1.28, indicating that the lionfish specimens examined were in a generally good physiological condition (Avşar, 2005). Lionfish are one of the species at the top of the food web in many coral reef environments. With a high prey capture rate, lionfish are known to feed on crustaceans (and other invertebrates) and local fish species, starting from small fry to fish up to their own size. *P. volitans* consumes on average 8.2 times its body weight in food per year. Juveniles consume 5.5-13.5 g of food per day, while adults consume 14.6 g of food per day. Assuming that lionfish eat about 8.5 g per day, they consume 3.10 kg of food per year, and for 80 fish living on a reef 1 km long, this would be about 228.48 kg per year (Fishelson, 1997).

This study exhibited a high proportion of fully digested stomach contents, which prolonged digestive retention, likely due to their ambush hunting strategy and low metabolic activity. An analysis of stomach contents showed that 17 individuals had full digestive systems, 38 were half-full, 76 were partially full, and 186 were empty. Lionfish are highly resistant to starvation; larger individuals tolerate longer fasting periods due to greater energy reserves (Fishelson, 1997). On the other hand, lionfish exhibit a broad diet, as observed in the Bahamas where their stomach contents included 41 bony fish species across 21 families (Morris, 2009). Studies indicate that their feeding habits remain consistent across invaded regions, showing no significant difference between

Mediterranean and Atlantic populations (Benkwitt, 2016). Experimental research demonstrated that a single lionfish could reduce reef fish abundance by 93.7%, exerting 2.6 times more predation pressure than native groupers (Albins, 2013).

Stomach content analysis of this study revealed prey items such as *Chromis chromis* (n = 5), *Cheilodipterus novemstriatus* (n = 4), *Sargocentron rubrum* (n = 4), *Siganus* sp. (n = 3), and *Coris julis* (n = 1) in 17 individuals with full stomachs. All invertebrate prey belonged to the infraorder Caridea. Similarly, Savva et al. (2020) identified fish as the dominant prey group in lionfish stomachs, with species such as *Chromis chromis*, *Spicara smaris*, *Apogon imberbis*, *Thalassoma pavo* and *Sparisoma cretense* being frequently consumed. The predominance of pelagic and reef-associated species may be attributed to a generalist and opportunistic feeding strategy, potentially extending to migratory fish.

The overall stomach content analysis of 320 individuals further revealed that vertebrates accounted for 77.5%, whereas invertebrates comprised only 5.9% (NOF). The longest vertebrate prey item found in a stomach was 12 cm. It should be noted that prey identification is highly influenced by the digestion state, limiting taxonomic resolution, especially in partially digested samples (Baker et al., 2014). Previous studies have revealed a broad diet of lionfish, with up to 50 different prey species including bony fish, crustaceans, and shrimp (Albins and Hixon, 2008; South et al., 2017). DNA barcoding has revealed 31-39 fish species in lionfish stomachs across different regions (Valdez-Moreno et al., 2012; Harms-Tuohy et al., 2016). Fish constituted the majority of the diet, accounting for 74.4% in the Bahamas and 84.1% along the Atlantic coasts of USA (Eddy et al., 2016). In the Iskenderun Bay, teleosts represented 65% of the stomach contents of 96 individuals (Demirci and Demirhan, 2022). The present study revealed results that closely coincided with the aforementioned findings.

In addition, lionfish are opportunistic predators that are predominantly active during the day, and their most intense feeding occurs early in the morning and at dusk (Fishelson, 1975; Jud and Layman, 2012; Benkwitt, 2016). Observations from the study confirmed this pattern; during the dives at 08:00-10:00 and close to sunset, stomach fullness increased. The lack of hunting in night dives supports their classification as diurnal hunters; however, there may also be occasional feeding due to their opportunistic nature.

Lionfish show limited sexual dimorphism during reproduction, with courtship involving circling, lateral displays, and following behaviors, typically occurring around dusk and extending into the night (Fishelson, 1975). Following courtship, females release two buoyant egg masses, externally fertilized by males, which rise to the surface; embryos become free-floating within 36 hours, enhancing reproductive success. Previous studies reported male-biased sex ratios, such as 1:1.2 (Chin et al., 2016), 1:1.64 (Jhonson and Swenarton, 2016), 1:1.06 (Edwards et al., 2014), and 1:0.67 (Dağhan and Demirhan, 2020). In contrast, our study revealed a female-biased ratio of 1:1.76, with females comprising 59.7% (191) and males 33.7% (108) of the sampled population.

Reproductive parameters measured for the 262 individuals in this study showed that gonad development progressed rapidly with age. The fish in the age group I had an average gonad weight of 1.18 g, producing an average of 46.6 eggs (0.4 mm), while those in the age group II produced

2.17 g and fecundity was ~81.7 eggs (0.56 mm). In the IV-V age groups, where reproductive capacity occurred, gonad weights averaged 7.9-8.3 g and fecundity was ~86-90 eggs (0.56-0.6 mm). Individuals in the VI-VII age group had reduced gonad mass, but the number of eggs was relatively stable, and the egg size was slightly larger (up to 0.65 mm). Previous studies have shown that lionfish usually reach 16.6-19.0 cm in length at the age of I, with a maximum lifespan of V-VIII years (Barbour et al., 2011; Edwards et al., 2014), while populations in the northern Gulf of Mexico rarely exceed IV-V years and attain sexual maturity within the first year (Fogg et al., 2017). Considering their early maturity, sustained reproductive activity, and high fertility, the invasive potential of lionfish in the eastern Mediterranean stands out.

Sexual maturation occurred between 16.0-18.0 cm total length (Figure 7), with peak reproductive efficiency observed at II-IV years of age and lengths of 18.0-28.0 cm. Minimum spawning sizes reported in Southern Cyprus were 15.4 cm for males and 15.8 cm for females (Savva et al., 2020), while other studies have documented sexual maturity at 17.5-19.0 cm (Morris, 2009; Gardner et al., 2015). The findings from the present study are consistent with these values. The smallest mature individual measured 16.0 cm, confirming that lionfish reach functional maturity at relatively small sizes; this contributes to their invasive success in the eastern Mediterranean.

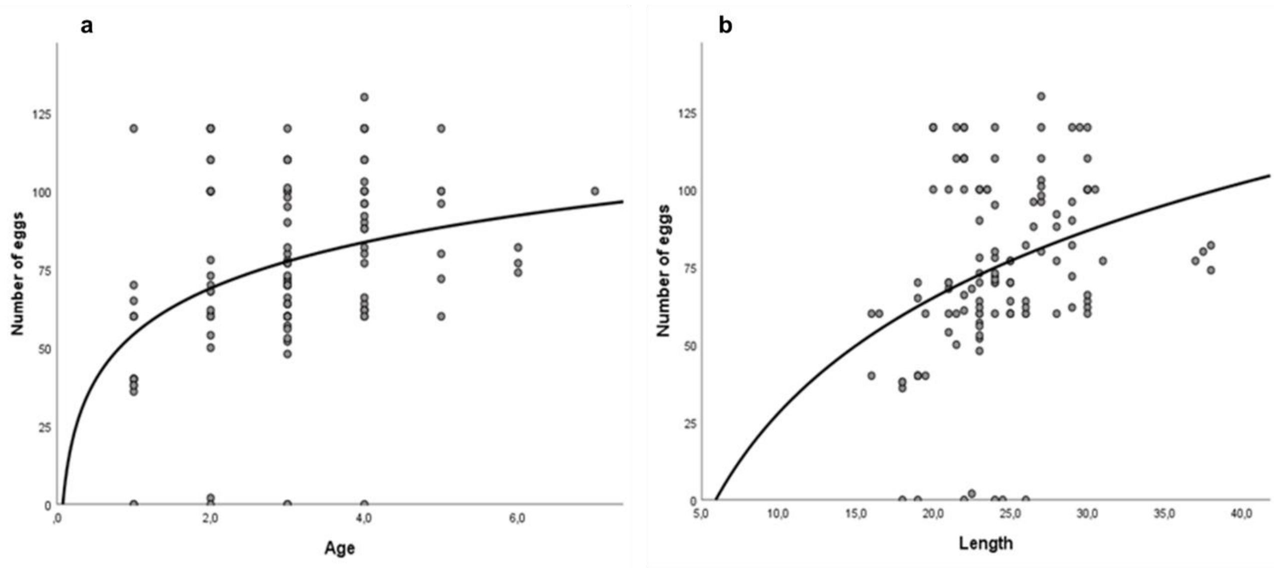

Figure 7. Relationship between female lionfish fecundity (egg count), age (a), and total length (b).

Gonadosomatic index (GSI) analyses have shown that reproductive activity occurs throughout the year, with seasonal variations occurring. GSI values were observed highest in summer and autumn, and lowest in winter (Figure 8). These findings are also supported by the fact that lionfish, which are also observed in different geographical regions, have the ability to reproduce throughout the year (Morris et al., 2008; Savva et al., 2020). The agreement between the fitness factor and the GSI indicates that the lionfish are ready for reproduction throughout the year and show more activity during the warmer months. Given their high fertility rates and rapid larval development, it seems quite difficult to control lionfish populations through fishing alone.

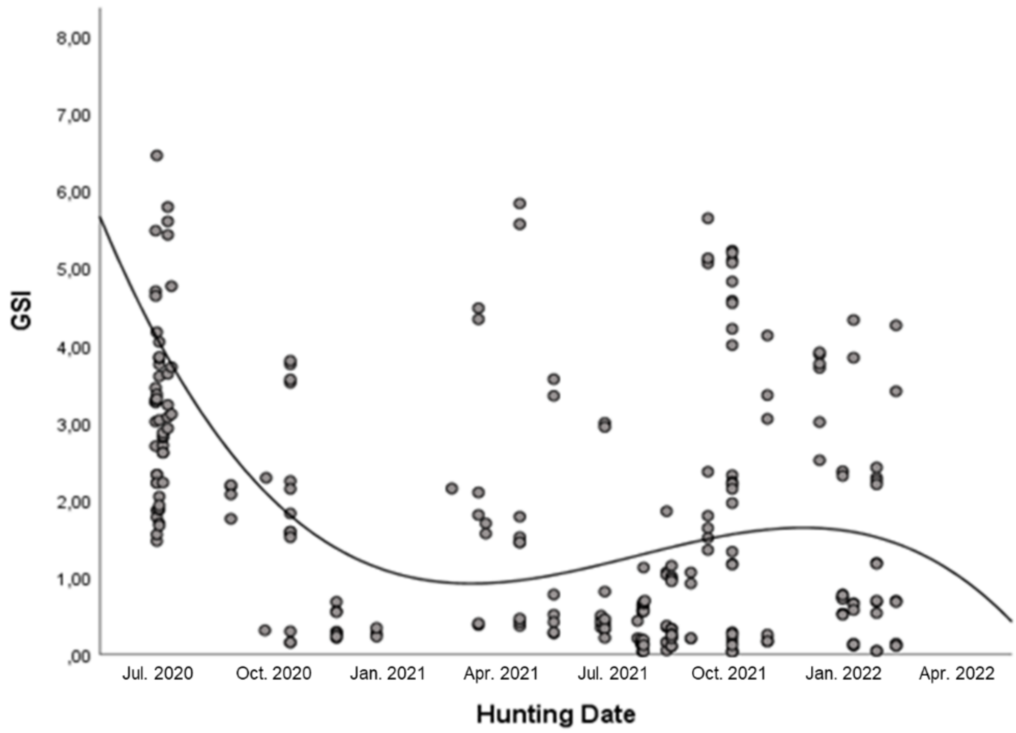

Figure 8. Seasonal variation in the gonadosomatic index of female lionfish (*Pterois* spp.) throughout the study period.

In conclusion, present study demonstrated that lionfish in the eastern Mediterranean have successfully established permanent populations due to favorable environmental conditions, rapid growth, early maturation, high fecundity, opportunistic feeding, and the absence of strong predators. They predominantly inhabit rocky areas, caves, artificial reefs, and shipwrecks, where small fish are abundant, and larger individuals are found at depths greater than 30 m. Length-weight analysis of *Pterois* spp. in the Mersin coastline indicated positive allometry, while age analysis showed fast early growth and the potential for longer lifespans under low predation pressure. Their diet, dominated by local and foreign fish species, overlapped with the diets of important species such as groper species, suggesting direct competition for food. Although eradication is not feasible, management strategies should focus on identifying and protecting natural predators, reducing fishing pressure on these species, and promoting controlled lionfish harvesting by trained divers. Without intervention, lionfish are likely to continue expanding, posing long-term risks to Mediterranean biodiversity and fisheries sustainability.

Acknowledgment

This study was supported by the Research Fund of Mersin University with Project Number: 2021-1-TP3-4377.

Conflict of Interest

The authors declare that for this article they have no actual, potential or perceived conflict of interest.

Author Contributions

The authors performed all the experiments and drafted the main manuscript text. All authors reviewed and approved the final version of the manuscript.

Ethical Approval Statements

No ethics committee permissions are required for this study.

Data Availability

The data used in the present study are available upon request from the corresponding author.

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.

Albins, M.A. (2013). Effects of invasive Pacific red lionfish *Pterois volitans* versus a native predator on Bahamian coral-reef fish communities. *Biological Invasions,* 15(1), 29-43.

Alkan, Ö., Ayaz, A., Altınağaç, U., Özekinci, U., Çakır, F., Daban, İ.B., Şen, Y., Uğur G.E., Ayaz O. (2023). An additional record of lionfish *Pterois miles* (Bennett, 1828) in Edremit Bay. *Doğanın Sesi*, 6(12), 19-28.

Andradi-Brown, D.A., Grey, R., Hendrix, A., Hitchner, D., Hunt, C.L., Gress, E., Madej, K., Parry, R.L., Regnier-McKellar, C., Jones, O.P., Arteaga, M., Izaguirre, A.P., Rogers, A. D., Exton, D.A. (2017). Depth-dependent effects of culling—Do mesophotic lionfish populations undermine current management? *Royal Society Open Science,* 4(5), 170027.

Arbuatti, A., Lucidi, P. (2010). Reef aquariofily: a hobby for everyone? How an adequate knowledge of *Pterois volitans*' behavior and welfare can avoid risks and accidents. *Aquaculture, Aquarium, Conservation & Legislation*, 3(1), 9-16.

Avşar, D. (2005). Fisheries biology and population dynamics. Nobel Bookstore Publications.

Ayas, D., Şen Ağılkaya, G., Yağlıoğlu, D. (2018). New record of the red lionfish, *Pterois volitans* (Linnaeus, 1758), in the Northeastern Mediterranean Sea. *Düzce University Journal of Science & Technology*, 6(4), 871-877.

Bagenal, T.B., Tesch, F.W. (1978). Age and growth. *In* Methods for Assessment of Fish Production in Fresh Waters (pp. 101-136). Blackwell Scientific Publications.

Baker, R., Buckland, A., Sheaves, M. (2014). Fish gut content analysis: robust measures of diet composition. *Fish and Fisheries,* 15(1), 170-177.

Barbour, A.B., Allen, M.S., Frazer, T.K., Sherman, K.D. (2011). Evaluating the potential efficacy of invasive lionfish (*Pterois volitans*) removals. *PLoS One,* 6(5), e19666.

Bariche, M., Torres, M., Azzurro, E. (2013). The presence of the invasive lionfish *Pterois miles* in the Mediterranean Sea. *Mediterranean Marine Science*, 14(2), 292-294.

Benkwitt, C.E. (2016). Invasive lionfish increase activity and foraging movements at greater local densities. *Marine Ecology Progress Series,* 558, 255-266.

Bilge, G., Filiz, H., Yapıcı, S., Gülşahin, A. (2016). On the occurrence of the devil firefish *Pterois miles* (Scorpaenidae), from the southern Aegean Sea with an elaborate occurrences in the Mediterranean coast of Turkey. In: Book of Proceedings. HydroMediT 2016 2nd International Congress on Applied Ichthyology and Aquatic Environment, 10-12 November 2016, Messolonghi, Greece, pp. 324-327.

Chin, D.A., Aiken, K.A., Buddo, D. (2016). Lionfish population density in Discovery Bay, Jamaica. *International Journal of Scientific and Engineering Research,* 7(12), 1327-1331.

Cote, 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.

Çete H.E., Ergene, S. (2018). Türkiye Doğu Akdeniz Bölgesi lagos balığı: büyüme oranları ve beslenme özelliklerinin incelenmesi. Lap Lambert Academic Publishing. [In Turkish].

Dağhan, H., Demirhan, S. A. (2020). Some bio-ecological characteristics of the lionfish *Pterois miles* (Bennett, 1828) distributed in the Gulf of Iskenderun. *Marine and Life Sciences*, 2(1), 28-40.

Darling, E.S., Green, S.J., O'Leary, J.K., Cote, I.M. (2011). Indo-Pacific lionfish are larger and more abundant on invaded reefs: a comparison of Kenyan and Bahamian lionfish populations. *Biological Invasions,* 13, 2045-2051.

Demirci, B., Demirhan, S.A. (2022). Food composition and dietary overlap of the lionfish species in Iskenderun bay. *Natural and Engineering Sciences*, 7(3), 228-239.

Eddy, C., Pitt, J., Morris, J.A., Smith, S., Goodbody-Gringley, G., Bernal, D. (2016). Diet of invasive lionfish (*Pterois volitans* and *P. miles*) in Bermuda. *Marine Ecology Progress Series,* 558, 193-206.

Edwards, M.A., Frazer, T.K., Jacoby, C.A. (2014). Age and growth of invasive lionfish (*Pterois* spp.) in the Caribbean Sea, with implications for management. *Bulletin of Marine Science,* 90(4), 953-966.

Ehemann, N.R., Perez-Palafox, X.A., Mora-Zamacona, P., Burgos-Vazquez, M.I., Navia, A.F., Mejia-Falla, P.A., Cruz-Escalona, V.H. (2017). Size-weight relationships of batoids captured by artisanal fishery in the southern Gulf of California, Mexico. *Journal of Applied Ichthyology*, 33(5), 1051-1054.

Evripidou, S. (2013). Toxic Lionfish makes its way to Cyprus waters. www.cyprus-mail.com/cyprus/toxicLionfish-makes-its-way-cyprus-waters/20130220, version 02/2013).

Farrag, M., El-Haweet, A.A., Moustafa, M.A. (2016). Occurrence of puffer fishes (Tetraodontidae) in the eastern Mediterranean, Egyptian coast-filling in the gap. *BioInvasions Record*, 5(1), 47.

Fishelson, L. (1975). Ethology and reproduction of pteroid fishes found in the Gulf of Aqaba (Red Sea), especially *Dendrochirus brachypterus* (Cuvier) (Pteroidae: Teleostei). *Pubblicazioni della Stazione Zoologica di Napoli,* 39, 635-656.

Fishelson, L. (1997). Experiments and observations on food consumption, growth and starvation in *Dendrochirus brachypterus* and *Pterois volitans* (Pteroinae, Scorpaenidae). *Environmental Biology of Fishes,* 50(4), 391-403.

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(3), 791-813.

Fogg, A.Q., Evans, J.T., Peterson, M.S., Brown-Peterson, N.J., Hoffmayer, E.R., Ingram, G.W. (2019). Comparison of age and growth parameters of invasive red lionfish (*Pterois volitans*) across the northern Gulf of Mexico. *Fishery Bulletin,* 117(3), 1-15.

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), 1-10.

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(2), 167-169.

Golani, D., Öztürk, B., Başusta, N. (2006). Fishes of the eastern Mediterranean. Turkish Marine Research Foundation (TUDAV).

Gökoğlu, M., Teker, S., Julian, D. (2017). Westward extension of the lionfish *Pterois volitans* Linnaeus, 1758 along the Mediterranean coast of Turkey. *Natural and Engineering Sciences*, 2(2), 67-72.

Green, S.J., Akins, J.L., Maljkovic, A., Cote, I.M. (2012). Invasive lionfish drive Atlantic coral reef fish declines. *PLoS One, 7*(3), e32596.

Gürlek, M., Ergüden, D., Uyan, A., Doğdu, S.A., Yağlıoğlu D., Öztürk B., Turan C. (2016). First record red lionfish *Pterois volitans* (Linnaeus, 1785) in the Mediterranean Sea. *Natural and Engineering Sciences*, 1(3), 27-32.

Harms-Tuohy, C.A., Schizas, N.V., Appeldoorn, R.S. (2016). Use of DNA metabarcoding for stomach content analysis in the invasive lionfish *Pterois volitans* in Puerto Rico. *Marine Ecology Progress Series*, 558, 181-191.

Johnson, E.G., Swenarton, M.K. (2016). Age, growth and population structure of invasive lionfish (*Pterois volitans/miles*) in northeast Florida using a length-based, age-structured population model. *PeerJ,* 4, e2730.

Johnston M.W., Purkis S.J. (2014). Are lionfish set for a Mediterranean invasion? Modelling explains why this is unlikely to occur. *Marine Pollution Bulletin*, 88, (1-2), 138-147.

Jud, Z.R., Layman, C.A., Lee, J.A., Arrington, D.A. (2011). Recent invasion of a Florida (USA) estuarine system by lionfish *Pterois volitans/P. miles*. *Aquatic Biology*, 13(1), 21-26.

Jud, Z.R., Layman, C.A. (2012). Site fidelity and movement patterns of invasive lionfish, *Pterois* spp., in a Florida estuary. *Journal of Experimental Marine Biology and Ecology*, 414, 69-74.

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(1), 31-50.

Kindinger, T.L. (2015). Behavioral response of native Atlantic territorial three spot damselfish (*Stegastes planifrons*) toward invasive Pacific red lionfish (*Pterois volitans*). *Environmental Biology of Fishes*, 98, 487-498.

Kletou, D., Hall-Spencer, J. M., Kleitou, P. (2016). A lionfish (*Pterois miles*) invasion has begun in the Mediterranean Sea. *Marine Biodiversity Records*, 9(1), 46.

Lagler, K.F. (1956). The pike, *Esox lucius* Linnaeus, in relation to water-fowl on the Seney National Wildlife Refuge, Michigan. *The Journal of Wildlife Management*, 20(2), 114-124.

Le Cren, E.D. (1951). The length-weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). *The Journal of Animal Ecology*, 20(2), 201-219.

Morris, J.A., Alkins, J., Barse, A., Cerino, D., Freshwater, D., Green, S., Munoz, R., Paris, C., Whitfield, P. (2008). Biology and ecology of the invasive lionfishes, *P. volitans* and *P. miles*. In: Book of Proceedings. 61st Gulf and Caribbean Fisheries Institute, 10-14 November 2008, Gosier, Guadeloupe, French West Indies. pp. 409-414.

Morris, J.A. (2009). The biology and ecology of the invasive Indo-Pacific lionfish. North Carolina State University, Graduate Faculty. North Carolina, p 168.

Oray, I.K., Sınay, E., Karakulak, F.S., Yıldız, T. (2015). An expected marine alien fish caught at the coast of Northern Cyprus: *Pterois miles* (Bennett, 1828). *Journal of Applied Ichthyology*, 31(4), 733-735.

Oruç, A.Ç., Şensurat-Genç, T., Özgül, A., Lök, A. (2022). The northernmost dispersal record of the lionfish, *Pterois miles* (Bennett, 1828) for the Aegean Sea. *Ege Journal of Fisheries and Aquatic Sciences*, 39(1), 84-87.

Otero, P., Rodriguez, P., Botana, A.M., Alfonso, A., Botana, L.M. (2013). Analysis of natural toxins. *In* Liquid Chromatography (pp. 411-430). Elsevier.

Özbek, E.Ö., Mavruk, S., Saygu, I., Öztürk, B. (2017). Lionfish distribution in the eastern mediterranean coast of Turkey. *Journal of Black Sea/Mediterranean Environment*, 23, 1-16.

Özgül, A. (2020). Occurrence of lionfish, *Pterois miles* (Bennett, 1828) in the coast of Aegean Sea (Turkey): The northernmost dispersal record. *Ege Journal of Fisheries and Aquatic Sciences*, 37(3), 313-317.

Perera-Chan, L., Aguilar-Perera, A. (2014). Length–weight and length–length relationships of the invasive red lionfish [*Pterois volitans* (Linnaeus, 1758): Scorpaenidae] in the Parque Nacional Arrecife Alacranes, Southern Gulf of Mexico. *Journal of Applied Ichthyology,* 30(1), 202-203.

Potts, J.C., Berrane, D., Morris, J.A. (2010). Age and growth of lionfish from the Western North Atlantic. In: Book of Proceedings. 63rd Gulf Caribbean Fisheries Institute, 1-5 November 2010, San Juan, Puerto Rico. pp. 313-314.

Poursanidis D. (2015). Ecological niche modeling of the invasive lionfish *Pterois miles* (Bennett, 1828) in the Mediterranean Sea. In: Book of Proceedings. 11th Panhellenic Symposium on Oceanography and Fisheries, 13-17 May 2015, Mytilene, Lesvos Island, Greece. pp. 621-624.

Pusack, T.J., Benkwitt, C.E., Cure, K. Kindinger, T.L. (2016). Invasive red lionfish grow faster in the Atlantic Ocean than in their native Pacific range. *Environmental Biology of Fishes*, 99(6-7), 571-579.

Render, J.H., Thompson, B.A., Allen, R.L. (1995). Reproductive development of striped mullet in Louisiana estuarine waters with notes on the applicability of reproductive assessment methods for isochronal species. *Transactions of the American Fisheries Society*, 124(1), 26-36.

Ricker, W.E. (1975). Computation and interpretation of biological statistics of fish populations. The Blackburn Press.

Sabido-Itza, M. M., Aguilar-Perera, A., Medina-Quej, A. (2016). Length–weight and length–length relations, and relative condition factor of red lionfish, *Pterois volitans* (Actinopterygii: Scorpaeniformes: Scorpaenidae), from two natural protected areas in the Mexican Caribbean. *Acta Ichthyologica et Piscatoria,* 46(4), 279-285.

Savva, I., Chartosia, N., Antoniou, C., Kleitou, P., Georgiou, A., Stern, N., Hadjioannou, L., Jimenez, C., Andreou, V., Spencer, M.H., 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.

Schneider, K., Erez, J. (2006). The effect of carbonate chemistry on calcification and photosynthesis in the hermatypic coral *Acropora eurystoma*. *Limnology and Oceanography*, 51(3), 1284-1293.

South, J., Dick, J.T., McCard, M., Barrios-O'Neill, D., Anton, A. (2017). Predicting predatory impact of juvenile invasive lionfish (*Pterois volitans*) on a crustacean prey using functional response analysis: effects of temperature, habitat complexity and light regimes. *Environmental Biology of Fishes*, 100, 1155-1165.

Sparre, P., Venema, S. C. (1992). Introduction to tropical fish stock assessment. Part 1: Manual. FAO.

Stamouli, C., Akel, E.H.K., Azzurro, E., Bakiu, R., Bas, A.A., Bitar, G., Boyacı, Y., Cakalli, M., Corsini-Foka, M., Crocetta, F., Dragicevic, B., Dulcic, J., Durucan, F., Zrelli, R.E., Ergüden, D., Filiz, H., Giardina, F., Giovos, I., Gönülal, O., Hemida, F., Kassar, A., Kondylatos, G., Macali, A., Mancini, E., Ovalis, P., Paladini De Mendoza, F., Pavicic, M., Rabaoui, L., Rizkalla, S., Tiralongo, F., Turan, C., Vrdoljak, D., Yapıcı, S., Zenetos, A. (2018). New Mediterranean biodiversity records (December 2017). *Mediterranean Marine Science*, 18(3), 534-556.

Toledo-Hernandez, C., Velez-Zuazo, X., Ruiz-Diaz, C.P., Patricio, A.R., Mege, P., Navarro, M., Sabat, A.M., Betancur-R, R., Papa, R. (2014). Population ecology and genetics of the invasive lionfish in Puerto Rico. *Aquatic Invasions,* 9(2), 227-237.

Turan, C., Ergüden, D., Gürlek, M., Yağlıoğlu, D., Uyan, A., Uygur, N. (2014). First record of the Indo-Pacific lionfish *Pterois miles* (Bennett, 1828) (Osteichthyes: Scorpaenidae) for the Turkish marine waters. *Journal of the Black Sea/Mediterranean Environment*, 20(2), 158-163.

Turan, C., Öztürk, B. (2015). First record of the lionfish *Pterois miles* (Bennett 1828) from the Aegean Sea. *Journal of the Black Sea/Mediterranean Environment*, 20(2), 334-388.

Turan, C., Ergüden, D., Gürlek, M. (2016). Climate change and biodiversity effects in Turkish seas. *Natural and Engineering Sciences*, 1(2), 15-24.

Turan, C., Gürlek, M., Başusta, N., Uyan, A., Doğdu, S.A., Karan, S. (2018). A checklist of the non-indigenous fishes in Turkish marine waters. *Natural and Engineering Sciences*, 3(3), 333-358.

Turan, C. (2020). Species distribution modelling of invasive alien species; *Pterois miles* for current distribution and future suitable habitats. *Global Journal of Environmental Science and Management*, 6(4), 429-440.

Turan, C., Ergüden, D., Gürlek, M., Doğdu, S.A. (2024). Checklist of alien fish species in the Turkish marine ichthyofauna for science and policy support. *Tethys Environmental Science*, 1(2), 50-86.

Ulman, A., Tunçer, S., Kızılkaya, İ.T., Zilifli, A., Alford, P., Giovos, I. (2020). The lionfish expansion in the Aegean Sea in Turkey: a looming potential ecological disaster. *Regional Studies in Marine Science*, 36, 101271.

Valdez-Moreno, M., Quintal-Lizama, C., Gomez-Lozano, R., Garcia-Rivas, M.D.C. (2012). Monitoring an alien invasion: DNA barcoding and the identification of lionfish and their prey on coral reefs of the Mexican Caribbean. *PLoS One,* 7(6), e36636.

von Bertalanffy, L. (1957). Quantitative laws in metabolism and growth. *The Quarterly Review of Biology, 32*(3), 217-231.

Yağlıoğlu, D., Ayas, D. (2016). New occurrence data of four alien fishes (*Pisodonophis semicinctus*, *Pterois miles*, *Scarus ghobban* and *Parupeneus forsskali*) from the north eastern Mediterranean (Yeşilovacık Bay, Turkey). *Biharean Biologist*, 10(2), 150-152.

Yılmaz, S., Demirhan, S.A. (2020). Age, growth parameters and food composition of Invasive Red Lionfish (*Pterois volitans* L., 1758) in İskenderun Bay. *Natural and Engineering Sciences*, 5(2), 82-91.

Zannaki, K., Corsini-Foka, M., Kampouris, T.E., Batjakas, I.E. (2019). First results on the diet of the invasive *Pterois miles* in the Hellenic waters. *Acta Ichthyologica et Piscatoria,* 49(3), 31-40.

Zenetos, A., Gofas, S., Morri, C., Rosso, A., Violanti, D., Raso, J.G., Çınar, M.E., Almogi-Labin, A., Ateş, A.S., Azzurro, E., Ballesteros, E., Bianchi, C.N., Bilecenoğlu, M., Gambi, M.C., Giangrande, A., Gravili, C., Hyams-Kaphzan, O., Karachle, P.K., Katsanevakis, S., Lipej, L., Mastrototaro, F., Mineur, F., Pancucci-Papadopoulou, M.A., Ramos Esplá, A., Salas, C., San Martín, G., Sfriso, A., Streftaris, N., Verlaque, M. (2012). Alien species in the Mediterranean Sea by 2012. A contribution to the application of European Union's Marine Strategy Framework Directive (MSFD). Part 2. Introduction trends and pathways. *Mediterranean Marine Science*, 13(2), 328-352.