



# Spatiotemporal patterns of public attention to invasive species across an invasion front: a case study of lionfish (*Pterois miles*) from the Mediterranean Sea

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**Abstract** Understanding societal interest in invasive species is crucial as greater public attention can support the success of conservation efforts. One of the main challenges in monitoring societal interest to support conservation is the absence of near-real-time indicators to track large-scale spatiotemporal dynamics of public attention. However, the digital revolution has opened up new opportunities to develop such indicators in support of invasive species research and management. Here, we aim to evaluate public

awareness and interest in the invasive lionfish (*Pterois miles*) in the Mediterranean Sea and investigate spatiotemporal patterns of public interest in the species along its invasion front by using Google search volumes as a proxy for public attention. We implemented topic searches for the lionfish to download Google search volumes from 2013 to 2022 and used these data to test two hypotheses: (1) countries experiencing lionfish invasion exhibit higher public attention than those without lionfish, and (2) in invaded countries, public attention peaks around the arrival year, followed by a decline to baseline levels. Our study confirmed the first hypothesis, showing higher public

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attention in invaded countries. However, temporal patterns of attention did not fully align with the year of lionfish arrival, suggesting that the socio-political complexity of the region (e.g., cultural trends or internet accessibility), may be a key aspect to consider in future studies. Overall our study shows that digital data sources provide a unique opportunity to monitor social aspects of biological invasions with low associated costs and quick access to a great amount of data generated by internet users.

**Keywords** Conservation culturomics · Environmental monitoring · Public engagement · Human dimensions · Digital data

## Introduction

Invasive species (IS) not only have ecological and economic impacts but also elicit varied societal responses (Jubase et al. 2021). While scientists and conservation practitioners often advocate for the eradication or management of IS, public perceptions can significantly differ based on the characteristics of the species (Shackleton et al. 2019; Jarić et al. 2020b). For instance, recreational fishers might view certain invasive species positively if they exhibit traits desirable for fishing, such as strength, aggressiveness, or size (Shackleton et al. 2019; Sbragaglia et al. 2022). Understanding these varied perceptions is essential to address the challenges posed by IS and develop successful conservation and management strategies that resonate with different stakeholders (Kleespies et al., 2024)

The study of social dimensions of biological invasions is still lagging behind research on biological and ecological factors, with numerous research gaps remaining (Vaz et al. 2017; Shackleton et al. 2020). Lower uptake of social sciences and humanities in invasion science is partly because the field emerged originally from ecology (Vaz et al. 2017), but also because sociocultural aspects of biological invasions are inherently complex, context-dependent, and challenging to study (Pfeiffer and Voeks 2008; Pejchar and Mooney 2009). Nevertheless, the research on public perceptions of IS has been recently growing, with numerous studies over the past decade evaluating public views on various invasive species such as cats, *Felix catus*, and wild pigs, *Sus scrofa*

(e.g., Bassett et al. 2020; McLean et al. 2021). This expanding body of work highlights the complexity and variability of societal responses to IS and underscores the need for new methods and further research (Verbrugge et al. 2013).

In an increasingly digital society, recent years have witnessed a wider recognition of the importance of digital data and their potential for understanding public perceptions and attitudes towards ecological issues (Correia et al. 2021). The vast amount of digital information passively generated by people represents a unique opportunity to gain insights in human preferences and behaviour related to nature. By utilising emerging research approaches such as conservation culturomics (Ladle et al. 2016) and iEcology (Jarić et al. 2020c), which respectively leverage online data to study human-nature interactions and ecological questions, researchers can mine online engagement and information-seeking indices to extract valuable information with low sampling costs and minimal time requirements (Jarić et al. 2020c). This approach can serve as a proxy for public interest, particularly in the marine environment where public perception of IS remains largely unexplored (Jarić et al. 2020c), allowing to understand drivers of public attention across both spatial and temporal dimensions. Furthermore, this approach has already been used (Jarić et al. 2021) and offer promising methods for monitoring and studying invasions, as well as understanding societal attitudes and interactions with IS.

Public attention to IS is likely to be driven by the species spatial distribution and physical presence in a given place. In fact, the heterogeneous distribution of IS can lead to differing levels of public exposure to IS, and in turn to different observations and experiences, which may lead to contrasting spatial patterns of public interest (Proulx et al. 2014). For example, Fukano and Soga (2019) found that the relative Google search volume for the invasive signal crayfish *Pacifastacus leniusculus* was significantly higher in Japanese prefectures invaded by the species compared to those that were not invaded. The variation of public attention over time can also provide valuable information for management efforts. As information spreads faster due to advancing communication technologies, public attention may decay quickly, in a range between days to weeks, due to the accelerating and fragmenting public discussion (Lorenz-Spreen

et al. 2019). Public attention transience could therefore be a remarkable issue in conservation (Jarić et al. 2023). Interest in a given topic can decrease as time passes, exacerbating the difficulty of supporting conservation goals and actions (Protess and McCombs 2016). It is particularly manifested during focusing events, i.e., sudden events of exceptionally high public attention concentrated on specific issues (Birkland 1998), such as environmental disasters or morally questionable behaviours. The perceived importance of such problems may determine whether they are included in political agendas (Pralle 2009). Such brief periods of high attention are prime occasions for conservation actions and advocacy, and can be used to maximize conservation efforts (Males and Van Aelst 2021).

Understanding spatiotemporal patterns of public attention to IS can be extremely challenging in complex geopolitical contexts such as the Mediterranean Sea, a semi-enclosed basin connecting three continents and over 20 countries with contrasting ecological and socioeconomic conditions. While the great diversity in terms of politics, culture, and laws constitute a richness for society, it also poses a challenge for marine conservation efforts (Katsanevakis et al. 2015). In this context, the north-westward invasion of lionfish (*Pterois miles*, Bennett, 1828) in the Mediterranean Sea offers a unique opportunity to explore the spatiotemporal patterns of public attention to IS possibly identified by emerging data sources, for example Google search volumes. This species has already invaded tropical and subtropical habitats in the western Atlantic area (Albins and Hixon 2008), and has more recently begun its invasion of the Mediterranean Sea. Entering through the Suez Canal, lionfish has rapidly expanded its range, causing considerable ecological disruptions and socio-economic consequences (Vallès et al. 2023; Whitfield et al. 2002), threatening the resilience of the ecosystems. The species is ranked by European Union Regulation (EU) 1143/2014 on IS as the second of 95 most damaging invasive species, representing a very high risk of threat to biodiversity and associated ecosystem services (Roy et al. 2015).

Here, we explored public attention to lionfish across the Mediterranean Sea with the overarching goal of understanding how the presence and timing of an IS arrival influence societal interest. Bearing in mind that (1) the spatial distribution

of IS can influence public attention, leading to variations in interest across invaded and non-invaded regions (Proulx et al. 2014), and that (2) public attention usually decreases as an event becomes less newsworthy (Jarić et al. 2023), we tested two hypotheses in the present study. First, countries experiencing lionfish invasion are expected to exhibit higher public attention compared to those countries where lionfish has yet to arrive. Second, based on public attention transience (Jarić et al. 2023), public attention is expected to peak around the year of arrival in countries where the lionfish already invaded and then decay, returning to baseline levels.

## Materials and methods

### Review of lionfish invasion in the Mediterranean Sea

In order to obtain an up-to-date distribution map of lionfish in the Mediterranean Sea, we downloaded the occurrences of the species from different sources. We started by collecting occurrences of the species from one of the most comprehensive online information systems on species distributions, the Global Biodiversity Information Facility (GBIF; <https://www.gbif.org>; DOI of the query: <https://doi.org/https://doi.org/10.15468/dl.a5hpz7>). Furthermore, we downloaded occurrences from the database Occurrence Records of Mediterranean Exotic Fishes (ORMEF; <https://ormef.eu>). We integrated occurrences that were not present on GBIF and ORMEF with reported lionfish sightings in literature published by Kleitou et al. (2021), and added relevant recent records published in peer-reviewed journals (Dragičević et al. 2021; Di Martino and Stancanelli 2021). To elucidate the spatial process of public interest towards lionfish, we divided the 21 Mediterranean countries according to the presence of lionfish (hereinafter “Present” or “Absent”) based on the above-mentioned recorded occurrences.

### Google search volumes

We downloaded Google search volumes for lionfish for the period from 1st of January 2013 to 31st of December 2022 for all 21 Mediterranean countries, at a weekly frequency. Moreover, in order to control for possible confounding effects on Google search

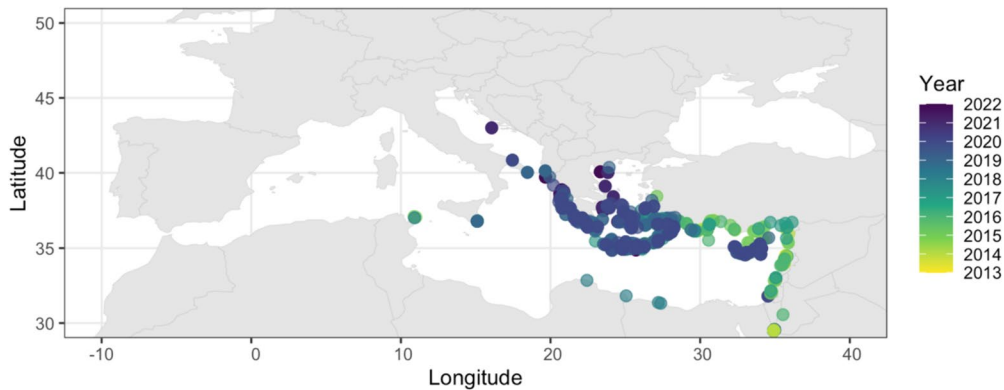
volumes of general trends in public attention to fish species, we selected nine other fish species that are native to the Mediterranean Sea and represent species of commercial and recreational interest, as well as emblematic species for conservation: gilthead bream (*Sparus aurata*), the Mediterranean rainbow wrasse (*Coris julis*), the European seabass (*Dicentrarchus labrax*), the white seabream (*Diplodus sargus*), the saddled seabream (*Oblada melanura*), the salemma (*Sarpa salpa*), the European sardine (*Sardina pilchardus*), the European hake (*Merluccius merluccius*), and the dusky grouper (*Epinephelus marginatus*).

Google search volumes were obtained using a topic search in Google Health Trends API, which represents automatically generated groups of related terms that share the same concept across languages based on their representation in Google's Knowledge Graph (Cooper et al. 2019). Topic searches in Google Trends provide combined results for all terms related to the topic of interest across languages, for both vernacular and scientific species names and their synonyms, as well as for searches where the terms were misspelled (Cooper et al. 2019; Britton et al. 2023; de Oliveira Caetano et al. 2023). At the same time, topic searches differentiate between homonyms (e.g., species name such as lion and the brand names that contain it; de Oliveira Caetano et al. 2023). Data were obtained using the Google Health Trends API (API Application Program Interface) and a dedicated Python library (google-api-python-client; [<https://pypi.org/project/google-api-python-client/>]; see Vardi et al. 2021). Data obtained are manipulated numbers representing search volumes calculated based on a sample (10–15%) of all searches (Green et al. 2018). While not indicating actual number of searches (Google policies), the search volumes retrieved are calculated relative to all searches made in the sampled region during the considered period and are comparable across time and countries (<https://tinyurl.com/2nxaky32>). Furthermore, to protect users' privacy, Google generates search volumes for terms searched more than a minimum threshold. Thus, zeros in our datasets may not represent a complete lack of interest, just too low to detect.

## Data treatment and statistical approach

Concerning the weekly Google search volumes, given the great number of zeros in the dataset, we aggregated the data per year by summing the weekly values to obtain the yearly Google search volumes for each country. This approach is justified because the Google Trends data is scaled and normalised to account for all searches made in the specific country at the given time, making the data comparable across many topics. Summing these values provides an aggregate measure of public interest over the year, which is suitable for our analysis of long-term trends. Given the non-normal distribution of the data, we used a two-sample Mann–Whitney U-Test to compare Google search volumes for countries where the species is considered either present or absent, and a Vargha and Delaney A measure to estimate the effect sizes (Vargha and Delaney 2000). Furthermore, in order to control for possible confounding effects on Google search volumes from general trends in public attention to fish species, we tested the relationship between Google search volumes for lionfish and the mean Google search volumes for the nine control species by using Kendall Rank correlation coefficient (with a confidence interval of 95%). An absence of correlation of Google search volumes between lionfish and the control would suggest a real interest in lionfish rather than a general interest in fish species.

We inspected the temporal trends of Google search volumes (Fig. 4) within each country to investigate temporal peaks of public attention and changes in the time series with respect to the arrival of the lionfish in the country (i.e., peaks of Google search volumes and their possible lags in relation to the arrival of the lionfish). In particular, we focused on assessing whether the maximum peak of Google search volumes occurred after the arrival of lionfish, in line with our second hypothesis. However, it is plausible that other scenarios could take place, such as that the maximum peak of Google search volumes occurred before the arrival of the lionfish, or that the peak of Google search volume occurred even if the lionfish has not arrived in a certain country. Furthermore, we assessed the lags between the arrival of the lionfish and the recorded maximum peak of Google search volumes. All analyses were run in R (version 4.2.0).



**Fig. 1** Map of the occurrences of lionfish in the Mediterranean Sea over the period 2013–2022. Each dot represents an occurrence ( $N=1301$ ), while the colour represents the year of

occurrence. Data were obtained via GBIF, ORMEF, and peer-reviewed journals (see methods for more details)

## Results

We obtained 1301 officially recorded lionfish

observations in the Mediterranean Sea between 2013 and 2022 (80% from Kleitou et al., 19% from GBIF and ORMEF and 1% from other peer-reviewed

**Table 1** Mediterranean countries in which the arrival of lionfish has been documented, together with the year of arrival and the associated reference

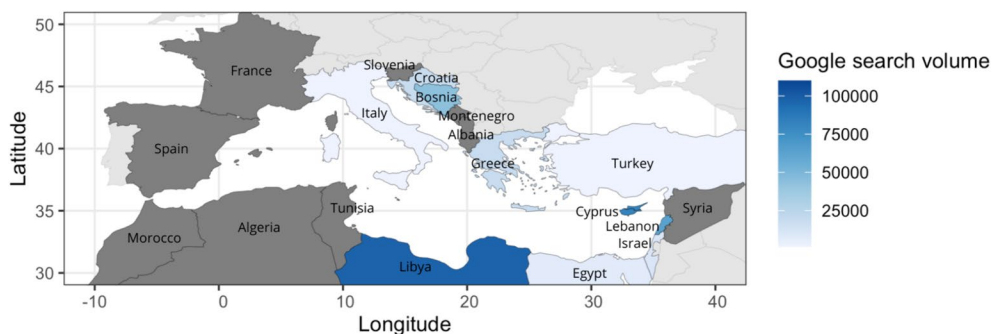
Country	Status	Year	Reference	Google search volumes		
				Min. (year)	Max. (year)	Total volume (sum)
Albania	Present	2019	Di Martino and Stancanelli (2021)	–	–	Insufficient
Algeria	Absent	–	Kleitou et al. (2022)	–	–	Insufficient
Malta	Absent	–	–	–	–	Insufficient
France	Absent	–	–	–	–	Insufficient
Monaco	Absent	–	–	–	–	Insufficient
Montenegro	Absent	–	–	–	–	Insufficient
Morocco	Absent	–	–	–	–	Insufficient
Slovenia	Absent	–	–	–	–	Insufficient
Spain	Absent	–	–	–	–	Insufficient
Syria	Present	2013	ORMEF	–	–	Insufficient
Tunisia	Present	2015	Dailianis et al. (2016)	–	–	Insufficient
Turkey	Present	2014	Turan et al. (2014)	92 (2022)	189 (2019)	1317
Italy	Present	2016	Azzurro et al. (2017)	73 (2014)	207 (2017)	1366
Egypt	Present	2016	ORMEF	517 (2022)	1127 (2017)	7270
Israel	Present	1991	Golani and Sonin (1992)	809 (2014)	1538 (2021)	10,732
Croatia	Present	2021	Dragičević et al. (2021)	544 (2020)	3409 (2016)	18,156
Greece	Present	2015	Crocetta et al. (2015)	911 (2013)	3591 (2019)	18,574
Bosnia and Herzegovina	Absent	–	Kleitou et al. (2022)	2153 (2013)	6242 (2018)	43,468
Lebanon	Present	2012	Bariche et al. (2013)	5064 (2022)	8978 (2019)	63,643
Cyprus	Present	2013	Oray et al. (2015)	4688 (2021)	12,643 (2020)	82,001
Libya	Present	2018	Al Mabruk and Rizgalla (2019)	4787 (2021)	19,704 (2013)	97,551

The year of the maximum and minimum Google search volumes is reported for each country together with the total volume (2013–2022)

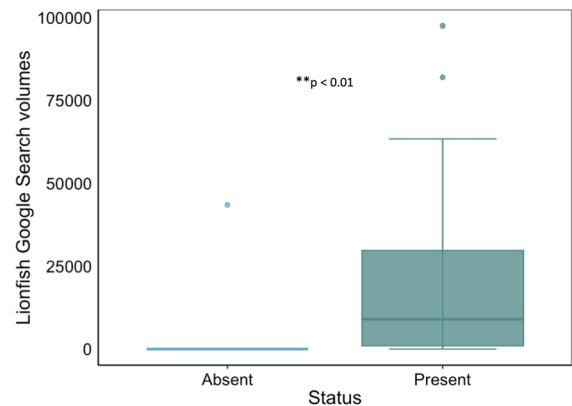
journals; Fig. 1). The lionfish distribution range changed over time, with the species increasingly spreading north-westward. By 2022 it was already recorded in 9 out of 21 Mediterranean countries (Table 1, Fig. 1).

### Google search volumes

We managed to obtain Google search volumes from 10 countries (Table 1), while 11 countries recorded no search volume, meaning searches for the species were either absent or too few to be recorded. The highest cumulative lionfish Google search volumes (2013–2022) were in Libya (97,551), followed by Cyprus (82,001) and Lebanon (63,643; Table 1, Fig. 2). Among the countries that showed values higher than zero, we recorded the lowest cumulative lionfish Google search volumes in Turkey (189) and Italy (207; Table 1, Fig. 2). Countries where, according to our review of the literature, the lionfish was not yet present and showed insufficient data included Montenegro, Slovenia, France, Malta, Monaco, Spain, Morocco and Algeria (Table 1, Fig. 2). Bosnia and Herzegovina had intermediate Google search volumes despite having no records of lionfish presence. Finally, Albania, Tunisia and Syria showed insufficient Google searches even though the presence of the species in these countries is confirmed (Table 1, Fig. 2). Google search volumes were significantly higher ( $p < 0.01$ ,  $A = 0.80$ ) in countries where lionfish has already arrived, compared to countries in which it has not been detected yet (Fig. 3). Furthermore, Google search volumes for lionfish and the control



**Fig. 2** Cumulative Google search volumes for lionfish in Mediterranean countries from 2013 to 2022. Google search volumes are indicated in the legend, from the lowest (light blue;



**Fig. 3** Boxplot of lionfish Google search volumes from 2013–2022 for countries in which the species is present or absent (see Table 1). The outliers in the Present category correspond to searches in Cyprus and Libya, while the one in the Absent category corresponds to searches in Bosnia and Herzegovina. The box ranges from Q1 (the first quartile) to Q3 (the third quartile). The median is represented by the line across the box. The whiskers extend from Q1 and Q3 to the most extreme data points

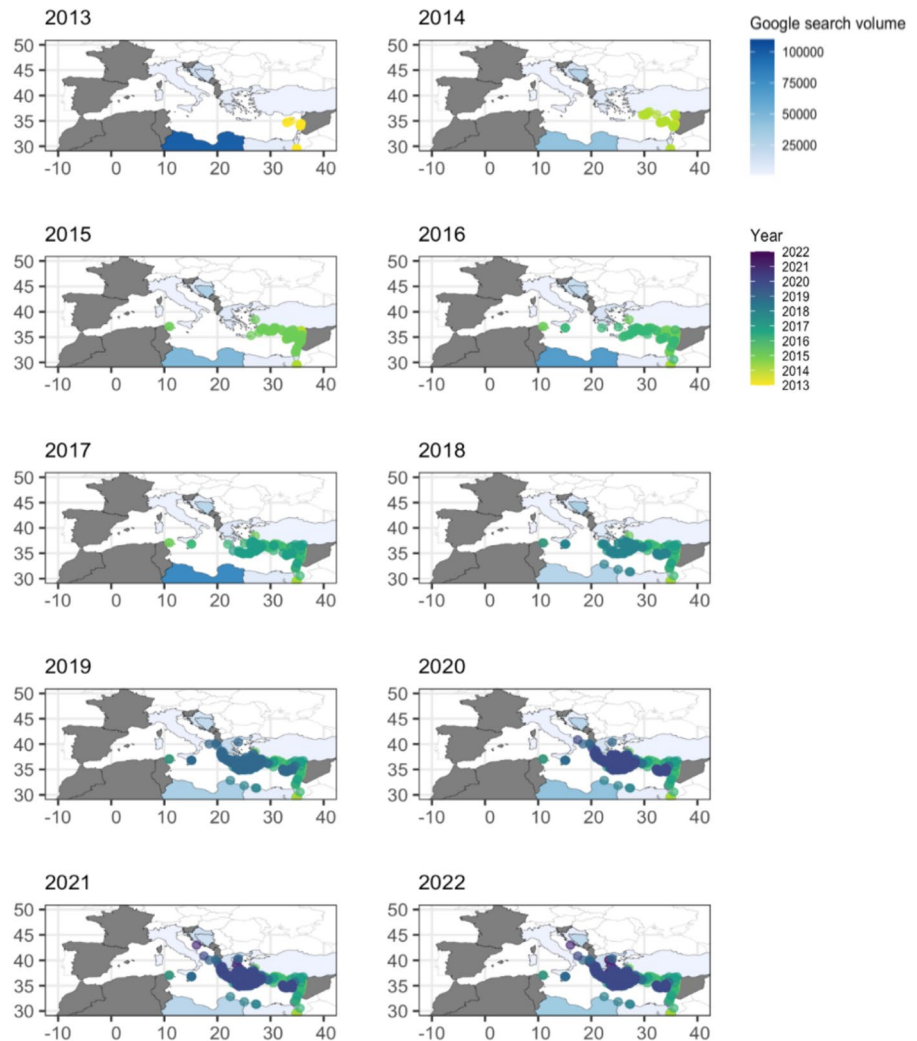
group were not correlated (Supplementary material, Figure S1).

### Temporal patterns of public attention

Google search volumes and the collected occurrences showed different trends over the years (Fig. 4). For example, Google searches for Libya decreased from 19,704 searches in 2013 to 7003 searches in 2022, while Greece displayed an increase from 910 in 2013 to 2800 in 2022, with a peak in 2019. There was therefore a lack of a clear

Turkey=1317) to the highest (dark blue; Libya=97,551). Countries in dark grey had insufficient Google search volumes for the selected period

**Fig. 4** Google search volumes across Mediterranean countries, for each year from 2013 to 2022. Values range from 1 (light blue) to 30,000 (dark blue). Countries in dark grey had insufficient Google search volumes. Each dot represents an occurrence (N = 1301), while the colour represents the year of occurrence. Data were obtained via GBIF, ORMEF, and peer-reviewed journals



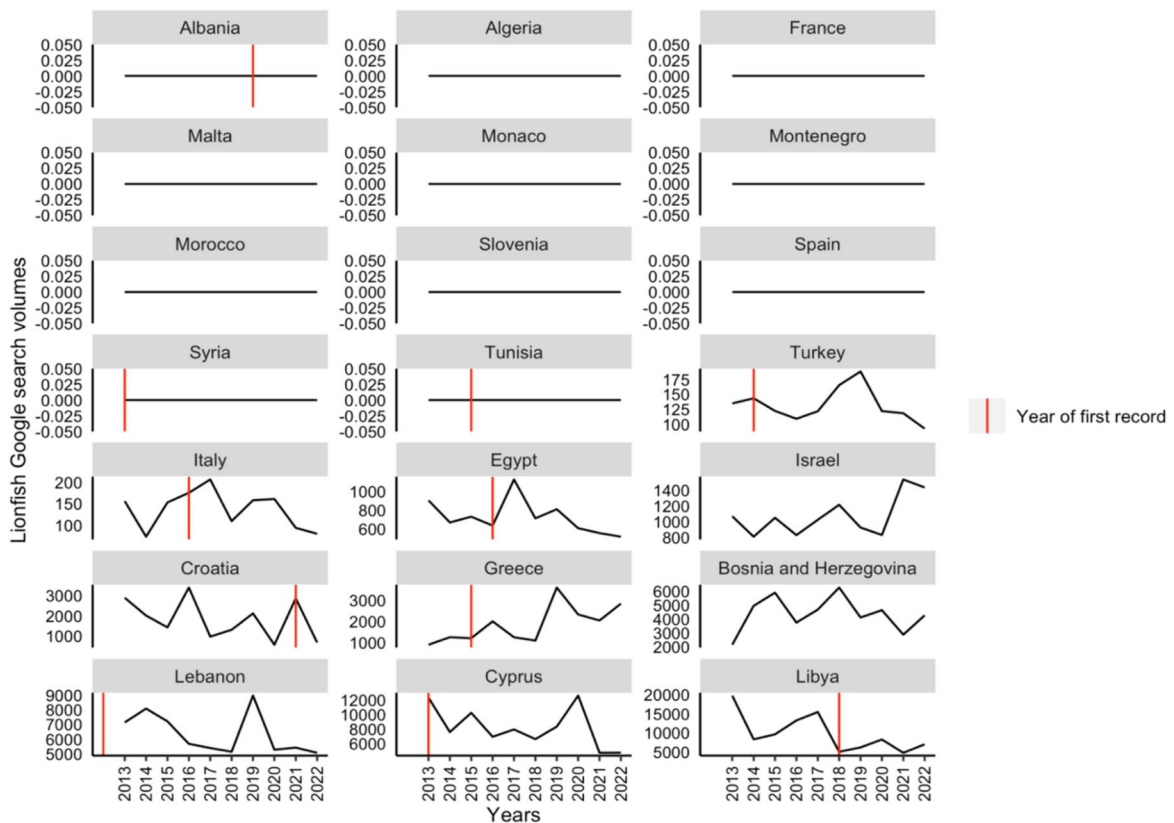
overall increasing or diminishing tendency in public's interest as manifested in Google search volumes across the Mediterranean Sea. Public attention declined after a peak in interest in Egypt and Italy, with time lags of one year after the species arrival (Fig. 5). Greece also showed a similar trend but the peak in interest in the year after the lionfish invasion (2016) was not the highest peak recorded in the country (2019, Table 1).

We noticed three different scenarios for other countries that did not follow our hypothesised relationship. The first is represented by Libya, where the peak of attention (2013) occurred five years prior to the documented arrival of lionfish in the country (2018). Another case is represented by Bosnia and Herzegovina, which showed Google search volume

dynamics despite having no recorded presence of the species (Figs. 4, 5). By contrast, Albania, Tunisia and Syria did not display Google search volume despite the species presence in those countries. Furthermore, Google search volumes for lionfish and the control group were not correlated for any of the countries except Libya (Kendall's rank-order correlation coefficient values for the same countries are shown in Table 2; Appendix, Figure S2).

## Discussion

The first hypothesis was confirmed, as our results showed significantly higher Google search volumes in the majority of countries where lionfish



**Fig. 5** Google search volumes for lionfish over time, from 2013 to 2022, in all Mediterranean countries. Note that the Y axes are in different scales, based on the search volumes of each country. The red line represents the year of first record of the lionfish in the country, when available. The year of

first record in Israel, 1991, is not presented as it is outside the selected time range. Countries are ordered based on Google search volumes, from the lowest (Albania) to the highest (Libya)

were already present. On the other hand, the second hypothesis was confirmed only in Egypt and Italy, where public interest showed a clear peak followed by a decline within a year of the lionfish arrival. Our results align with the concept that the spatial distribution of invasive species can influence public interest, leading to variations in attention across invaded and non-invaded regions. For instance, Fukano and Soga (2019) showed how the presence of 31 major IS species (e.g., *Procyon lotor*, *Vespa velutina*, and *Chelydra serpentina*) was positively correlated with Google search volumes across Japan, and that public attention spatially overlapped with actual distribution of those species. Similar results were also reported by Proulx et al. (2014), who showed that spatial distribution of Google search volumes for five invasive species in the United States reflected their respective areas of origin

and dispersion range. Likewise, Schuetz and Johnston (2019) observed strong spatial overlap between the relative popularity of different birds based on Google searches for 621 bird species and their true distribution across the United States. These studies showcase the potential of using internet search volumes as indicators of public attention towards IS. In case of the lionfish invasion in the Mediterranean Sea, these data sources can be used to advise management planning about the level of public attention and awareness about the species and its spread. Furthermore, these data sources can serve as a proxy to monitor lionfish presence in countries not yet affected by its invasion as an early warning tool (Schuetz et al. 2014). For example, Sbragaglia et al. (2023) found that both local ecological knowledge and social media posts effectively tracked the long-term distributional range

**Table 2** Correlation values between lionfish Google search volumes and the control Google search volumes (calculated as the mean of the nine selected fish species)

Country	<i>p</i> -value	$r_{\tau}$	Correlation
Turkey	0.60	-0.15	No
Italy	0.60	0.15	No
Egypt	0.60	0.15	No
Israel	0.38	0.25	No
Croatia	0.38	-0.24	No
Greece	0.11	0.42	No
Bosnia and Herzegovina	0.60	-0.15	No
Lebanon	0.73	0.11	No
Cyprus	0.60	0.15	No
Libya	0.02	0.60	Yes

Correlation values are calculated through Kendall's rank-order correlation coefficient, with a 95% confidence interval. Tau's coefficient ( $r_{\tau}$ ) returns 1 or -1 for maximum positive or negative correlation and 0 to show minimum correlation. Countries are displayed in Google search volumes order, from the lowest to the highest

shift of the white grouper *Epinephelus aeneus*. Such potential monitoring is of utmost importance, especially in the context of the Mediterranean Sea where, despite experts' recommendations, lionfish has not yet been included in the European Regulation on IS (EU Regulation no. 1143/2014). Such monitoring programs should be especially established in areas predicted to experience the invasion in the upcoming years, such as Algeria (Kleitou et al. 2022).

Temporal patterns of interest were diverse, showing different trends in both invaded and not-invaded countries. Egypt, Italy and Greece showed peaks of Google search volumes during the year after the arrival of the species in the country, although in Greece the peak was not the highest within the time series explored. The observed one-year time-lag between the arrival and the peak of public attention might be due to media and oral spread of news about the species at the local level (e.g. among fishers and their societies). In fact, first records may demand a certain amount of time to be officially recorded, and dissemination of specific events by the media could have had an influence on Google search volumes. For example, in Italy the news of the arrival of lionfish in 2017 was immediately covered by one of the major newspapers (Redazione Repubblica 2017), which may have contributed to raise public attention about

the event. Egypt represents a peculiar case because of its location, with the Red Sea to the east and the Mediterranean Sea to the north. The presence of two different seas means that lionfish is a native species in one part of the country while it is an IS in the other. This difference in the regulations might have contributed to polarized discussion and the major peak in public attention in 2017, after the arrival of the species in the Mediterranean in the 2016. Whilst peer-reviewed literature on the management strategy for lionfish in Egypt is scarce, it is possible to make a comparison with Israel, where lionfish are both native and invasive at the Red and Mediterranean seas respectively. Since lionfish is native to the Red Sea it is treated as a protected species under the Israeli law, making it illegal to fish or trade the species (Galil et al. 2021). These regulations represent a barrier to the management actions in the Mediterranean Sea, and are regularly discussed by competent authorities (Stern et al. 2019). The periodic discussion might also explain the recurrent peaks of interest observed in Israel, potentially indicating recurrent debates around the question, boosting societal attention. However, it was impossible to study the effects of the species arrival on public attention in Israel, because the lionfish arrived in the Mediterranean in 1991 and Google search volumes are not available for that period.

There were several countries in which we did not find a peak in attention following the invasion of lionfish to the country. These countries can be divided into three major categories according to their deviation from the prediction: (1) countries where the major peak of attention appeared before the arrival of the lionfish. This is the case for Libya, where the attention peak was observed five years before the arrival of lionfish there. Further research is needed to understand such results. Interestingly, Libya was the only country displaying a significant positive correlation between Google search volumes for lionfish and the control group (Supplementary material, Figure S2). Therefore, it is possible that the public attention directed at lionfish was confounded by the general attention towards fishes in this country. (2) Countries with detectable Google search volumes despite the absence of lionfish, as is the case in Bosnia and Herzegovina. One possible interpretation is that the species has most probably occurred in Bosnian waters, given the fact it has been registered

in both the North and South borders of its coastline, but has not been officially recorded. In this case, Google search volumes could represent early warning about the presence of the species. (3) Countries with no observed public attention on Google despite the presence of the lionfish. This is the case in Albania, Tunisia, and Syria, where the species was recorded in 2019, 2015 and 2013, respectively. In Albania, the first peer-reviewed paper recording the arrival of the lionfish was published in 2021, two years after the first recording. This data might already indicate a general, weak link of the population with coastal ecosystems. A possible explanation is that there was no media coverage of the news, therefore public attention was not stimulated. Moreover, Albania lacks information on the presence of IS species in general, and this region is less studied compared to others in the Adriatic (Kamberi et al. 2022). Similarly, the southern basin of the Mediterranean Sea is subjected to lower research efforts when compared with its northern basins, with frequent calls for greater research efforts to increase knowledge on IS in the area (Zenetos et al. 2010). The scarcity of research effort could explain the lack of Google search volumes in these three countries. Regarding Syria, lack of data was also affected by the lack of Google traffic in the country and the political context, as the region experienced a civil war that led to a severe degradation of living conditions, with 90% of people living below the poverty line (United Nations, 2023). Clearly, public attention to ecological dynamics is strongly dependent on socioeconomic and political circumstances, and the war in Syria has directly affected education and internet access (Abdullah Omaish et al. 2022). Thus, lack of Google search volumes for this country may not be representative.

Finally, it is important to highlight the case of Cyprus, which displayed high Google search volumes since 2013, the year of arrival of lionfish in the country. Given the frequent sightings of lionfish from the coastal waters of south Cyprus, the University of Cyprus and the University of Plymouth started a project funded by the European Union's LIFE programme, RELIONMED (<https://relionmed.eu/>), from 2017 to 2022, seeking to stem the lionfish invasion in the Mediterranean Sea. RELIONMED promoted not only active culling of lionfish, but also raised awareness and educated the public about invasive species, improving ecological and societal

knowledge (Kleitou et al. 2022). Therefore, a high public attention to lionfish invasion might be expected for this country. Previous attempts to get a glimpse of public perceptions of lionfish have been made in Cyprus (Kleitou et al. 2019), involving surveys of general public and stakeholders, and finding limited awareness and recognition about the lionfish from the public, but strong support for local management from stakeholders. The data analysed here might give additional and complementary information to surveys, by expanding their sample size and providing temporal and retroactive information about public attention.

#### Limitations and future directions

Using digital data in the context of marine ecological research offers a great potential but also faces a number of caveats and limitations (Jarić et al. 2020c). Sociocultural aspects can influence data generation in terms of users' age, gender, cultural norms, language barriers, education and technical skills to access the internet (Correia et al. 2019). Moreover, internet access varies among countries and regions (World Bank Open Data, n.d.), which has a direct effect on digital data availability. These issues are exacerbated in the context of marine environments, where data coverage decreases in relation to distance from the coast (Jarić et al. 2020c). To mitigate these limitations, such data should be coupled with other data sources such as surveys and citizen science activities (Jarić et al. 2020b; Kerhoas et al. 2019; Sbragaglia et al., 2023).

The selected period of time during which we analysed Google search volume also included the COVID-19 outbreak period, that caused substantial changes in popularity for a variety of topics searched online during lockdowns (Brodeur et al. 2021; Heerfordt and Heerfordt 2020; Roll et al. 2021). Therefore, we cannot exclude similar effects on lionfish Google search volumes during the pandemic period. It is also important to note that, while Jarić et al. (2023) refer to a peak duration of days or weeks, we aggregated the data from Google yearly. Such temporal resolution might have masked subtle attention peaks related to the arrival of the lionfish. In fact, elevated public attention often lasts for several days or weeks (Lorenz-Spreen et al. 2019), thus an additional analysis at a finer temporal scale

(such as monthly or weekly frequency) is required to uncover possible shorter temporal dynamics and seasonal patterns that might have been overlooked. In this context, future refinements could also deepen the influence of digital media on public attention and emotions by the spread of news and/or social media posting (Happer and Philo 2013; Ahmad and Murad 2020). This phenomenon is also true for environmental issues, such as the greater media coverage of climate change that influenced people's awareness on the issue (Han and Cheng 2020). Therefore, further research could focus on assessing news data for each country, to understand how media coverage and dissemination on lionfish invasion shapes societal attention. Focusing on the relationship between media and societal attention in biological invasions could also allow detecting successful approaches and/or mismatches between media coverage and research activity, and consequently the opportunity to replicate or enhance such communication strategies (Ballari and Barrios-García 2022).

## Conclusions

Emerging technologies and digital data sources provide a unique opportunity to monitor biodiversity, with low associated costs and quick access to a great amount of data generated by internet users (Jarić et al. 2020a; Ladle et al. 2016). By analysing Google search volumes, we were able to provide insights in societal attention to lionfish across its invasion front in the Mediterranean Sea. The socio-political complexity of the Mediterranean region and the diversity of political and cultural systems (Micheli et al. 2013) create heterogeneous temporal patterns of public attention to this species. While we found increased attention for lionfish in many countries, it is important to note that this trend was not consistent, and the temporal patterns varied among countries. This variability suggests that our analyses reveal interesting patterns, but further research is needed to enhance their consistency and reliability for conservation applications. Detecting periods of elevated public attention is of utmost importance, as they represent optimum moments to push management and conservation efforts (Males and Van Aelst 2021). Identifying this dynamic could

encourage policymakers to pursue and prioritise effective communication to tackle biological invasions and coordinate international actions (Jarić et al. 2021). Additionally, while our study focuses on Google search volumes as a proxy for public attention, future research could benefit from incorporating parallel measures of media and scientific attention in the respective countries. Both academic interest and media exposure of the lionfish invasion may be drivers of public attention and consequently enhancing the understanding of the factors influencing public interest and informing more comprehensive management strategies. In a rapidly changing world, in which ecosystems are simultaneously threatened by multiple challenges and pressures, approaches such as conservation culturomics and iEcology could unveil the complex human-nature interactions with quantitative indicators across time and space with the necessity of limited resources. Overall, our findings underscore the potential of digital data sources in conservation efforts and highlight the necessity for continued investigation to fully harness this approach.

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## Declarations

**Conflict of interest** The authors have not disclosed any competing interests.

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