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Tracking the Lionfish (*Pterois miles*) invasion through public engagement: new records and implications for Species Distribution Models in the Mediterranean Sea

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Abstract

A comprehensive update on the distribution of lionfish (*Pterois miles*) in the Mediterranean Sea was conducted by documenting 16 newly confirmed photographic records from southern Italy, collected through a national alert campaign supported by three Italian ministries. The campaign, titled *Attenti a quei 4!* ("Beware of those 4!"), also led to the detection of other invasive species, although lionfish were the most frequently recorded. These new observations, along with 60 georeferenced records from recent scientific literature, were integrated into the www.ormef.eu dataset, resulting in the most up-to-date compilation of *P. miles* records in the Mediterranean as of March 2025. This updated dataset, now comprising a total of 1,840 georeferenced records, was visualized in a distribution map and compared with predictions made by previously published species distribution models. Notably, most new occurrences were concentrated in the Ionian Sea, a region where climate change projections had previously identified a high risk of invasion for this tropical species. These findings offer valuable insights into the ongoing expansion of *P. miles*, lending support to model predictions of high-risk areas.

Keywords: Non-indigenous species; citizen science; invasive species; Lessepsian migration; alert campaign; species distribution models.

Introduction

The Lionfish, *Pterois miles* (Bennett, 1828), is a highly impactful marine invader. Over the past three decades, this species, and the morphologically similar *Pterois volitans* (Linnaeus, 1758), have rapidly expanded their range throughout the western Atlantic Ocean, posing significant threats to coastal ecosystems and ranking among the

world's top conservation challenges (Ballew *et al.*, 2016). More recently, *P. miles* entered the Mediterranean Sea via the Suez Canal, as confirmed by molecular analyses (Bariche *et al.*, 2017). After a first isolated report in 1991 (Golani & Sonin, 1992), the population exploded about eleven years ago, shortly after *P. miles* was recorded along the coast of Lebanon (Bariche *et al.*, 2013). Lately, *P. miles* has reached high densities in the Levantine Sea and has spread across several Mediterranean countries favored by increasing suitable climatic conditions and by the lack of natural biological controls (Kleitou *et al.*, 2024).

Several studies have highlighted that climate change is facilitating the geographic expansion of suitable conditions for both *Pterois miles* and *P. volitans* (e.g., Grieve *et al.*, 2016; Kimball *et al.*, 2004; Bennett *et al.*, 2021; Loya-Cancino *et al.*, 2023). Grieve *et al.* (2016) estimated that, over the 21st century, the spatial extent of suitable year-round lionfish habitats on the Southeast United States Continental Shelf will increase by 45%, eventually covering 90% of the region.

In the Mediterranean, species distribution models (SDMs) predicting the potential distribution of *P. miles* under climate change scenarios project a significant expansion of suitable habitats in the coming decades (D'Amen & Azzurro, 2020a; Schickele *et al.*, 2021; Azzurro & D'Amen, 2022; Poursanidis *et al.*, 2022; Mitchell & Dominguez Almela, 2025). SDMs are simplified representations of ecological systems that link species occurrences to environmental variables, enabling predictions of species distributions across space and time (Guisan *et al.*, 2017). When applied to invasive species, SDMs aim to identify the environmental conditions under which these species can establish and spread, helping managers assess areas at the highest risk of invasion, both now and under future climate scenarios. However, this application is challenging because SDMs rely on the assumption that species-environment relationships remain constant over time, a condition that is rarely met by invasive species (Srivastava & Carroll, 2023). Validating SDM predictions with independent data is essential to assess their reliability, even though it is rarely done. Invasive species offer a valuable opportunity for such validation, as their rapidly expanding ranges provide new records over time, allowing researchers to evaluate SDM performance based on later stages of an invasion (Barbet-Massin *et al.*, 2018).

In recent years, successful efforts to document new species occurrences in the Mediterranean Sea have increasingly involved collaborations with local communities. These initiatives are often supported by awareness campaigns (e.g., Ben Souissi *et al.*, 2014; Andaloro *et al.*, 2016), and their potential is greatly enhanced by the widespread use of mobile phones and social media platforms. These tools have proven highly effective for collecting timely and reliable observational data (e.g., Tiralongo *et al.*, 2019, 2020; Al Mabruk *et al.*, 2021).

In this study, we aimed to: (i) document new occurrences of *P. miles* in Italian waters; (ii) review its distribution across the Mediterranean Sea; and (iii) assess the most recent spread of the species against predictions made by SDMs under climate change scenarios.

Materials and Methods

Revision of the Mediterranean occurrences of Pterois miles

To update the current distribution of *P. miles* in the Mediterranean Sea, we utilized geo-referenced occurrence data from the ORMEF (Occurrence Records of Mediterranean Exotic Fishes) geoportal (https://ormef.eu) and incorporated additional records published in the scientific literature after November 2022. This update, conducted as part of the 2024 revision of the ORMEF geoportal, underwent a rigorous validation process as outlined by Azzurro *et al.* (2024). All records were cross-checked against original data sources to ensure accuracy and reliability. The occurrence data were geographically projected using QGIS version 3.34.4-Prizren.

The alert campaign "Attenti a quei 4!"

In November 2021, a national alert campaign was launched in Italy with the dual purpose of warning citizens about the presence of dangerous invasive species and encouraging public involvement in monitoring efforts. This initiative was formalized through an agreement between the National Research Council (CNR) - Institute for Biological Resources and Marine Biotechnologies (IRBIM) and the Italian Institute for Environmental Protection and Research (ISPRA). The campaign, titled 'Attenti a quei 4!' ('Beware of those 4!'), aimed to educate the public, promote citizen science, and enhance early detection of four invasive species potentially hazardous to human health: the Silver cheeked pufferfish *Lagocephalus sceleratus*, the Lionfish *Pterois miles*, the Dusky spinefoot *Siganus luridus* and the marbled spinefoot *S. rivulatus*. In 2022, the campaign received official endorsements from three Italian Ministries: Ministero della Salute - MS (Health Ministry); Ministero dell'Ambiente e della Sicurezza Energetica - MASE (Ministry of the Environment and Energy Security); Ministero dell'Agricoltura, della Sovranità Alimentare e delle Foreste – MASAF (Ministry of Agriculture, Food Sovereignty, and Forests). A formal collaboration with the General Command of the Port Authorities and the national projects USEIt and AlienFish (Tiralongo *et al.*, 2020) was also established. The campaign was primarily carried out through the online distribution of a dedicated poster (Fig. S1) and other educational materials, through local or national press as well as radio, TV and online videos (e.g., https://www.youtube.com/watch?v=ZtuX2vn4bzM). A dedicated phone number and Facebook group Oddfish facilitated the contactthe contact between the research team and the potential observers. To minimize potential bias, only records accompanied by a picture or video were validated, following contact with the observer either by phone or in person.

Results

The outcomes of the Attenti a quei 4! *campaign: new records of* Pterois miles

The *Attenti a quei 4!* campaign resulted in a total of 62 Italian records, of which 37 referred to the four target species and 25 related to other species. Most of the reports concerned *Pterois miles* (N = 25). The remaining reports were distributed among *Siganus luridus* (6), *Lagocephalus sceleratus* (4), and *Siganus rivulatus* (2). The other 25 reports submitted by citizens pertained to species misidentified as one of the campaign targets. Additionaly, a single specimen of *Chilomycterus reticulatus*, was also reported and sampled, representing its second record in the Mediterranean Sea. It is missing from the references).

The lionfish (*Pterois miles*) was the most frequently reported species by citizens during the campaign. In total, 16 validated records were collected from Italian waters (Table 1, Fig. 1). These confirmed observations were supported by detailed information provided directly by the observers, along with photographic or video evidence (e.g., https://youtube.com/shorts/4k0-Nt39HP0?feature=share) An additional nine unverified reports originated from the Ionian coasts of Calabria, Apulia, and Sicily (Catania, San Vito Lo Capo, and Favignana), but were excluded due to the absence of visual documentation and the resulting inability to confirm their accuracy.

Distribution update of Pterois miles *in the Mediterranean Sea*

These 16 validated observations, along with 60 georeferenced records extracted from 10 scientific articles published after March 2023, were added to the ORMEF dataset, resulting in a comprehensive and up-to-date compilation of *P. miles* records in the Mediterranean as of March 2025. The updated ORMEF dataset now includes a total of 1,840 validated records of *P. miles* extracted from 41 scientific papers published between 1992 and 2024, along with 160 additional validated records collected through social media platforms, primarily Facebook and Instagram.

Mapping all these observations with color-coded dots by year of observation (Fig. 2) illustrates that, by 2018, the western invasion front of *P. miles* had reached the Peloponnese. The invasion subsequently advanced along the Albanian coast and extended into southern Croatia, with the most recent records reported from southern Italy, particularly along the coasts of Puglia and Calabria. The increasing presence of lionfish in these areas is further supported by the records collected during the present study, all of which are concentrated in the Ionian Sea (Fig. 2).

Table 1. Details of the 16 validated *Pterois miles* records gathered through the alert campaign *Attenti a quei 4!* The table provides information on the date of sighting, location, geographical coordinates, number of individuals, depth at the bottom, bottom typology, and the collection method. The pictures associated with each of these records are presented in Figure 1.

Date	Location	Latitude	Longitude	N. of individuals	Depth	Bottom	Method
25 Jun 2023	Marina di Gioiosa Ionica	38.30082° N	16.34083° E	1	13	Artificial reef	Observation
26 Jun 2023	Crotone - Le Castella	38.9052° N	17.02911° E	1	24	Mixed	Trammel net
3 Jul 2023	Marina di Gioiosa	38.30072° N	16.34098° E	1	15	Artificial reef	Observation
24 Aug 2023	Taranto - Porto Pirrone	40.3691° N	17.30512° E	1	22	Sandy	Observation
17 Sep 2023	Cirò Marina	39.37° N	17.13897° E	1	14	Rocky	Speargun
22 Nov 2023	Reggio Calabria - Catona	38.18014° N	15.63947° E	1	17	Rocky	Observation
27 May 2024	Corigliano-Rossano	39.62206° N	16.68738° E	1	14	Rocky	Observation
11 Jul 2024	Taranto - Porto Pirrone	40.36979° N	17.30526° E	1	18	Rocky	Observation
27 Jul 2024	Reggio Calabria - Catona	38.18496° N	15.63362° E	1	17	Rocky	Observation
28 Oct 2024	Reggio Calabria - Capo dell'Armi	37.94938° N	15.68255° E	1	4	Rocky	Trammel net
29 Oct 2024	Gallipoli	40.03733° N	17.9642° E	1	na	na	Trammel net
3 Nov 2024	Reggio Calabria - Pellaro	38.03764° N	15.65512° E	1	25	Rocky	Observation
10 Nov 2024	Reggio Calabria - Lazzaro	37.97212° N	15.66091° E	1	17	Rocky	Observation
24 Nov 2024	Letojanni - Baia di Mazzarò	37.86134° N	15.31287° E	1	20	Rocky	Observation
28 Nov 2024	Torre Colimena	40.295017° N	17.743354° E	1	18	Rocky	Gillnet
28 Mar 2025	Baia di Soverato	38.69322° N	16.54714° E	1	7	Mixed	Observation

Fig. 1: Composite images illustrating the 16 *Pterois miles* sightings listed in Table 1. Each photograph is labeled with the corresponding Record ID from Table 1, highlighting the verified observations documented during the *Attenti a quei 4!* campaign.

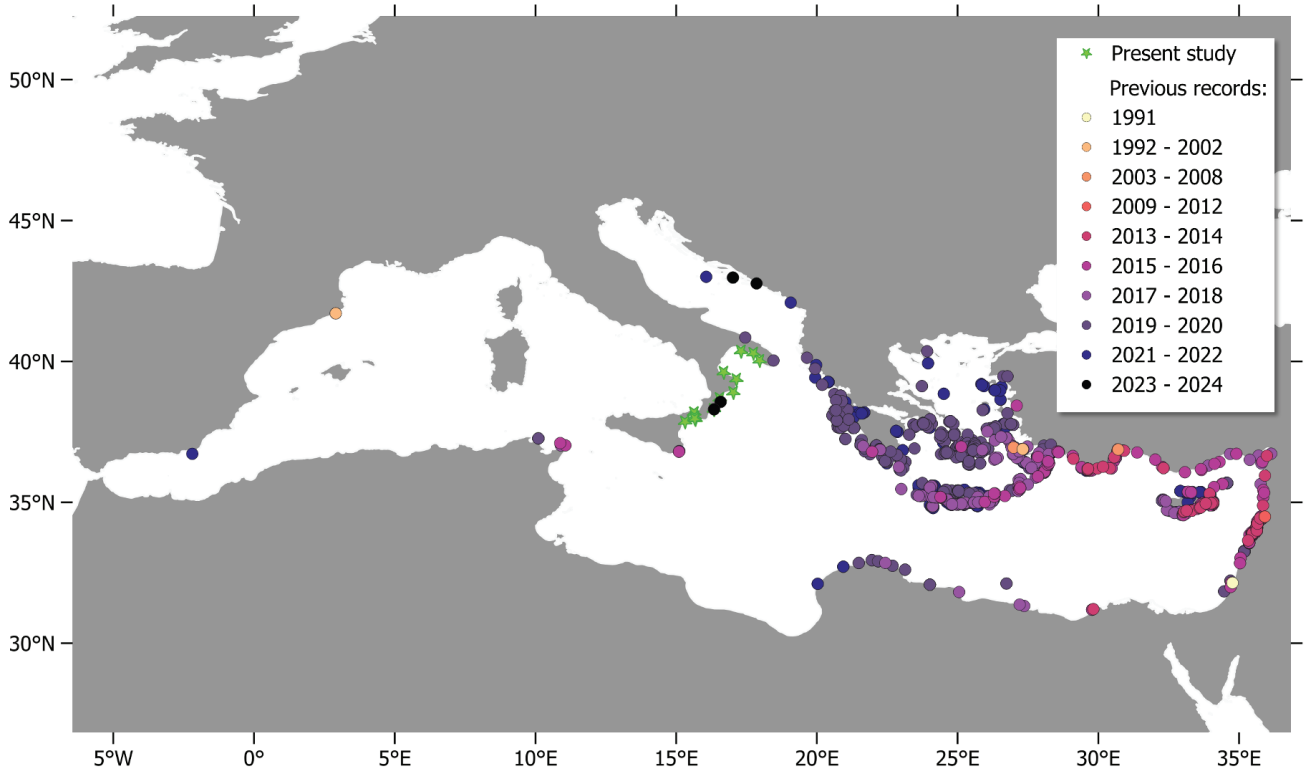

Fig. 2: Map of the Mediterranean Sea showing 1,840 geo-referenced records of *Pterois miles*. Observations extracted from the ORMEF database www.ormef.eu enriched by a literature update are represented as dots, color-coded by the year of observation, while 16 newly reported sightings from the *Attenti a quei 4!* campaign are marked with green stars.

Discussion

This study provides a comprehensive assessment of the Lionfish (*Pterois miles*) distribution in the Mediterranean Sea, highlighting its recent geographical expansion and updating previous revision efforts (Dimitriadis *et al.*, 2020; Azzurro *et al.*, 2022; Bottacini *et al.*, 2024).

In Italian waters, following an initial record in 2016 in the southern Ionian Sea (southeast of Sicily; Azzurro *et al.*, 2017), colonization by this species began in the summer of 2023, with subsequent reports from both the Ionian and southern Adriatic Seas. Notably, all new records provided by the alert campaign *Attenti a quei 4!* were temporally and spatially concentrated in these same areas, particularly in the Ionian Sea. This pattern cannot be attributed to potential geographical biases, as the campaign, widely promoted through social media, was uniformly disseminated across all Italian coastal regions. The marked geographical clustering of these records prompted us to compare these empirical observations with predictions generated by species distribution models (SDMs) under both current conditions and climate change scenarios.

The first modelling attempt to predict Lionfish settlement and expansion in the Mediterranean underestimated its potential, demonstrating unfavorable connectivity patterns and the Bay of Marseilles (where the species is currently not registered) to be particularly susceptible (Johnston & Purkis, 2014). In the following years several predictive models correctly predicted the observed trend, projecting an expansion of suitable habitats for Lionfish in the Ionian Sea under climate change scenarios (e.g., D'Amen & Azzurro, 2020a; 2022; Schickele *et al.* 2021; Poursanidis *et al.* 2022; Mitchell & Dominguez Almela, 2025). Although we are aware that this does not constitute a true validation of Species Distribution Models (SDMs), it is worth noting that all 16 new occurrence points fall within a region consistently identified by several published SDMs as having a high probability of lionfish presence under climate change scenarios (D'Amen & Azzurro, 2020a; Schickele *et al.*, 2021; Azzurro & D'Amen, 2022; Poursanidis *et al.*, 2022; Mitchell & Dominguez Almela, 2025). This trend is particularly evident in the geographical projections by D'Amen & Azzurro (2020a), based on the ORMEF dataset (updated to 2018). Their model predicts a shift in the Ionian Sea from low to high habitat suitability, as shown by the comparison between Figure S2, depicting current conditions (2000-2014), and Figure S3, which presents future projections for 2040–2050 under the RCP 8.5 scenario.

Other studies modeling the invasion dynamics of lionfish in the Mediterranean, such as Azzurro & D'Amen (2022) and Poursanidis et al. (2022), project a similar trend for the 2040-2050 period, although the latter authors predicted lower habitat suitability along the Ionian coast. Schickele *et al.* (2021) produced projections in a nearer future (2030-2039) and already foreseen a great increase in habitat suitability in the Ionian and Tyrrhenian coasts.

A similar trend of increasing habitat suitability could be predicted for the southern Adriatic sectors (Azzurro & D'Amen, 2020 and 2022; Schickele 2021; Dragičević *et al.*, 2021; Bakiu *et al.*, 2024). Conversely, in sectors where recent observations were documented (e.g., Di Martino & Stancanelli, 2021) as the Sicily Channel, Tunisia and the remaining Western Mediterranean Sea, low habitat suitability may still act as a barrier to the Lionfish invasion. Indeed, the species is still considered occasional in these areas (Amor *et al.*, 2021), and future observations will be essential to determine whether the invasion dynamics align with model predictions.

In fitting SDMs, most of the studies on Lionfish (D'Amen & Azzurro, 2020a; Azzurro & D'Amen 2022; Poursanidis *et al.*, 2022; Mitchell & Dominguez Almela, 2025) still use the classic approach of a temporal baseline condition, averaging predictors over several years, namely 2000-2014. As a result, the environmental data does not sufficiently cover the Lionfish invasion (which began in 2012 and has progressively expanded), leading to model uncertainties (Poursanidis *et al.*, 2022). Employing a more refined temporal match between the records' year of collection and the biophysical variables could produce an improvement in the SDMs' outcome (Mannocci *et al.*, 2017; D'Amen *et al.*, 2024).

This is now made possible by the increasing availability of environmental data with high temporal resolution, such as those provided by Copernicus Climate Change Service (C3S), part of the Copernicus Earth Observation (EO) Programme of the European Union. The available time series of climate projections could also allow modelling species habitat suitability over multiple time intervals in the next century, allowing transition from static to dynamic species spatial analyses with a better estimate of invasion trajectories. This approach should be considered alongside other strategies to enhance species distribution models (SDMs) applied to invasive species (e.g., D'Amen & Azzurro, 2020b).

In conclusion, a series of recent Lionfish observations, sourced from the latest literature and collected through the alert campaign, closely align with the model's spatial predictions of invasion risk, highlighting the potential for a future population explosion in these areas. These findings emphasize the value of participatory initiatives in enhancing the effectiveness of Lionfish monitoring, enabling continuous validation of model predictions and providing new data to refine forecasts.

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Supplementary Material

The following supplementary material is available for this article:

Fig. S1: Poster for the national campaign *Attenti a quei 4!* (Beware of those 4!) raising awareness about the risks and monitoring of invasive fish species in Italian waters. The campaign, promoted by CNR-IRBIM, ISPRA and Ente Fauna Marina Mediterranea (AlienFish) aimed to inform the public about the presence of four hazardous invaders: *Lagocephalus sceleratus, Pterois miles, Siganus luridus,* and *S. rivulatus*.

Fig. S2: Model outputs for a current scenario (corresponding to the 2000-2014 period) developed by D'Amen and Azzurro 2020.

Fig. S3: Model predictions for the decade 2040-2050 under the RCP 8.5 scenario developed by D'Amen and Azzurro 2020.