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ORIGINAL ARTICLE

Invasion underway: exceptional number of records of the devil firefish *Pterois miles* (Bennett, 1828) in the eastern Adriatic Sea (Croatian coast)

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Abstract: The study presents an exceptional number of records of the devil firefish *Pterois miles* along the Croatian coast. These records are based on 122 confirmed sightings of the species recorded between June 2024 and January 2025, providing evidence of a rapid and extensive expansion of the species in the eastern Adriatic waters. Most records originated from citizen science *via* direct reports of sightings, complemented by monitoring of social networks and online media platforms. The highest number of sightings was recorded around the islands of Lastovo and Vis, while the area around Dubrovnik had the highest number of sightings along the mainland coast. The majority of individuals (72.7%) were sighted within the first 15 meters of depth, with most individuals estimated to be 15 cm or smaller in length. No correlations between depths and lengths of individuals, as well as between time and latitude of sighting were detected. Most sightings occurred during diving activities, with a few involving captured specimens. The observed expansion is likely a result of larval transport *via* sea currents and subsequent settlement, as the pattern of records aligns with general circulation patterns along the eastern Adriatic coast. Given the species' biological traits, which facilitate rapid and extensive establishment in invaded areas, this expansion poses certain ecological risks, particularly in key coastal habitats that host ecologically and economically important fish species. We encourage targeted removal strategies, particularly in ecologically significant areas such as Marine Protected Areas (MPAs), commercialization of the species and reduction of fishing pressure on natural predators as mitigation measures.
Keywords: common lionfish; citizen science; new records; devil firefish; NIS; alien species

Sažetak: INVAZIJA U TIJEKU: IZNIMAN BROJ NALAZA VRSTE *PTEROIS MILES* U ISTOČNOM DIJELU JADRANSKOG MORA (HRVATSKA OBALA). U radu se prikazuju nova i mnogobrojna opažanja vatrenjače *Pterois miles* uz hrvatsku obalu. Ukupno 122 potvrđena opažanja ove vrste zabilježena su u razdoblju od lipnja 2024. do siječnja 2025. godine, što je dokaz brzog širenja vrste u vodama istočnog dijela Jadranskog mora. Većina opažanja prikupljena je uz pomoć građanske znanosti, uglavnom putem izravnih dojava, te podataka prikupljenih putem društvenih mreža i online medija. Najveći broj opažanja zabilježen je oko otoka Lastova i Visa, dok je područje oko Dubrovnika imalo najveći broj opažanja duž kopnenog dijela obale. Većina jedinki (72,7 %) zabilježena je do 15 metara dubine, a većina je bila procijenjene duljine 15 cm ili manje. Nisu utvrđene korelacije između dubine i duljine jedinki, kao ni između vremena i zemljopisne širine opažanja. Većina opažanja se dogodila tijekom ronilačkih aktivnosti, a samo je manji broj uključivao ulovljene jedinke. Širenje ove vrste vjerojatno je rezultat transporta jaja i ličinki morskim strujama i kasnijeg naseljavanja, budući da obrazac opažanja odgovara općim obrascima strujanja uz istočnu obalu Jadrana. S obzirom na biološke karakteristike vrste koje omogućuju brzo i opsežno uspostavljanje populacije u novim područjima, ovo širenje predstavlja i određene ekološke rizike, osobito u ključnim obalnim staništima koja nastanjuju ekološki i gospodarski važne vrste riba. Kao mjere ublažavanja, preporučuje se ciljana strategija uklanjanja osobito u ekološki značajnim područjima kao što su morska zaštićena područja (MZP), komercijalizacija vrste te smanjenje ribolovnog pritiska na prirodne predatore.
Ključne riječi: riba lav; građanska znanost; novi nalazi; vatrenjača; NIS; strana vrsta

INTRODUCTION

Marine bioinvasions are among the most significant threats to marine ecosystems worldwide, mainly due to the impact of invasive species, a subset of non-indigenous species also referred to as alien, exotic, or non-native (Bax *et al*., 2003; Molnar *et al*., 2008). These species establish and spread in new environments, impacting marine ecosystems through various mechanisms, for example by displacing native species *via* competition for resources and predation, acting as vectors for diseases and parasites, or through other processes, ultimately reshaping community structures causing serious ecological, economic and health risks (Côté *et al*., 2013; Ricciardi *et al*., 2013). Considering the rate of introduction of non-indigenous species, their number, and impact, the Mediterranean Sea is considered one of the most affected marine regions by bioinvasions world-

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wide (Zenetos *et al*., 2010). Moreover, unprecedented warming in this region is expected to further accelerate the spread and impact of these species, amplified by numerous human interventions and activities that facilitate their relocation and expansion (Pancucci-Papadopoulou *et al*., 2012; Ragkousis *et al*., 2023). The primary pathway for non-indigenous species introductions into the Mediterranean is the Suez Canal, which is located in Egypt and provides an artificially made connection between the Mediterranean Sea and the Red Sea. It has also provided a passageway for a diverse array of Indo-Pacific biota, referred to as Lessepsian migrants, to enter and significantly alter the Mediterranean ecosystem, especially in its south-eastern regions (Galil *et al*., 2018). Among Lessepsian taxa, approximately 130 fish species are expanding within the Mediterranean basin, with a dominant trajectory of northwestward spread from their initial introduction in the Levant Basin. Environmental changes, particularly sea warming, further support a northward shift for certain species (Vagenas *et al*., 2024).

The devil firefish, *Pterois miles* (Bennett, 1828), also known as common lionfish, can be considered a recent Mediterranean invader of Indo-Pacific origin being detected for the first time in the basin in 1991 (Golani and Sonin, 1992), but experiencing expansion in the basin since at least 2012 (Bariche *et al*., 2013; Azzurro and Bariche, 2017). Through time, it seems that the invasion path of *P. miles* followed a typical Lessepsian northwestward trajectory with first records appearing in the vicinity of the Suez Canal and gradually appearing in northern areas, subsequently reaching the Ionian and Adriatic Seas (Vagenas *et al*., 2024). At present, it seems that *P. miles* is almost ubiquitous in the south-eastern Mediterranean coastal areas with relatively rare records in its central part (Bottacini *et al*., 2024). Exceptional invasion in the Mediterranean by *P. miles* has previously already been mirrored in the Caribbean region in the west Atlantic by the *P. volitans/miles* complex (Kimball *et al*., 2004; Côté *et al*., 2013). Traits such as high fecundity, generalist diet, habitat versatility, rapid growth, and specific morphological characteristics, among others, have been identified as some of the key factors contributing to the success of this species in the Western Atlantic (Albins and Hixon, 2013; Rojas-Vélez *et al*., 2019). Similar traits in the Mediterranean Sea have been identified by Savva *et al*. (2020) for *P. miles* in Cypriot waters, where large aggregations of this species were commonly found in complex rocky habitats at depths ranging from 0 to 50 meters. Furthermore, adult individuals are capable of year-round spawning, and the species exhibits faster growth and achieves larger sizes compared to its native range. The same authors studied the species' diet in the invaded range and found that it is a generalist predator, feeding on a wide variety of fish and crustacean prey.

Additionally, lionfish exhibit relatively limited movement as adults, with recorded movements varying from no displacement to approximately 1.35 km over a 15-day period (Tamburello and Côté, 2015). Therefore, their range expansion potential primarily relies on propagules, mainly through larval dispersal (Johnston and Purkis, 2011; Del Río *et al*., 2023; Schilling *et al*., 2024).

To combat the invasion of lionfish species in the Western Atlantic and Mediterranean waters, targeted removal efforts have proven to be primarily effective at local scales, but still with limited potential as the species can undergo culling-induced behavioral changes (Barbour *et al*., 2011; Phillips *et al*., 2024). However, in the case of *P. miles* in the Mediterranean, public engagement in such activities has been shown to be a useful strategy. While these efforts have an impact, particularly in smaller areas of high conservation value, they must be continuous, as the species is capable of rapid recovery following removal events (Savva *et al*., 2024).

The limited number of records of Lessepsian fish species in previous years indicated difficulties in their ability to establish populations in the Adriatic Sea (Dulčić and Dragičević, 2023). This, along with previous modeling-based studies, also suggested a limited potential for the expansion of *P. miles* in this northernmost Mediterranean region (Poursanidis *et al*., 2020; Dimitriadis *et al*., 2020). However, the invasion of the Adriatic Sea by this species, first documented in 2019 with initial sightings along the Albanian and Italian coasts, has progressed gradually yet sporadically across the eastern Adriatic, with new records continuing to appear in the following years (Di Martino and Stancanelli, 2021; Dragičević *et al*., 2021; Fortič *et al*., 2023; Dulčić *et al*., 2024; Bakiu *et al*., 2024). It seems likely that these distribution models failed to accurately predict lionfish Mediterranean hotspot areas due to climatic niche expansion in the novel areas and the presence of a favorable climate in the invaded domain still not occupied by the species (Kleitou *et al*., 2021).

Here we report on the exceptionally large number of novel records of *P. miles* along the Croatian coast detected through citizen science and sightings shared on various interest groups on social networks and online media platforms. Additionally, we provide a brief overview of several ecological parameters analyzed using additional data provided alongside observations, documenting the early onset of invasion and establishment of this species.

MATERIALS AND METHODS

Data collection

To systematically collect and track sightings of *Pterois miles* along the Croatian coast, we established a dedicated database in response to the first sighting reported and supported by video footage in an online news portal in June 2024. Following this initial report, the Institute of Oceanography and Fisheries launched a public call for reporting sightings and raising awareness of the species' presence *via* its social media platforms. This has resulted in numerous sightings being reported directly to the authors; however, some sightings have been obtained from other sources through the extensive, daily monitoring of social media groups and news portals. Additionally, four individuals were documented during scientific surveys conducted *via* SCUBA diving. To ensure verifiability, sightings were required to be accompanied by photographs or video. However, sightings without photographic evidence were also considered, in which case observers were contacted and asked to confirm identification by referencing images of the species. Due to the diverse reporting methods and the number of reports, it was not possible to gather additional data for all sightings. The majority of data collected and recorded in the database included the sighting location (exact or approximate) and date, estimated length of the individuals, depth of sighting, number of individuals per location, and the method of observation (e.g., diving, fishery-related catch, etc.). It is important to note that sightings of common lionfish recorded through diving and other direct observation methods (excluding captured specimens) were treated as separate individuals, although it cannot be determined whether some sightings represent repeated observations of the same fish, particularly within the same areas.

To facilitate geospatial analysis, locations of sightings were entered as coordinates in the database. In a few cases when data on exact locations were unavailable, or these were not sufficiently precise, random locations (coordinates) were assigned for sightings where the mentioned location was not too broad (e.g., small islands). However, for broader locations (e.g., large islands), where assigning a random location would not be appropriate, coordinates were considered not available. In a single case, when the observer mentioned multiple sightings at the same location in the same month, without specifying a number, three specimens were considered observed for the same location.

Data analysis

All collected data were processed and analyzed using RStudio software (RStudio Team, 2020). The available variables, such as estimated lengths of individuals and depth of sighting, were summarized primarily using ranges to produce histograms, since the majority of those were approximated by observers. However, to analyze the relationship between the depth and length of individuals, we considered continuous data, which needed to be approximated. Therefore, when values for both depth and size were given as a range, we used the mid-value as a representative variable. When a single approximate value was provided (e.g., "about 20 cm"), we considered the absolute value (i.e., 20 cm) for consistency. Only sightings with both variables available were considered.

To assess the correlation between the length of individuals *vs*. depth, we performed a linear regression with depth as an independent variable, and length as a dependent (Ewing *et al*., 2025). Similarly, linear regression was used to assess whether occurrences exhibited a northward spreading over time, using latitude as the independent variable and the date of sighting as the dependent. When only the month of sighting was available, the 15th day of the month was assigned as the date of sighting. In one instance where "autumn" was specified as the period of sighting, October 15th was chosen as the sighting date. This analysis was performed by regressing dates converted to Julian days (with January 1st, 2024 as day one) with the R package *lubridate* (Grolemund and Wickham, 2011).

All analyses were performed in RStudio using built-in functions for linear regression. The significance level was set at $\alpha = 0.05$.

Visualization of records

Geo-referenced occurrence data of *P. miles* were processed in RStudio using *sf* (Pebesma, 2018) and *leaflet* packages (Cheng *et al*., 2025). The package *sf* was used to encode coordinates into spatial vector data and calculate the number of records within a set radius, while the *leaflet* package enabled the creation of the map with color-coded points of sightings. More precisely, this method enabled visualization of the concentration of records by calculating the number of georeferenced occurrences of sighted individuals within a 10 nautical miles (~18.52 km) radius for each location, allowing the identification of areas with a higher number of records. Density variations were depicted by different color codes. Each recorded occurrence on the map is displayed as an individual point representing the occurrence, with its color intensity representing the number of neighboring occurrences within a mentioned radius.

RESULTS

In total, we obtained reports of sightings of 122 individuals of *Pterois miles* along the eastern Adriatic, all along the Croatian part of the coast. The period of sightings lasted from June 2024 until January 2025, when the preparation of the manuscript and analysis of data started (although several records occurred after this period, these were not included in the analysis). In four cases, which considered 4 separate individuals, only the year (2024) was provided without an exact date, month, or season. For 96 individuals, the method of sighting was provided. The majority of individuals (71; 73.96%) were sighted during recreational diving (including spearfishing), 16 individuals (16.7%) were caught using a speargun, 6 individuals (6.3%) were either sighted or captured from the shore, and 3 (3.1%) individuals were caught by professional fishermen by bottom set-nets or traps. Except for four instances - three cases where two individuals were sighted and one case where three individuals were sighted in close proximity or within the same dive (see Fig. 1E, F), all other sightings in-

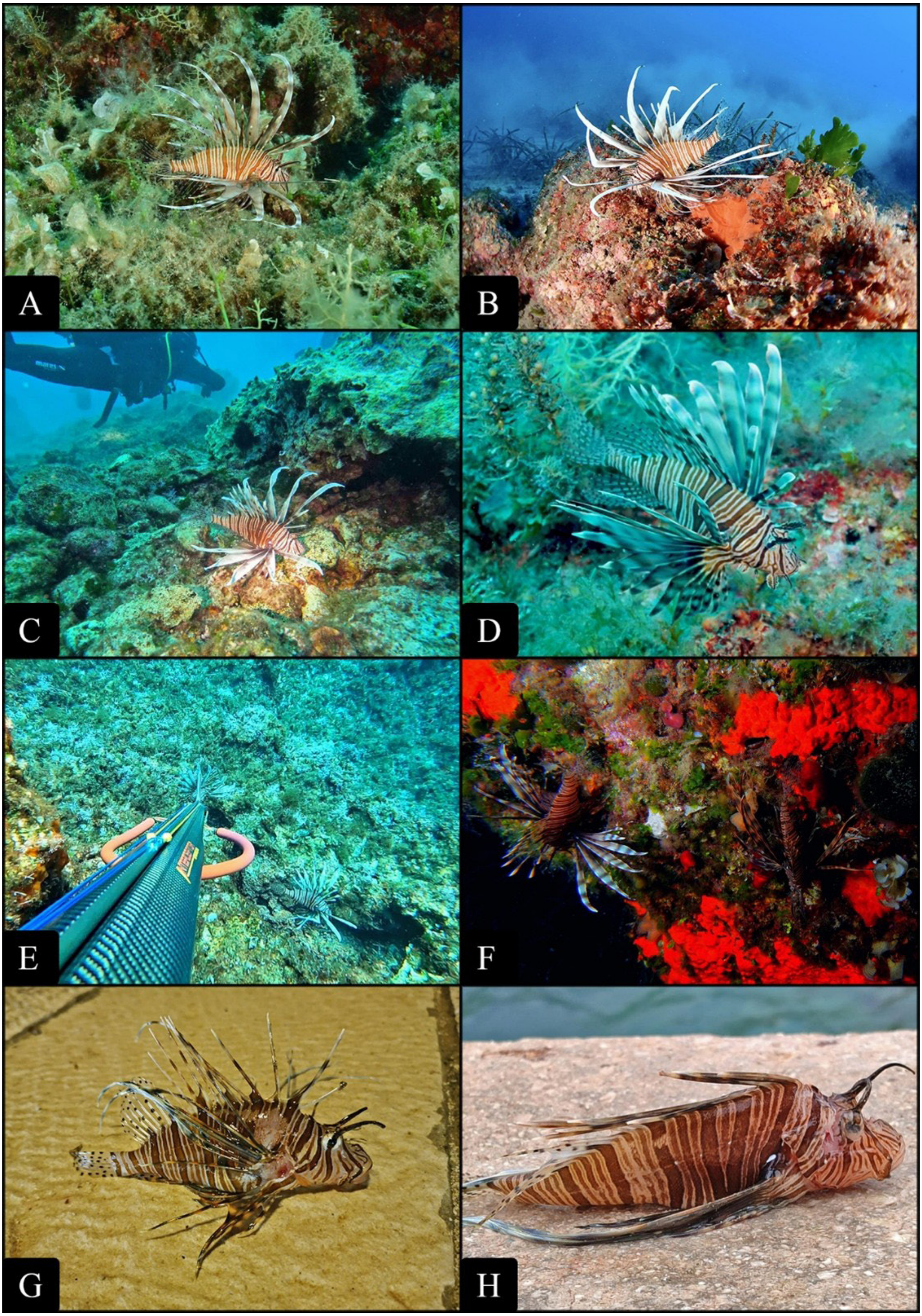

Fig. 1. Examples of photographed individuals of *Pterois miles* in the eastern Adriatic (Croatian coast). Photo credits: Petar Kružić **(A)**, UPA Rostrum diving **(B)**, Ronilački klub Mostar **(C)**, Ante Žuljević **(D)**, Mario Rumek **(E)**, Tomislav Gašpić **(F)**, Matko Duplica **(G)**, Igor Kovačić **(H)**.

volved a single individual *per* location, either sighted or caught. Although this study did not assess the habitat where sightings took place, most individuals documented through *in situ* photographs were observed in rocky habitats with algal cover (as seen in Fig. 1).

In Fig. 2, a frequency of sightings per month is shown. The number of sightings varied considerably by month with a clear domination of sightings in the period from August to October 2024, in which 67 sightings were recorded (71.3%), peaking in August with 27 reported individuals.

Depth or approximate depth of sighting was available for 44 individuals. In Fig. 3, a histogram depicting depths of occurrences is shown. The majority of sightings (72.7%) occurred in the first 15 meters of depth. The shallowest sightings involved individuals spotted

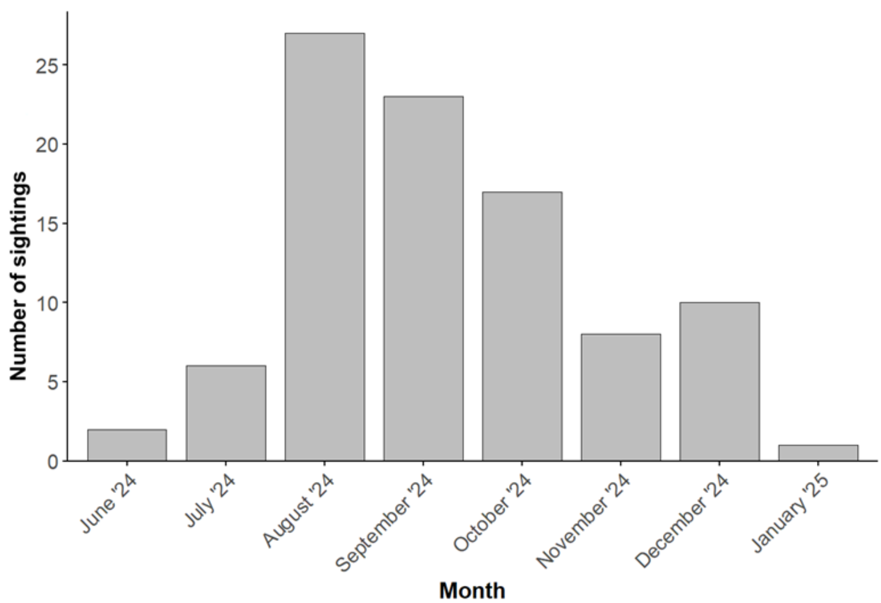

Fig. 2. Histogram showing the number of sightings *per* month of occurrences of *Pterois miles* in the eastern Adriatic (Croatian coast) in the period June 2024 - January 2025.

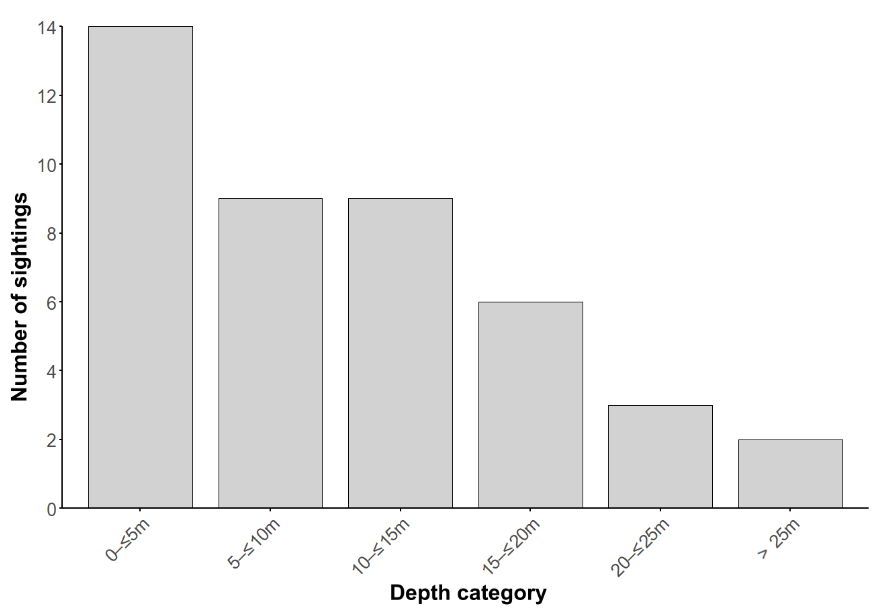

Fig. 3. Histogram depicting the number of sightings per depth category of *Pterois miles* in the eastern Adriatic in the period June 2024 - January 2025.

in four separate events at less or approximately at 0.5 meters depth directly from the coast, while the deepest sighting considered a single individual spotted by the diver at a depth of 38 meters.

Approximate lengths were reported for 69 individuals. Except for one case, when the caught specimen was measured by a ruler (13 cm), all other lengths were estimated by the observers. The smallest estimated lengths included a range of 6-7 cm, while the largest length was estimated at 25 cm. For the majority of individuals (74%), lengths were estimated at or under 15 cm. In Fig. 4, a histogram of the estimated length ranges of sighted individuals is shown.

Linear regression was performed to assess the relationship between the length of individuals and the depth of sighting, which were both available for 31 observed individuals (Fig. 5). In all cases, the considered individuals were observed or caught while diving/spearfish-

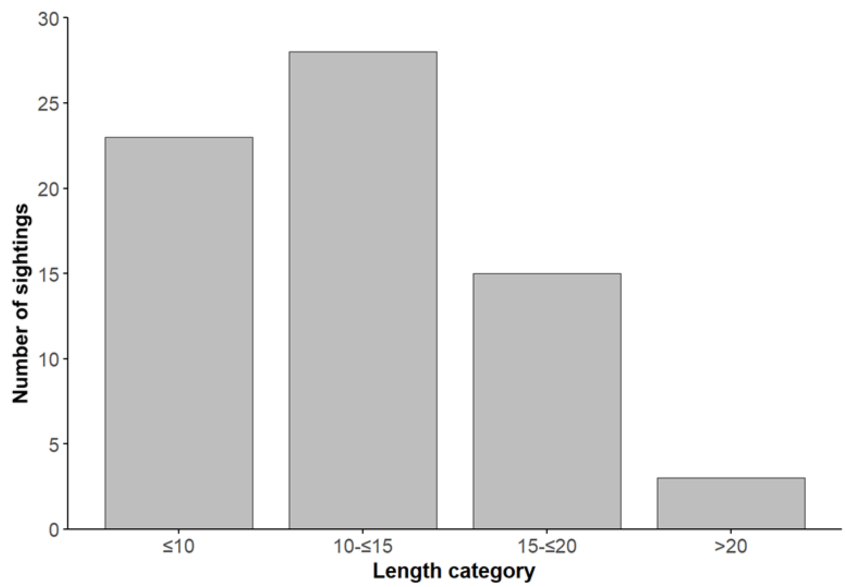

Fig. 4. Histogram of length categories estimated by the observers of *Pterois miles* along the Croatian coast in the period June 2024 - January 2025.

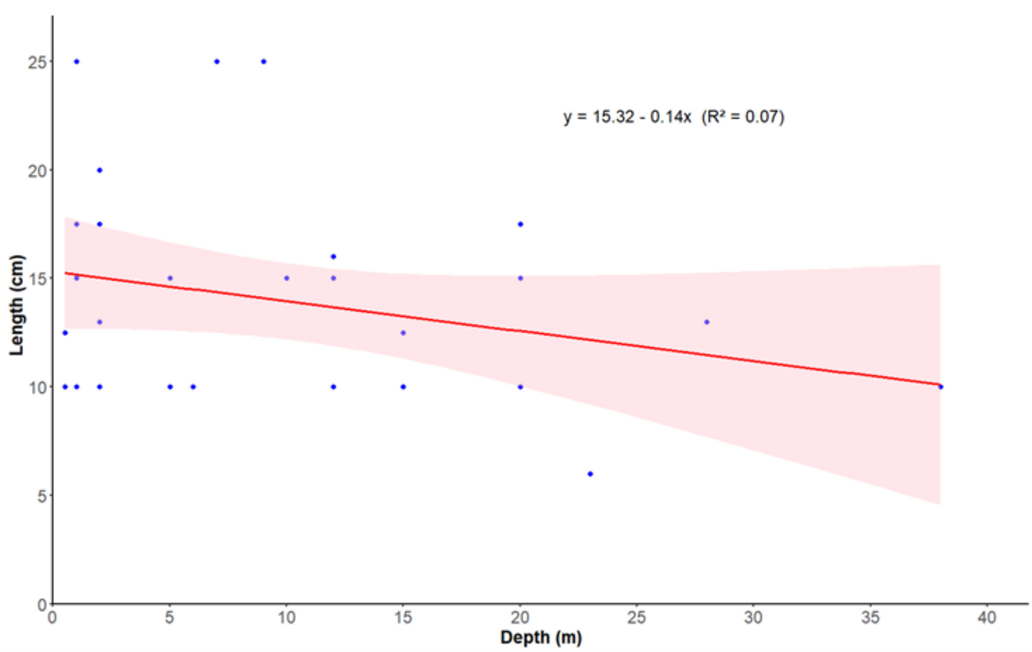

Fig. 5. Linear regression of estimated fish length *vs.* depth of sighting of *Pterois miles* in the eastern Adriatic in the period June 2024 - January 2025. The red line represents the regression line; the 95% confidence interval is represented by a light red area.

ing or were observed from the shore. Despite the slight downward trend of the regression line, the trend was not statistically significant (F(1,29)=2.174, p=0.151). Similarly, linear regression of Julian day of the year *vs*. latitude, performed on the data available for 67 observed individuals (Fig. 6), showed a slight upward trend, also without statistical significance (F(1,65) = 0.368, p=0.546). In both cases, R^2 was very low, suggesting a weak linear relationship between the variables.

The southernmost sighting was in the Prevlaka area in June 2024, at the southernmost point of Croatia, while the northernmost was near Mali Garmenjak Island in Telašćica Nature Park in August of the same year. In Fig. 7, the locations of sightings are shown with color-coded concentrations within a 10 NM radius. As can be seen, the highest concentrations occurred around the islands of Lastovo and Vis, where 15-20 individuals were sighted within the radius. It should be noted that due to

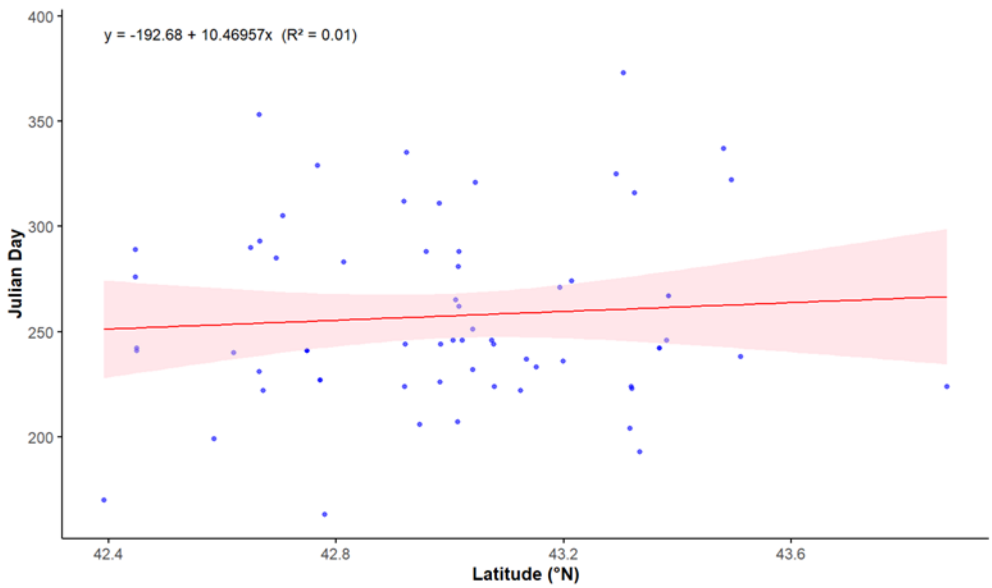

Fig. 6. Linear regression of latitude (north) *vs.* Julian day (at time of sighting) of *Pterois miles* in the eastern Adriatic in the period June 2024 - January 2025. The red line represents the regression line; the 95% confidence interval is represented by a light red area. January 1st, 2024 is considered Julian day 1.

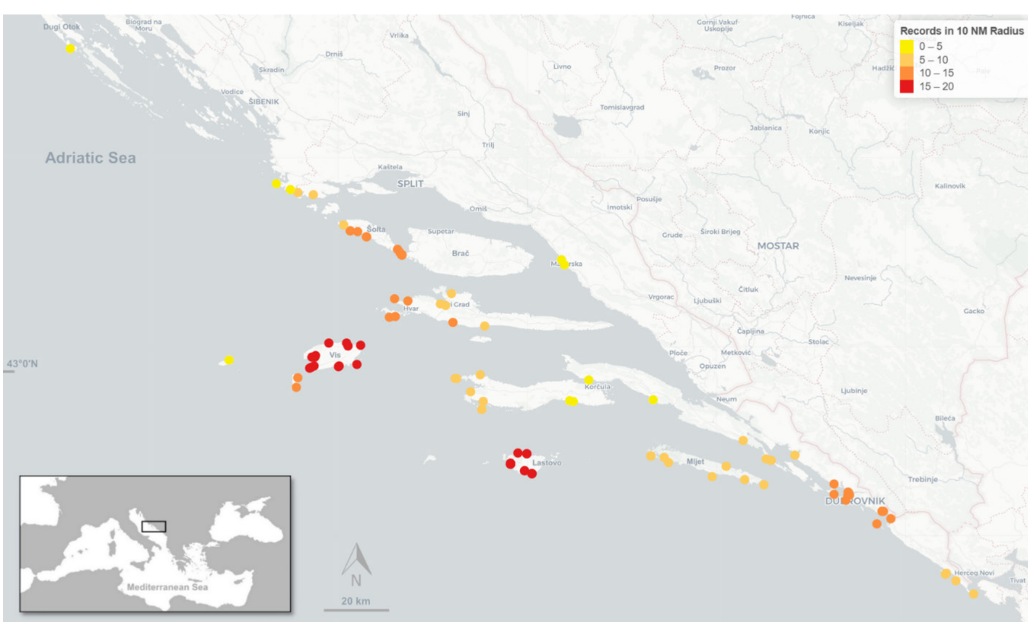

Fig. 7. Map of sightings of *Pterois miles* in the eastern Adriatic in the period June 2024 - January 2025. Colors correspond to concentrations of records (see Materials and Methods for details). Basemap provided by CARTO (https://carto.com/).

randomly selected locations for some sightings around the mentioned islands, locations should not be considered as precise. A slightly lower (10-15 individuals per 10 NM), but still notable number of sightings, was found at certain areas near Dubrovnik, Mljet, Korčula, Hvar, and the area between Šolta and Brač islands. In contrast, except for outer islands, the channel areas between larger islands closer to the coast exhibited a lower number of sightings compared to their southern and south-western shores exposed toward the open sea. Additionally, only a single record (the aforementioned northernmost sighting) was documented beyond Punta Planka near Rogoznica, a location considered the most prominent and exposed cape on the eastern Adriatic coast. In the coastal area extending from Voluja Cove near Rogoznica on the north to Mali Ston on the south, *P. miles* was recorded only in the vicinity of Makarska.

DISCUSSION

The present study provides evidence of the population establishment and significant expansion of *Pterois miles* along the Croatian coastal area of the eastern Adriatic, five years after the first record of this species in the Adriatic Sea (Di Martino and Stancanelli, 2021). This expansion appears to be rapid and extensive, in contrast to some previous predictions based on modeling (Dimitriadis *et al*., 2020; Poursanidis *et al*., 2020). A recent study by Mitchell *et al*. (2025) demonstrated that shifting environmental conditions in the Mediterranean will likely expand suitable habitat for *P. miles* across the Mediterranean in the future, while the northern Adriatic is expected to remain an unfavorable area. However, the authors relied on data that had not been updated with recent Adriatic occurrences, potentially limiting the accuracy of distribution modeling. The exceptionally high number of sightings highlights a major establishment phase of *P. miles* in the eastern Adriatic, particularly along the Croatian coast; an event that can justifiably be described as a rapid and extensive invasion, considering the low number of recorded individuals in the Adriatic waters until 2024 (Dulčić *et al*., 2024; Bakiu *et al*., 2024).

The majority of lionfish sightings occurred during diving activities, with only three records resulting from fishing activities using passive gears. This disparity is likely due to the lionfish's preference for habitats such as rocky and structured substrates with overhangs and crevices (Fishelson, 1975; Samourdani *et al*., 2024), which make it difficult to set such gears, reducing fishing efforts in these areas. The main observational method, i.e., direct observations through diving, also influenced the temporal pattern of records, with the majority of sightings occurring during the warmer months, most likely due to increased diving activity during this period compared to other times of the year, particularly the winter months. Furthermore, most sightings in our study occurred within the first 15 meters of depth, with the number of sightings decreasing at greater depths. This is in contrast with a study by Kleitou *et al*. (2024), who reported that lionfish densities increased with depth in certain areas of the Mediterranean, likely due to reduced human exploitation in deeper waters, as spearfishing and targeted removals are more effective in shallower areas. In our case, this trend may indicate an early stage of establishment, where the species has not yet become a primary target for fishery removals at shallower depths. However, the pattern may also be biased by the observation methods used. Namely, recreational diving and spearfishing are primarily conducted at shallower depths, increasing the likelihood of encountering lionfish in such areas. In this regard, it is important to note that fisheries monitoring conducted as part of the EU's Data Collection Framework (DCF), carried out by the Institute of Oceanography and Fisheries in Croatia, which covers all major commercial fishing métiers along the Croatian coast, did not record a single individual of common lionfish in fishermen's catches throughout 2024 including all previous years (IOF, unpublished data).

Our results did not show a correlation between *P. miles* size and depth, which may be attributed to the species' recent expansion and settlement. At this early stage of colonization, populations are often dominated by smaller individuals or those of similar size, making it too soon to observe a more balanced length distribution that includes older and larger specimens. A similar lack of correlation between depth and length was found in the invasive congener *P. volitans* in the Northern Gulf of Mexico (Fogg *et al*., 2013). However, Ewing *et al*. (2025) detected a significant trend of larger *P. volitans* occurring with increasing depth in the Caribbean region, although the mentioned study included a much larger range of depths (greater than 150 m). Furthermore, Savva *et al*. (2020) reported that the *P. miles* population in Cypriot waters was primarily composed of individuals in the 20-25 cm size range, presumably being about 1.5 to 2.5 years old, while Kondylatos *et al*. (2024) recorded dominant size class of about 25 cm, corresponding to fishes in the third year of life in the Aegean Sea. In the present study, the dominant size class was estimated to be under 15 cm, likely representing individuals within their first year of life. This aligns with findings from Savva *et al*. (2020), who reported that *P. miles* individuals reach approximately 16.3 cm by the end of their first year and Kondylatos *et al*. (2024), who recorded a mean total length of about 18 cm for age group 1. Therefore, it can be presumed that the majority of individuals observed in this study settled in the area within a year before the study period. However, as in the previous case, data may still be biased due to observational methods. In particular, bias in underwater size estimations by divers is a well-documented phenomenon, with a tendency to underestimate the sizes of smaller fish (Edgar et al., 2004). Furthermore, the range of depths at which individuals were observed may be too narrow to reveal size-related trends. All mentioned, including the relatively small sample size, particularly for individuals recorded at greater depths, limit potential conclusions on this matter.

The predominance of smaller and younger individuals may indicate an important factor driving the expansion of lionfish along the Croatian coast. A regression analysis of latitude *vs.* time of sighting showed no significant trend, suggesting that settlement likely occurred before the period of observations rather than as a result of northward expansion during this period. This points to propagule transport (*via* eggs and larvae) and subsequent settlement before the observational period as the dominant mechanism driving the species' expansion. Therefore, larval transport driven by ocean currents from southern regions where spawning takes place is likely a key factor contributing to this rapid and widespread expansion in the Adriatic. Ahrenholz and Morris (2010) found that larvae of *P. volitans* remain pelagic on average for 26 days, which is sufficient for long-distance dispersal and invasion, even across areas with low connectivity, such as the Straits of Florida (Freshwater *et al*., 2009). Schilling *et al*. (2024) provided support for the hypothesis that the expansion of *P. miles* in the Mediterranean is primarily driven by passive dispersal through ocean currents, as the observed distribution patterns of this species in the invaded range aligned with the predicted pathways of current-driven expansion. Similarly, Johnston and Purkis (2011) concluded that ocean currents play a major role in lionfish larval dispersal in the Caribbean, with rapid colonization driven by major currents like the Gulf Stream and Loop Current. In the case of the eastern Adriatic, the hypothesis of primarily larval transport as the dominant process for recent expansion can also be supported by the distributional pattern of lionfish sightings, with higher number of sightings found around islands, particularly Lastovo and Vis, and exposed southern shores influenced by open-sea currents, a pattern which aligns with surface circulation of eastern Adritic current (EAC) (see Lipizer *et al*., 2014). In contrast, channel areas (those between islands and the coast) show lower invasion rates, suggesting that recent settlement was more strongly influenced by general open-sea circulation rather than by local hydrodynamic processes as water exchange between the semi-enclosed basins along the eastern coast and the open sea is mainly governed by local forcings, particularly wind regimes (Orlić *et al*., 1992). Mostowy *et al*. (2020) found that *P. volitans* larval densities in the Western Atlantic were significantly higher at depths of 20-30 m compared to other sampled depths, suggesting that larvae could be less prevalent in deeper intermediate layers. Therefore, surface Levantine waters ingressing through the eastern coast could serve as a potential vector, particularly given their connection to the Adriatic-Ionian Bimodal Oscillating System (BiOS), which is known to periodically influence Adriatic biodiversity and can facilitate the arrival of Lessepsian species (Orlić *et al*., 1992; Civitarese *et al*., 2023). The interplay and influence of specific currents on the appearance patterns of non-indigenous species along the eastern Adriatic coast require further study in the future, as they may be crucial to understanding some of the distribution patterns of such species. Also, possible source populations where spawning takes place, could be located through backward tracing in the future (Džoić *et al*., 2017).

Although less likely, the observed pattern of occurrence could indeed be biased due to diving activities being more concentrated in areas that appear to be hot spots in the current study, increasing the likelihood of encounters. However, taking into account that areas along the mainland are more densely populated than islands, and therefore a high number of diving activities, particularly those involving spearfishing, can still be expected. Hence, the observed pattern may still reflect actual distribution trends, even though accounting for bias in the current analysis was not possible.

Despite the indirect nature of observations of this invasive species, i.e., data collected through means such as direct reports by citizens and social and news media scanning, all falling under the umbrella of citizen science, this approach has already proven to be a convenient and effective method for various biodiversity studies. For example, Tiralongo *et al*. (2020) provided a significant update on ichthyofaunal changes in Italian seas using similar methodology and Giovos *et al*. (2019) demonstrated that large-scale citizen science programs can substantially contribute to monitoring of biological invasions on the example of Greek waters. Likewise, Al Mabruk *et al*. (2021) effectively utilized social media and citizen science to compensate for the lack of field studies, notably by detecting new fish species in Egyptian waters. Finally, Phillips and Kotrschal (2021) demonstrated that citizen science initiatives, particularly those involving divers affiliated with diving centers, can aid in tracking the spread of *Pterois miles* across the Mediterranean region. However, in contrast to some of the aforementioned studies, where data collection relied on organized efforts conducted through comprehensive citizen science campaigns, our data do not originate from a structured initiative or large-scale campaign. Instead, they are mainly opportunistic in nature, with a portion of the records obtained through online searches and the monitoring of social media groups and news portals, and as such hold inherent biases that hamper drawing robust conclusions.

Unfortunately, a proliferation of *P. miles* in highly structured coastal habitats along the Croatian coast is alarming, as such habitats host a plethora of ecologically and economically important fish species that can experience increased competition as well as predation by this invasive species as similarly evidenced in lionfish species in western Atlantic region (Albins and Hixon, 2013). In the Mediterranean, the primary prey fish species appears to be damselfish *Chromis chromis*, along with other species associated with rocky habitats, including those from the Scorpaenidae, Blennidae, Gobiidae, and Labridae families, as well as various crustaceans (Zannaki *et al*., 2019; D'Agostino *et al*., 2020; Koilakos *et al*., 2024). In this context, some steps will need to be undertaken to mitigate the effects of the invasion in the Adriatic Sea.

Ulman *et al*. (2022) reviewed successful and unsuccessful approaches aimed at lionfish control in the Western Atlantic and provided a set of do's and don'ts to be implemented in the Mediterranean based on the outcomes of these approaches. Successful strategies included targeted removals through lionfish hunting tourism, controlled scuba with pole spear initiatives, recreational removal tournaments, participatory management, promotion of commercialization, and regional collaborative efforts. These strategies proved effective in contrast to approaches relying on bounty programs or attempts to train native predators to feed on lionfish. In the case of Croatia, given the complexity of its coastline and the numerous islands providing abundance of suitable habitats for this species, an approach involving targeted removals should be carefully planned, particularly in areas of high conservation or ecological importance, such as Marine Protected Areas (MPAs). These areas could benefit from population control measures, not only to preserve local biodiversity but also because, if left unmanaged, they could serve as sanctuaries for the species, potentially acting as stepping stones or source populations that facilitate further spread into other regions (Kleitou *et al*., 2024). Additionally, given the species' potential as a high-quality food fish, its consumption should be further encouraged, along with targeted fishery-related potential, accompanied by increased awareness regarding potential health risks associated with its venomous nature. It has been shown that integrating lionfish as a target species in commercial fisheries, could address several issues, such as providing an additional source of income for fishers, reducing pressure on wild fish stocks, but also help in educating the general public on the issues connected with invasive species in general (Chapman *et al*., 2016; Yandle *et al*., 2022). However, it remains to be seen how extensively this species will interact with fisheries along the Adriatic coast, particularly considering the highly structured habitat utilized by this species and the very low number of specimens captured by professional fishermen in this study. Finally, we strongly emphasize that reduction of fishing pressure on its natural predators, primarily groupers and common octopus (Crocetta *et al*., 2021; Bottacini *et al*., 2024), could also serve as an effective strategy to mitigate the potential ecological impacts of *P. miles*.

CONCLUSION

The expansion of *Pterois miles* can be considered the first large-scale establishment of a non-indigenous fish species in the entire Adriatic Sea. While other Lessepsian fish species such as *Siganus luridus*, *Fistularia commersonii*, *Bregmaceros nectabanus*, and *Lagocephalus sceleratus* have been recorded multiple times, with some potentially regarded as established (Dulčić and Dragičević, 2023), none have exhibited such a rapid and extensive „outbreak", nor have they been documented in such large numbers within such a short time frame. It is to be seen how the species will cope with Adriatic ecosystem and especially if it can reach and establish its population in its northern sector where winter temperatures reach below 10 °C, which is determined to be a chronic lethal temperature for this species (Kimball *et al*., 2004; Russo *et al*., 2012). However, given the warming trends and possibility of climatic niche expansion of the species, it is quite possible *P. miles* will become a permanent inhabitant of the Adriatic Sea (Côté and Smith 2018; Grbec *et al*. 2018).

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AUTHOR CONTRIBUTIONS

B.D.: Data collection; Data curation; Data analysis; Conceptualization; Writing - original draft; Writing - editing. P.U.: Data collection; Data curation; Conceptualization; Writing - editing.

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