



POTENTIAL INVASIVENESS OF DEVIL FIREFISH *Pterois miles* (BENNETT 1828) IN THE EASTERN ADRIATIC SEA

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ABSTRACT

Devil firefish *Pterois miles* is an invasive alien species which has severely impacted biodiversity and ecological processes in invaded areas of the Mediterranean. In recent years, its presence has been documented in several countries of the Adriatic Sea. Based on the negative ecological and socio-economic impacts in other areas of the Mediterranean Sea, the potential invasiveness of devil firefish was analyzed for the coastal areas of the three eastern Adriatic countries (Albania, Croatia and Montenegro) using the *Aquatic Species Invasiveness Screening Kit*. Generally, based on the average value of the Basic Risk Assessment and the threshold used, the outcomes suggest that this species will be highly invasive in the eastern Adriatic countries. In addition, the results have shown that the most affected sector is represented by the local species populations and relative characteristics, while commercial sectors represent the least affected sector. However, considering that the negative impact of non-native species is not seen directly, the governments of these countries should address this issue as soon as possible.

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INTRODUCTION

In the era of climate change, the Mediterranean Sea is among the fastest-warming marine regions in the world and, for this reason, is recognized as a hotspot of global change (Moullec et al., 2019). The Mediterranean Sea is a semi-enclosed body of water characterized by high biodiversity as the product of its geological history, with well-defined mosaics of contrasting ecosystems, where changes repeatedly occurred in the past (Giangrande et al., 2020; Aurelle et al., 2022). Along with climate change, during the last decades human activities in the Mediterranean Sea have caused rapid biological invasions of non-native species (NNS), with a recent list including more than 1300 new species (Zenetos et al., 2022). Changes in the biogeography of species, associated with changes in productivity, could result in changes in the ecosystem structure and trophic functioning of the Mediterranean Sea by the end of the century (Moullec et al., 2019). Furthermore, climate change combined with fishing pressure has the potential to render marine ecosystems more vulnerable to invasions by NNS (Moullec et al., 2019).

Although there are a lot of species introduced to the Mediterranean Sea from the Atlantic Sea, a major driver of non-native species introductions has been the progressive enlargement of the Suez Canal since the 1960s, which has established a permanent sea-level waterway connecting thermophilic species of Indo-Pacific origin from the Red Sea (Galil et al., 2017). Considering the location of the Suez Canal, most of the first non-native species records were reported from the Eastern Mediterranean Sea. However, recently a considerable number of species have expanded their distribution into new Mediterranean Sea areas, the Central Mediterranean Sea and Adriatic Sea being the main recipients of this expansion. The expansion of tropical and sub-tropical species into the cooler waters of the Aegean and Adriatic Sea indicates that the warming of Mediterranean Sea waters due to climate change is also facilitating the geographic expansion of non-native species in the region (Zenetos and Galanidi, 2020).

The Adriatic Sea is a semi-enclosed basin, within the larger semi-enclosed Mediterranean Sea, with the eastern and western coasts having different morphological and topographic properties. The eastern coast is composed of limestone and its steep and narrow shelf deepens fast, whereas the western coast has a wider shelf because of sediments brought by rivers (Dulčić et al., 2005). A recently updated checklist of Adriatic Sea fishes with a critical assessment of each species using an evidence approach listed a total of 444 species (Kovačić et al., 2020), which represents nearly 60% of the Mediterranean Sea species richness (Lipej et al., 2022). Although the lower temperatures of the Adriatic Sea restrict the northward expansion of thermophilic non-native species, so far in the Croatian coastal areas the presence of 24 new non-native fish species has been recorded (Dulčić and Dragičević,

2011), whereas in Montenegro and Albania there are at least seven new non-native fish species, including silver-cheeked toadfish *Lagocephalus sceleratus* and those belonging to the genus *Siganus* (Otero et al., 2013).

Not all non-native species have the same potential impact on local ecosystems. However, there are some species that are considered very harmful. Amongst these is devil firefish *Pterois miles* (Bennett 1828), also known as lionfish. The introduction of this species in the Western Atlantic is considered one of the fastest and most ecologically harmful to date (Albins and Hixon, 2013). *P. miles* belongs to the family Scorpaenidae and is native to the Indo-Pacific Ocean, and was recorded for the first time in the Mediterranean Sea off the Levantine coast in 1991 (Golani and Sonin, 1992). However, this record can be considered an unsuccessful invasion attempt, as the species had not established itself in the Mediterranean Sea for more than two decades. However, new records were reported in 2012 in the northern part of the Lebanese coast (Bariche et al., 2013), and since then *P. miles* has spread more rapidly with several new records in adjacent areas of the eastern Mediterranean Sea (Kletou et al., 2016). Considering the presence of few native predators, the dispersal capabilities of the planktonic larvae of *P. miles* and the species ability to adapt to a range of habitats, a rapid expansion throughout the Mediterranean Sea may soon follow with substantial impacts on local ecosystems and fisheries (Kletou et al., 2016). The concerns associated with the occurrence of this species in the Mediterranean Sea are mostly motivated by the Western Atlantic experience, whereby a non-native lionfish (i.e. *Pterois miles/Pterois volitans* complex) severely impacted the biodiversity and ecological processes in the invaded areas (Dragičević et al., 2021). For example, high predation rates of this generalist piscivore species negatively impact local fish communities by reducing their abundance and recruitment at the invaded locations (Ballew et al., 2016; Goodbody-Gringley et al., 2019).

In the Adriatic Sea, the first observation of *P. miles* was near Lecce (Italy) in July 2019 (Di Martino and Stancanelli, 2021). Later on 27 July 2021, an individual of *P. miles* was caught with a spear gun by a member of the Facebook group "Speciet Invazive në Bregdetin Shqipëtar/ Invasive Species in Albanian Coast" on a rocky beach (Teqeja Sarande) close to Saranda (South Albania), at a depth of 1 m and a distance of about 70 meters off the coast (Table 1, Figure 1). After 15 days of being recorded in Albania, a specimen of *P. miles* was observed and photographed by a professional underwater photographer during scuba diving on 13 August 2021 at a depth of 15 m near Komiza at Cape Stupišće (Vis Island, Croatian waters, middle Adriatic). In Montenegro, the presence of *P. miles* was recorded about a year later when a single specimen was observed in Montenegrin territorial waters at the end of October 2022.



Fig 1. Map of observations (A) (orange dots indicate the registered observation in the considered countries), map of the Mediterranean Sea (B) and photo of the specimen caught by a fisher close to Palase/Rruget e Bardha (Albania) (C) (photo provided by Luciano Vangjeli) and the recent observation from Croatia (photos by D - Nikša Sibiljan and E - Luka Srzić)

Table 1. Observations of devil firefish in the countries of the eastern Adriatic; location and the associated references

	Location (Coordinates)	Reference
Albania	Teqeja Sarande 39.876667° N, 19.974972° E	Bakiu and Mejdani in New Alien Mediterranean Biodiversity Records (November 2021) Collective Article A, Mediterranean Marine Science
Croatia	Rt Stupišće near Komiža, Vis Island: 43.01825° N, 16.4127° E	Dragičević et al., 2021
Montenegro	Cape Volujica 42.089190° N, 19.069170° E	Marković and Četković in New records of introduced species in the Mediterranean Sea (April 2023) Collective Article A, Mediterranean Marine Science
Croatia	Slano, 42.770678° N, 17.856881° E	Soldo, unpublished data
	Račišće, Korčula Island, 42.9795760N, 17.0134320E	Soldo, unpublished data

The record took place near Cape Volujica, on a rocky bottom at a depth of approximately 15 m. In 2023 a record was reported from Slano, Croatia when an individual of 300 g was caught at a depth of 5 m by a trammel net on 5 May 2023. The last record was from the Island of Korčula in Croatia where a spear diver caught a 500 g specimen near Račišće at a depth of 17 m on 15 August (Table 1, Fig. 1).

The aim of this study is to assess the invasiveness potential of *P. miles* in the eastern Adriatic basin, with particular reference to the three countries: Albania, Croatia and Montenegro (risk assessment areas). This screening, conducted using the *Aquatic Species Invasiveness Screening Kit* decision-support tool (AS-ISK: Copp et al., 2016, 2021), aimed to evaluate the current and future invasiveness potential of *P. miles* in the risk assessment areas.

MATERIAL AND METHODS

In order to identify the potential invasiveness of *P. miles*, the AS-ISK decision-support tool was used. Responses to the questions provide a Basic Risk Assessment (BRA) score, which is complemented by six additional Climate Change Assessment (CCA) questions for the assessor to foretell the likely effects of predicted future climate on the risk screening (risks and magnitude of introduction, establishment and dispersal), and result in the BRA+CCA score. The screening was conducted independently by each of the authors for the respective risk assessment areas (Albania, Croatia and Montenegro). In order to identify a threshold value for the risk assessment areas to rank the risk of invasiveness of *P. miles*, the global threshold value of 19.5 for marine fishes in temperate climates was used (after Vilizzi et al., 2021; Vilizzi et al., 2022; Vilizzi and Piria, 2022).

RESULTS AND DISCUSSION

The results of the expert evaluation reports in Table 2 clearly show that there are differences in BRA and BRA+CCA scores and confidence, though the confidence level in each expert evaluation seems to be good (more than 0.5).

The confidence level indicates that at least 70% of the answered questions ranged from 'high' to 'very high'. BRA outcome in Albania, Croatia and Montenegro indicate that *P. miles* will be highly invasive in the coastal areas of these countries. In addition, the BRA+CCA outcome in all countries indicates that climate change will favour the presence of this species in all these countries, with the highest BRA+CCA score reported for Montenegro. For instance, the ongoing climate change in the eastern Mediterranean basin indicates that its rapid increase and establishment are favoured by the overall environmental conditions and that there is no obstacle to its further dispersal (Giovos et al., 2018). In the eastern Adriatic, the result indicates that the average invasiveness of *P. miles* will be considerable and even high, considering the average value shown in Figure 2. Similarly to our analyses, devil firefish (for both BRA and BRA+CCA) was among the highest-scoring species (most likely invasive) in the study conducted by Tarkan et al. (2021) on the risk screening of the invasiveness of non-native aquatic species in the eastern Mediterranean region under current and projected climate conditions.

The scores of the two partition characteristics (biogeography/historical and biology/ecology), which were evaluated by the experts using AS-ISK, are shown in Table 3. The most contributing biogeography/historical characteristic in the overall score is represented by the historical/biogeographical results (from other authors) of being invasive elsewhere. The corresponding score values for Albania, Croatia and Montenegro were 14, 7 and 10.5, respectively.

Table 2. Estimated scores, relative outcome of the used threshold (BRA threshold value = 19) and the level of confidence

Countries	BRA Score	BRA Outcome	Confidence	BRA+CCA Score	BRA+CCA Outcome	Confidence
Albania	39.0	High	0.84	51	High	0.84
Croatia	31.0	High	0.82	43	High	0.81
Montenegro	40.5	High	0.73	52.5	High	0.73

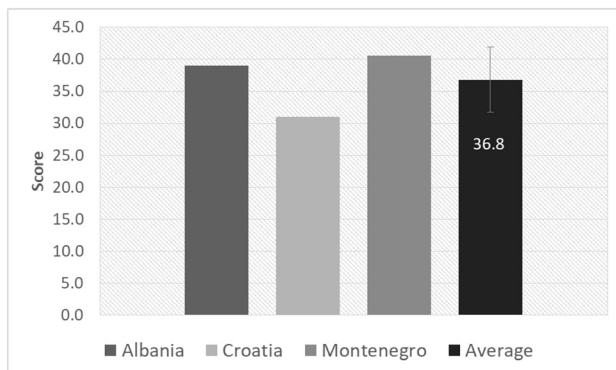
**Fig 2.** Estimated BRA scores for each of the countries and the relative average score for the eastern Adriatic

Table 3 also shows that the climate, distribution and introduction risk factors (one for Albania and two for Croatia and Montenegro) do not contribute considerably to the overall score, unlike the assessment of invasiveness of *P. miles* in Turkey by Filiz et al. (2017). However, in the biology/ecology characteristics, similar to the evaluations of Filiz et al. (2017), the tolerance of a wide range of environmental conditions, flexibility in utilizing food resources, high fecundity, small size at maturity, high reproductive effort and high invasiveness potential (undesirable or persistence traits; resource exploitation; tolerance attributes) were the factors contributing most to the overall score increase. On the other hand, reproductive characteristics such as no hybridization with native fish, no parental care, and no data on parasite transmission lowered the overall score of this partition (see the supplementary material).

Results indicate that in the eastern Adriatic Sea countries, the biology/ecology characteristics (factors) (average score value = 22) contribute more to the invasiveness of devil firefish in comparison to biogeography/historical characteristics (average score value = 14.8) (Figure 3A and 3C).

The average scores show the results of other authors, indicating that the species is invasive elsewhere, together with the biological and ecological characteristics of the undesirable traits that contribute most to the species' invasiveness in this region of the Adriatic basin (Figure 3B and 3D). The dispersal mechanism factor is characterised by a high value of variance (standard deviation), due to the different opinions of the evaluators on the dispersal mechanism of this species. In any case, it is the factor with

the lowest contribution to the average overall score of the biology/ecology partition.

Data from the literature show there are several biological and ecological traits that have contributed to *Pterois* spp. invasion success in other regions of the world, including being a generalist and opportunistic predator (Eddy et al., 2016; Peake et al., 2018), anatomical and physiological traits that optimize its feeding strategy (Rojas-Vélez et al., 2019; Galloway and Porter, 2019), defensive venomous spines (Galloway and Porter, 2019), rapid maturity (Fogg et al., 2017), iteroparous, broadcast and highly fecund spawning (Morris and Whitfield, 2009). Generally, all three species show a pelagic larval phase that allows dispersion of larvae across great distances for about 20–35 days (Ahrenholz et al., 2010).

More specifically, according to Goodbody-Gringley et al. (2019), lionfish tend to be non-selective in their prey choice (Morris and Akins, 2009). The proportion of various species in lionfish diets varies by location, depth, and season, indicating that lionfish preferentially consume certain prey based on their availability or ease of capture (Dahl and Patterson, 2014; Peake et al., 2018), though it is unclear whether the distribution and abundance of prey may influence the abundance and distribution of lionfish. In addition, despite having intermediate consumption rates (Kleitou et al., 2021), the higher densities and catch efficiency of lionfish have resulted in high impacts on the local biodiversity (DeRoy et al., 2020). Numerous studies from the Western Atlantic have demonstrated that an increase in lionfish abundance can lead to a significant decline in the recruitment, biomass, and abundance of native fish species (Green et al., 2012; Côté et al., 2013; Ingeman, 2016), with the impacts felt at a regional level (Ingeman, 2016). At some invaded sites, there have been reports of up to a 95% reduction in the abundance of small native species (Côté et al., 2013).

Apart from climate change, ecological characteristics such as dispersal via ocean currents or regional biological interactions such as predators, dispersal barriers or specific facilitators might also be an important driver for *P. miles* invasion (Turan, 2020) that are not accounted for and included in the models.

The estimated average scores in the histograms of the potential impact of *P. miles* on the affected sectors in each of the eastern Adriatic Sea countries are shown in Table 4 and Figure 4. The greatest impact will be on the species or local population with nuisance traits.

Table 3. Estimated scores for each of the species characteristics/features partitions (Biogeography/Historical and Biology/Ecology)

	Albania	Croatia	Montenegro
Biogeography/Historical	17.0	13.0	14.5
Domestication/Cultivation	2.0	4.0	2.0
Climate, distribution and introduction risk	1.0	2.0	2.0
Invasive elsewhere	14.0	7.0	10.5
Biology/Ecology	22.0	18.0	26.0
Undesirable (or persistence) traits	9.0	9.0	9.0
Resource exploitation	5.0	7.0	7.0
Reproduction	2.0	2.0	3.0
Dispersal mechanisms	3.0	-1.0	4.0
Tolerance attributes	3.0	1.0	3.0

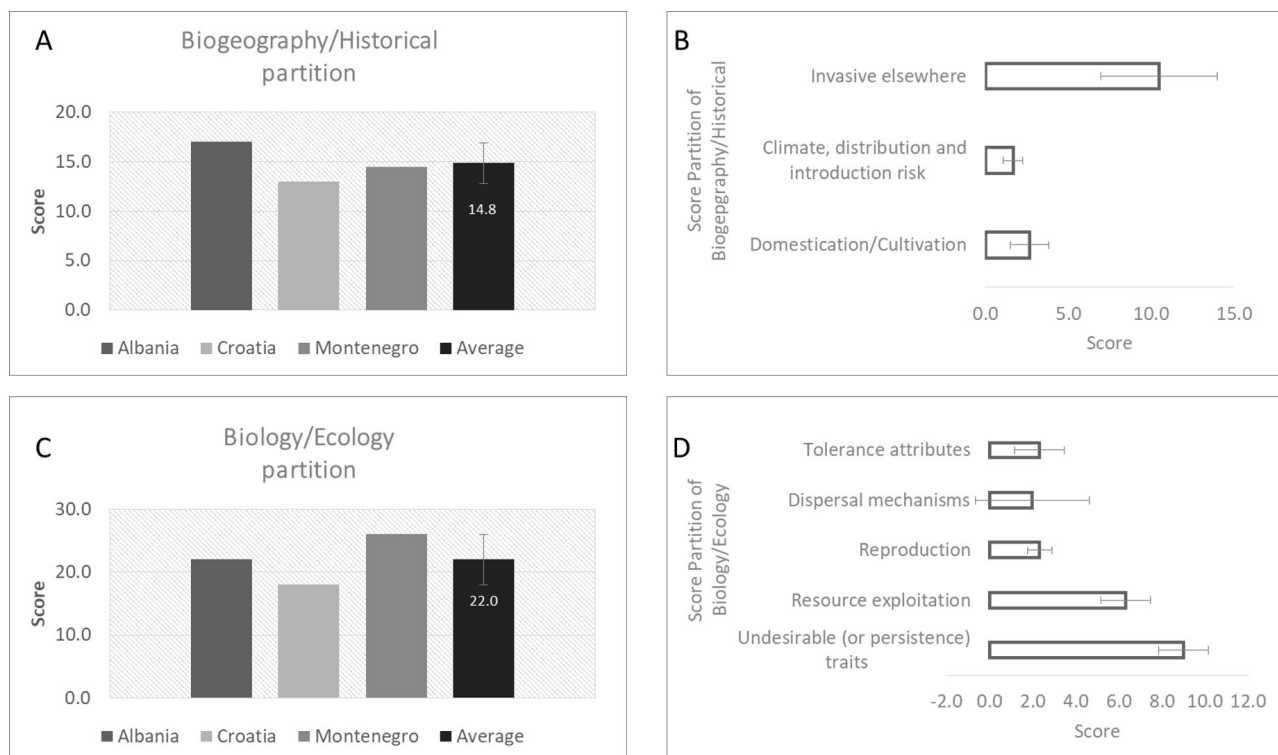


Fig 3. Graphical presentation of the estimated scores for each of the partitions (A and C) and the corresponding partition characteristics (B and D)

Table 4. Estimated scores of the potential impact to the affected sectors in each of the eastern Adriatic Sea countries

	Albania	Croatia	Montenegro
Commercial	15	12	12
Environmental	17	14	16
Species or population nuisance traits	22	21	29

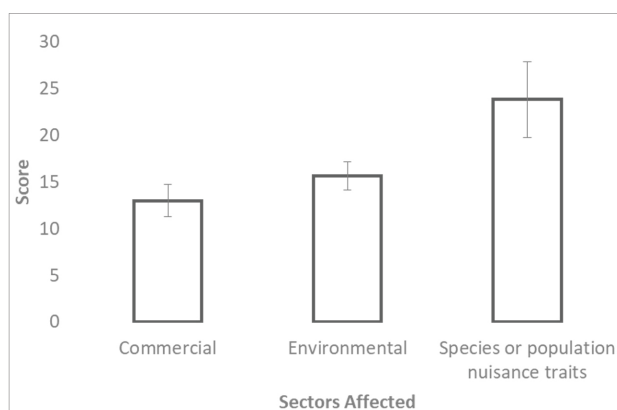


Fig 4. Average estimated score of the potential impact to the affected sectors in the eastern Adriatic Sea countries

Commercial sectors will be less impacted by the presence of *P. miles* populations in the coastal areas of the three considered countries of the eastern Adriatic Sea basin.

Similar to these coastal areas, a study by Moonsammy et al. (2011) found that the invasion of lionfish (*Pterois volitans* and *Pterois miles*) has numerous ecological impacts on the abundant marine ecosystems surrounding the islands. The predominant effect of the lionfish invasion was on the biodiversity in the marine habitats, which means that the highest invasiveness was toward the native species and the environment. Kleitou et al. (2021) showed that apart from direct impacts on local fish communities, lionfish were capable of driving an overall shift in invertebrate assemblage composition (Layman et al., 2014) and shifting sites to algal-dominated habitats through predation on herbivorous reef fishes (Kindinger et al., 2017; Lesser and Slattery, 2011; Slattery et al., 2014). Using an ecological model that utilizes prey consumption and biomass production, Green et al. (2014) suggested that predation effects of lionfish are nonlinear, but begin to occur beyond a particular threshold of predation mortality, thus impacting communities with high biomass are unlikely at low lionfish densities.

However, relative consequences are direct and indirect economic implications, especially in the areas of domestic fisheries, marine tourism (both represent commercial activities) and the non-market value of maintaining biodiversity. It is also important to note that although studies can generate certain economic costs of invasions, the true economic impact can never be derived since these invasions impact numerous environmental systems, each of which is invaluable (Moonsammy et al., 2011). Furthermore, the economic costs of biological invasions include the cost of programs and projects developed to manage and mitigate the invasion (Moonsammy et al., 2011). Expenses increase even more when *P. miles* becomes established and population biomass in Albania, Montenegro, Croatia and other regions of the Adriatic basin is substantial. In terms of alien invasive

species management, *P. miles* colonizes large parts of the Mediterranean and seems to spread to habitats which cover its bioclimatic range. *P. miles* has the potential to change the natural marine ecosystem of the region by distracting native species (Turan, 2020).

Consequently, the measures to be implemented in order to prevent these scenarios in all considered countries of the Adriatic basin should be immediate, because there are not only ecological costs but also economic and social costs from the negative impact of devil firefish. Since the negative impacts of IAS are not directly visible, the environmental departments and local authorities should address this challenge that would affect local livelihood in all Adriatic basin countries, especially when indicated that the climate change effects will favour its persistence in the coastal areas of the considered countries.

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POTENCIJALNA INVAZIVNOST RIBE PAUNA *Pterois miles* (BENNETT, 1828) U ISTOČNOM JADRANU

SAŽETAK

Riba paun *Pterois miles* je invazivna strana vrsta koja je ozbiljno utjecala na biološku raznolikost i ekološke procese u invadiranim područjima Sredozemlja. Posljednjih godina njegova je prisutnost dokumentirana u nekoliko zemalja Jadranskog mora. Na temelju postojećih negativnih ekoloških i socioekonomskih utjecaja u drugim područjima Sredozemnog mora, procjena potencijalne invazivnosti ribe pauna analizirana je za obalna područja triju istočnojadranskih država (Albanije, Hrvatske i Crne Gore) korištenjem alata *Aquatic Species Invasiveness Screening Kit*. Općenito, na temelju prosječne vrijednosti ocjene osnovne procjene rizika i korištenog praga, rezultati sugeriraju da će ova vrsta biti visoko invazivna u zemljama istočnog Jadrana. Osim toga, rezultati su pokazali da su najugroženiji sektor lokalne populacije vrsta i relativne karakteristike, dok komercijalni sektori predstavljaju manje pogođeni sektor. Međutim, s obzirom na to da se negativni utjecaji alohtonih vrsta ne promatraju izravno, vlade ovih zemalja trebale bi se pozabaviti ovim problemom što je prije moguće.

Ključne riječi: riba paun, Jadransko more, invazivne strane vrste, procjena invazivnosti.

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