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RESEARCH

Venomous Foes in Mediterranean Africa: Occurrence of *Physalia physalis* (Linnaeus, 1758), and First Records of *Glaucus atlanticus* Forster, 1777 for Algeria and Tunisia

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Abstract

Climate change can promote shifts in species' biogeographical distribution, but their monitoring is a challenge in the hardly accessible marine environment. In such cases, citizen science allows collecting data on scales unattainable for researchers. This study uses a citizen science approach through social media platforms to describe a high-occurrence event of the siphonophore *Physalia physalis* in Tunisia during April 2021, which, in addition to literature records, add to more than 50 colonies recorded in 2021 in Algeria and Tunisia. This is the highest abundance ever reported in these countries. Moreover, 20 specimens of *Glaucus atlanticus* were recorded in August 2022 in Tunisia, and 1 specimen in June 2023 in Algeria, constituting the first record for the species in both countries. For *P. physalis*, the reported event could result from an increase of citizen science in these countries, driving an increase of reports uploaded to social media, along with a high occurrence of colonies in 2021. Finally, high occurrence events might be partially predicted by westerly wind prevalence in the Strait of Gibraltar and nearby areas, a geographic bottleneck for colony entrance in the Mediterranean Sea. Overall, this study illustrates the key role of citizen science in resource-limited countries and the need of reinforcing these networks to generate eco-environmental awareness and scientific knowledge towards the achievement of UN Sustainable Development Goals.

Keywords Citizen science · Pleuston · Neuston · Harmful fauna · Mediterranean sea

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Introduction

The Mediterranean Sea, accounting for less than 1% of global aquatic surfaces, is home to 18% of macroscopic marine species, with approximately 30% being endemic (Bianchi and Morri 2000). However, it is also one of the most heavily affected marine regions by human activities, such as urbanisation, pollution, overfishing, and climate change, which have significantly impacted its biodiversity, ecosystem functioning, and human well-being (Coll et al. 2010; Pecl et al. 2017). The region is experiencing warming rates > 25% than the global average, with summer temperatures rising > 40% than the global mean (Lionello and Scarascia 2018), which combined to an increase in the frequency of extreme events, like marine heatwaves, are leading to mass mortality events of marine organisms and a severe loss of biodiversity (Garrabou et al. 2022). The decline of local populations facilitates the climate-mediated relocation of species, which are shifting their ranges due to changes in seawater circulation and temperatures (Vergés et al. 2014; Nota et al. 2023).

The African coasts of the west and central Mediterranean Sea are a marine biodiversity hotspot within the Mediterranean region (Coll et al. 2010). In this region, the seawater circulation from the Atlantic Ocean carries species like the cosmopolitan siphonophore *Physalia physalis* (Linnaeus, 1758), which can pose a risk to human health. Although this species is typically found in tropical and subtropical areas, its neustonic nature can lead to massive strandings in temperate latitudes (Totton 1960; Headlam et al. 2020). This predatory species has been historically present in the Mediterranean, where it was recorded in small numbers (Tiralongo et al. 2022). However, a high-occurrence event in 2010, which saw numerous colonies reaching Sardinia, resulted in a fatal allergic reaction for a swimmer (see Prieto et al. 2015). This event was related to a particular combination of meteorological and oceanographic conditions during winter and was followed by similar events in 2013 and 2018 (Prieto et al. 2015; Macías et al. 2021). Their impact on human health and tourism, coupled with potential ecological effects in a vertebrate hotspot within the Mediterranean (Coll et al. 2010), raises concern on whether these events may be becoming more frequent.

The colonies of *P. physalis* can serve as means of species transportation, such as the neustonic aeolidocean *Glaucus atlanticus* Forster, 1777. This carnivorous nudibranch usually preys and accompanies pleustonic cnidarians colonies like *Velella velella* (Linnaeus, 1758) and *P. physalis*, and can use uneaten parts of their prey to attach their egg strings (Helm 2021). However, our knowledge on these species biology and ecology is still scarce (Munro et al. 2019), with most of the research focusing on *P. physalis* toxin and human envenomations (e.g., Edwards and Hessinger 2000; Lopes et al. 2016). In the context of climate change, tracking species distribution and phenology is critical, particularly when the species present a potential hazard to human health. Citizen science can serve as a valuable tool for these purposes, as it uses public collaboration in challenging scientific projects to gather data on large spatiotemporal scales (Tiralongo et al. 2020; Callaghan et al. 2022). The aims of this study are to (1) provide citizen-generated data on *P. physalis* for Tunisia in 2021 and 2022, including the first record of *G. atlanticus* in Tunisia and Algeria; (2) provides sea surface temperature maps for the region, as warmer winters could favour colonies survival, and (3) examines wind conditions in the Strait of Gibraltar, hypothesizing that strong westerlies in this and nearby areas could predict high-occurrence events and/or the observation of colonies of *P. physalis* in several sectors of the West Mediterranean region (Prieto et al. 2015; Macías et al. 2021).

Materials and Methods

In April 2021, an unusually high number of pictures and videos of *Physalia physalis* were uploaded by the members of the Facebook® group TunSea (Tunisia), created in August 2020, and with > 50.000 members. Following this event, all photos and videos of *P. physalis* uploaded to the group from January 2021 to December 2022, were revised and validated. Similarly, *Glaucus atlanticus* records were collected from two Facebook® groups: TunSea for Tunisia and Oddfish for Algeria, which were created with the aim of collecting data on non-indigenous and strange-looking species in general. All *P. physalis* and *G. atlanticus* records were validated using image reverse search to discard material downloaded from the internet and by contacting the uploaders to obtain verbal confirmation of the records and details on the location and conditions in which the specimens were found. Once validated, the location and date of the records were annotated.

Mean winter wind intensity, direction prevalence and windward direction in the Strait of Gibraltar were obtained from Puertos del Estado (2024), which provides average and average maximum winds from the SIMAR model (station: 2022072; 36° 0’ N, 5° 10’ 12” W), based on the models HIRLAM (AEMET) and HARMONIE-AROME (Puertos del Estado 2024). This data was available from 2010 to 2022, and was used to create wind roses using Portus online visualization tool (Puertos del Estado 2024). SIMAR model data was not downloadable as monthly speed and direction data, which prevented further analyses. Averaged Sea Surface Temperature in the West Mediterranean region during the summers and winters of this study timeframe (2021 and 2022) were obtained from E.U. Copernicus Marine Service Information (Pisano et al. 2016; Saha et al. 2018; Merchant et al. 2019). Maps were created using QGIS3 software.

The possible relationship between the prevalence of westerly winds in areas near the Strait of Gibraltar, —a geographic bottleneck for the entrance of colonies—, and the yearly variation of occurrence/high-occurrence events of *P. physalis* in the Mediterranean region, was explored by obtaining the yearly occurrence of *P. physalis* in the Mediterranean from 2009 to 2022 from the literature (see Supplementary Table 1). These were categorized by the Mediterranean biogeographic sectors of Spanish Levante, Balearic Islands, southern Thyrrenian Sea, Sicily Strait coasts, and Argelia and north Tunisia coasts (Bianchi et al. 2011). This data was used to generate two discrete dependent variables: Local and Regional, with values from 0 to 3, with 0 indicating years with no reports (L and R columns in Supplementary Table 1). Local: 1 = years with at least > 1 colony detected in one sector, 2 = more than 30 colonies reported, and 3 = hundreds of colonies reported. Regional: 1 = occurrence of specimens in more than one Mediterranean sector; 2 = occurrence of several specimens in several sectors; 3 = occurrence of specimens in non-adjacent sectors.

The prevalence (%) of hourly maximum winds intensity (m/s) and direction (°) near the Strait of Gibraltar for months within the studied timeframe (2009–2022) was obtained from the data collected by the oceanographic Sea-Watch buoy installed in the Gulf of Cadiz (36° 29' 24.0" N, 6° 57' 36.0" W) by Puertos del Estado (2024), which was used to obtain the percentage of time in a month in which the hourly maximum westerly wind, from 225° (SW) to 315° (NW), had a speed from 1 to 6 m/s (w1-6ms) and ≥ 6 m/s (w ≥ 6ms). These two wind-speed variables were collected for T0, the month when the first colony was recorded in any of the studied sectors each year (obtained using WM month in Supplementary Table 1), and the previous month to T0 (T-1), to account for a possible delay between colonies crossing the Strait of Gibraltar and their arrival to the studied sectors.

Statistical Analyses

The westerly wind variables for T0 (T0_w1-6ms; T0_w ≥ 6ms) and T-1 (T-1_w1-6ms; T-1_w ≥ 6ms) were analyzed a priori using the ggpairs command from the GGally library to avoid collinearity. We conducted Generalized Additive Models (GAMs) using a Poisson family and a log link function (Guisan et al. 2002). The GAMs aimed to explore the relationship between the predictor variables from T0 and T-1 and the response variables Local and Regional, with 4 models: T0_Local, T0_Regional, T-1_Local and T-1_Regional. The smooth terms of the predictor variables were obtained by Gaussian process basis function with a smoothing parameter k = 4. We further investigated the residuals against the variables included in the model using DHARMa package functions. Analyses were carried out with R and RStudio software.

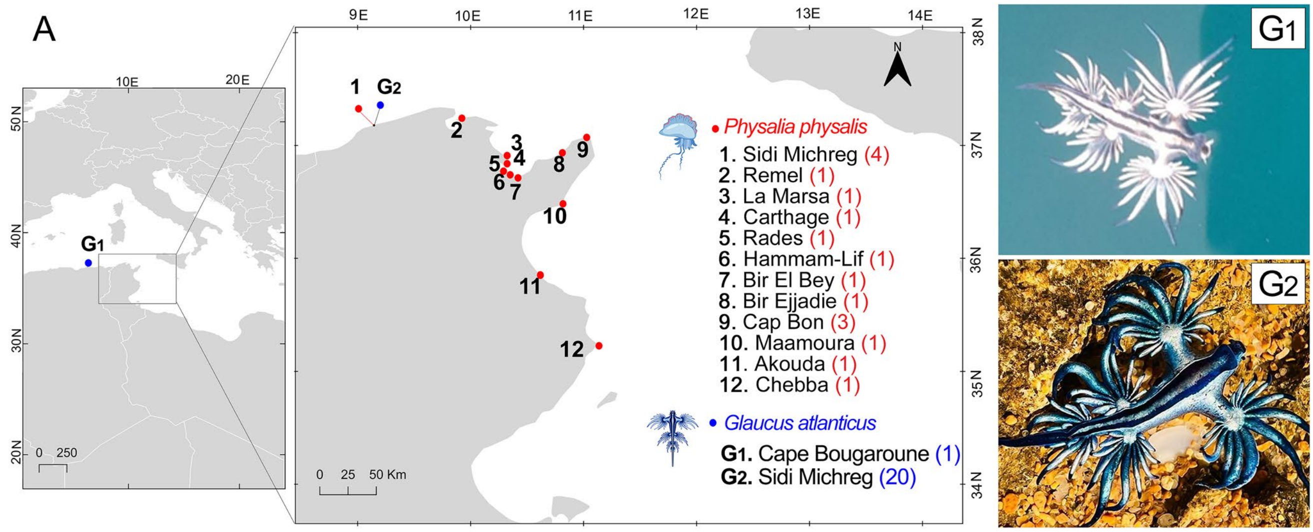


Fig. 1 **A** Distribution and number of *Physalia physalis* colonies in Tunisia in April 2021 (red dots), and *Glaucus atlanticus* specimens (blue dots). **G1** specimen of *G. atlanticus* recorded in Algeria on June 2023; **G2** one of the specimens found in Tunisia on August 2022 (**G2**, credit: Kaissar Blagui)

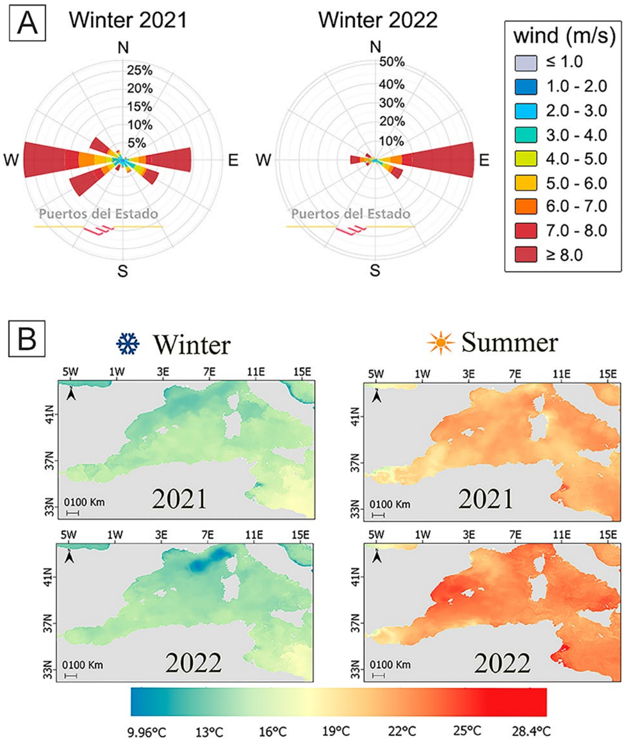


Fig. 2 **A**: Mean wind intensity (m/s), wind direction prevalence (% of time), and windward direction in the Strait of Gibraltar during the winters of 2021 and 2022. **B**: Average Sea surface temperatures in the West Mediterranean region during winter and summer of 2021 and 2022

Results

In April 2021, 19 colonies of *Physalia physalis* were observed across 12 northern and central Tunisian locations, with the furthest south being Chebba and the Gulf of Hammamet (Fig. 1A). While most locations reported a single colony, Sidi Michreg and Cap Bon had 4 and 3 colonies respectively. No additional *P. physalis* records were submitted to TunSea in 2021 and 2022. Nevertheless, a live specimen of *Glaucus atlanticus* was observed by a professional fisherman off the Algerian coast near Cape Bougaroune, Skikda (37° 5’ 18.27” N, 6° 28’ 5.40” E) in June 2023 (Fig. 1G1); and 20 live individuals of *G. atlanticus* were found at Sidi Michreg beach in Tunisia (37° 9’ 43.6” N, 9° 07’ 09.1” E) in August 2022 (Fig. 1G2).

Westerly winds with a 4 or higher intensity in the Beaufort scale (≥ 6 m/s) were frequent in the Strait of Gibraltar during winter 2021, while it was dominated by intense easterlies for more than 50% of the 2022 winter season (Fig. 2A). Strong westerlies were frequent in the area during the winters of the 2010s decade, including years with high-occurrence events: 2010, 2013 and 2018 (Supplementary Fig. 1). In the Gulf of Cadiz, westerlies with hourly maximum ≥ 6 m/s were predominant (> 40% prevalence) during the month preceding *P. physalis* high-occurrence events of 2013 (T-1) and during T0 for the events of 2010 and 2018, being T0 the month in which colonies started to be recorded

Table 1 Independent variables are colour-graded from blue (low) to yellow (high), for 2009 to 2022 (Puertos del Estado 2024). T0 = month of first record of colonies in the studied sectors or most common month for first record for years without records (see Methodology); T-1 = previous month to T0; w1-6ms = percentage of the month in which the hourly maximum was a westerly wind with a speed from 1 to 6 m/s; w ≥ 6ms = percentage of the month in which the hourly maximum was a strong westerly (≥ 6 m/s speed). Dependent variables are colour-graded from green (low) to yellow (high). WM month = month of first record of colonies in the studied sectors, extracted from literature (see Supplementary Table 1); Lo = Local, registering the abundance of colonies (high-occurrence events), and Re = Regional, reporting colonies across biogeographical sectors

Year	T0	T0_w1-6ms	T0_w≥6ms	T-1_w1-6ms	T-1_w≥6ms	WM month	Lo	Re
2009	Apr	38.858	35.097	18.892	18.219	Apr - Jun	1	3
2010	Mar	29.919	42.857	13.457	33.773	Mar	3	3
2011	Jan	22.222	23.473	8.872	22.714	Jan	1	1
2012	Mar	18.548	3.359	22.127	7.471	Mar	1	1
2013	Apr	33.472	17.5	18.01	48.791	Apr - Jul	2	1
2014	Apr	32.5	22.223	24.226	22.073		1	0
2015	Apr	25.694	6.667	35.417	11.804		0	0
2016	Apr	39.443	24.583	48.387	17.338		0	0
2017	Apr	19.999	5.972	24.496	18.573		0	0
2018	Mar	18.144	57.662	24.404	12.501	Mar - May	3	3
2019	Apr	24.168	36.528	20.564	6.048	Apr	2	3
2020	Apr	20.416	22.084	25.001	21.505	Apr	0	1
2021	Apr	31.506	12.659	19.355	4.032	Apr - May	2	3
2022	Apr	18.684	18.327	18.684	18.327		0	0

Table 2 Effects for the Generalized Additive Models (GAMs) at T0 and T-1 on Local and Regional response variables

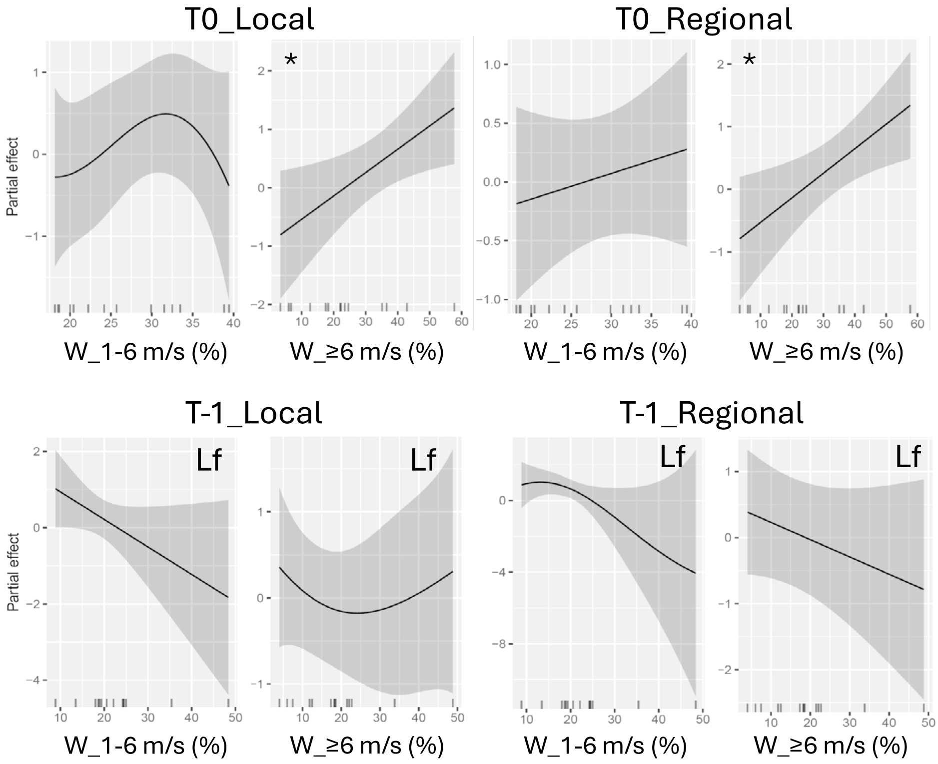
T0_Local	R2 = 0.636			**T0_Regional**	R2 = 0.358		
	Ex.Dev = 51.9%				Ex.Dev = 33.3%		
	Estimate	Std.Error	p-value		Estimate	Std.Error	p-value
Intercept	-0.088	0.3	0.769	Intercept	0.12	0.27	0.673
	Df	Chi.Sq	p-value		Df	Chi.Sq	p-value
T0_w1-6ms	1.94	1.97	0.361	T0_w1-6ms	1	0.50	0.479
T0_w ≥ 6ms	1	5.66	0.017*	T0_w ≥ 6ms	1	6.78	0.009*
T-1_Local	R2 = 0.152			**T-1_Regional**	R2 = 0.222		
	Ex.Dev = 34.0%				Ex.Dev = 40.5%		
	Estimate	Std.Error	p-value		Estimate	Std.Error	p-value
Intercept	-0.054	0.3	0.858	Intercept	-0.112	0.42	0.792
	Df	Chi.Sq	p-value		Df	Chi.Sq	p-value
T0_w1-6ms	1	2.72	0.099	T0_w1-6ms	1.78	3.18	0.230
T0_w ≥ 6ms	1.62	1.20	0.534	T0_w ≥ 6ms	1	1.42	0.234

Ex.Dev explained deviation, *Std.Error* standard error, *df* degrees of freedom, *Chi.sq* Chi squared, *T0* month of first record of colonies in the studied sectors, *T-1* previous month to T0, *w1-6ms* percentage of the month in which the hourly maximum was a westerly wind with a speed from 1 to 6 m/s, *w ≥ 6ms* percentage of the month in which the hourly maximum was a strong westerly (≥ 6 m/s speed)

*significant results (p-value < 0.05)

in the studied sectors (see Table 1). Overall, wind conditions in this area could be related to the entrance of colonies in the Mediterranean, despite of factors such as the direction and speed of surface wind and currents influencing colonies drift within the region, as well as less-relevant factors, such as sea surface temperature (SST), which might potentially

Fig. 3 Contour plots for the partial effects of wind variables in the T0 and T-1, Local and Regional GAMs. * = significant effects (see Supplementary Table 2); Lf = low fit of residuals (see Supplementary Fig. 3); W_1–6 m/s (%) = percentage of the month in which the hourly maximum was a westerly wind with a speed from 1 to 6 m/s; W_≥6 m/s (%) = percentage of the month in which the hourly maximum was a strong westerly (≥ 6 m/s speed)



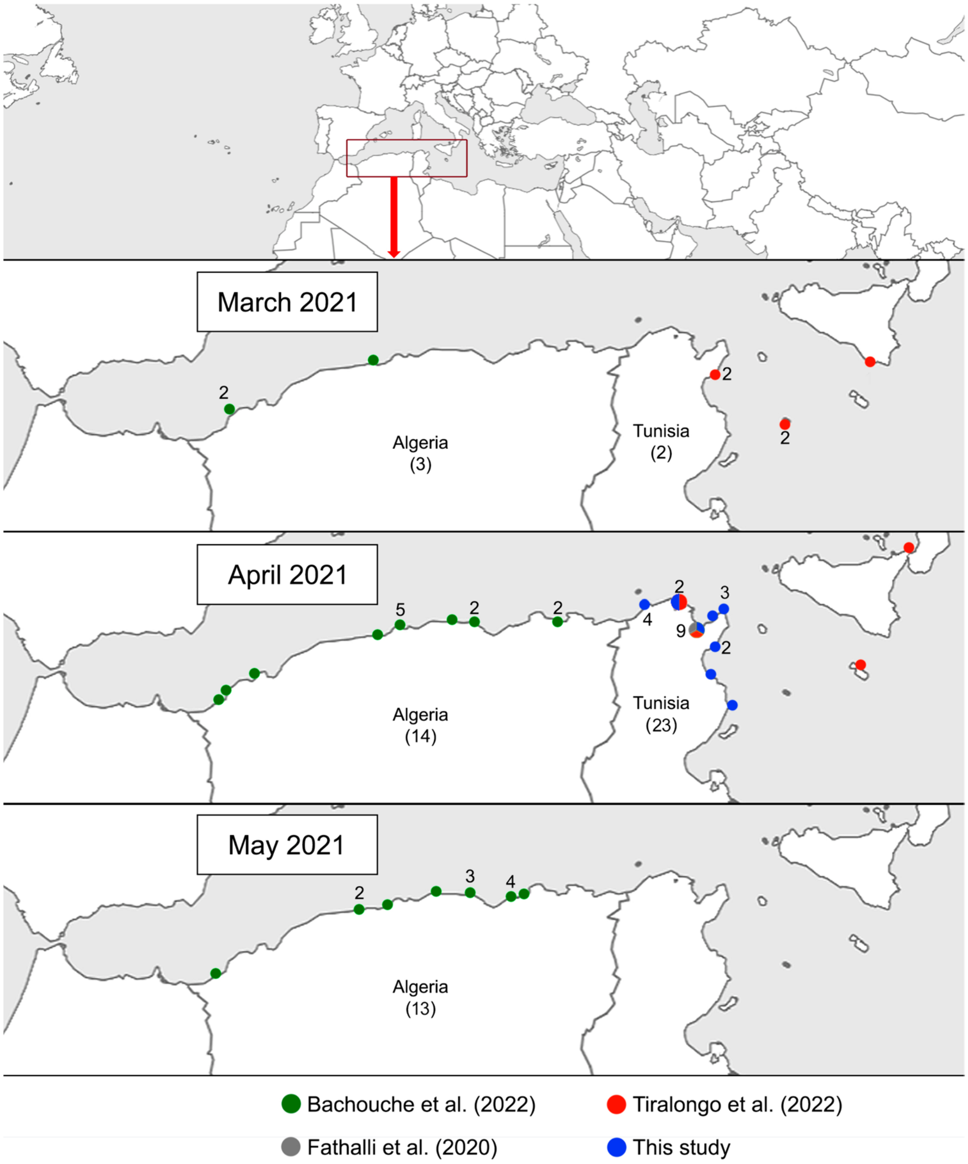


Fig. 4 Records of *Physalia physalis* in the southwest and central Mediterranean. Dots colour indicate the source study. Dot colour denotes the study source and pie chart dots indicate multiple study contributions. Numbers by dots represent colonies recorded (default is 1), and bracketed numbers show monthly totals in Algeria and Tunisia. Duplicate records from different studies for the same month, location and source (e.g., online platforms) were not combined

affect the fate of colonies within the region. In this study, 2021 and 2022 had a similar winter-averaged SST (~ 16 ºC) in the West Mediterranean region, but experiencing a noticeably higher SST in summer 2022 than 2021 (see Fig. 2B).

A prevalence of hourly maximum westerlies with ≥ 6 m/s speed (w ≥ 6ms in Table 2) in the Gulf of Cadiz during the month of first record of colonies in the studied sectors (T0) was a partial predictor for yearly high-occurrence events of *P. physalis* (Local) and the detection of colonies across Mediterranean sectors (Regional) (Table 2). However, low-speed westerlies (w1-6ms) had no effects in T0 models. Moreover, no effects were detected by T-1 GAMs (T-1_Local and T-1_Regional). Overall, T0 GAMs showed a good fit of residuals (Supplementary Fig. 2), while T-1_Local and T-1_Regional were low-fit models (Table 2; Supplementary Fig. 3) Fig. 3.

Discussion and Conclusions

Physalia physalis was first recorded in the Mediterranean Sea in 1850 (Tiralongo et al. 2022) and in Tunisia (Sidi Michreg), in 1992 (Gueroun et al. 2022). High-occurrence events were reported in 2010, 2013, and 2018 in some areas of Mediterranean Europe (Prieto et al. 2015; Macías et al. 2021). However, the first high-occurrence event for Tunisia and Algeria occurred from March to May 2021, with over 50 colonies observed in these countries (Fig. 4) (Fathalli et al. 2020; Bachouche et al. 2022; Tiralongo et al. 2022). This number of colonies is similar to the 2013 event in Spain, Maltese Archipelago and Sicily, but lower than the hundreds of colonies registered in 2010 and 2018 in Europe (Prieto et al. 2015; Mghili et al. 2022; Tiralongo et al. 2022).

In Tunisia, citizen science platforms such as Méduses. Tunisie (Gueroun et al. 2022) or Découvrons Les Méduses (Marambio et al. 2021) did not register high occurrences of *P. physalis* during the 2010s. Therefore, it is possible that 2010, 2013 and 2018 events did not occur in Algeria and Tunisia, in a similar way as the 2021 event described in this study did not occur in Mediterranean Europe, due to the distribution of *P. physalis* within the Mediterranean depending on wind and sea surface currents conditions (Prieto et al. 2015). However, the lack of records might also be due to a lower engagement by the public during 2010s, as these groups were specialised platforms in cnidarians with fewer members than TunSea (SKMG pers. obs.). Therefore, awareness and citizen science collaboration in Tunisia should be supported to enhance our understanding of this understudied Mediterranean region (Bachouche et al. 2022; Gueroun et al. 2022).

Physalia physalis is a thermophilic siphonophore that may benefit from increased mean winter temperature in colder regions like the Mediterranean (Copeland 1968; Mackie et al. 1988; Bourg et al. 2022). This, combined with a predicted increase in sea surface temperature and winds intensity in the west Mediterranean and the Strait of Gibraltar (Lionello and Scarascia 2018; Santos et al. 2018; Marriner et al. 2022) could have an impact on arrival, survival, and persistence of *P. physalis* colonies into the Mediterranean in the near future.

Wind primarily controls the drift of pleuston and neuston, driving *P. physalis* oceanic drift in the Atlantic Ocean and its entrance to the Mediterranean Sea (Mackie et al. 1988; Prieto et al. 2015; Headlam et al. 2020). Strong westerly winds in the Strait of Gibraltar were present during winter for the 4 high-occurrence events registered to date in the Mediterranean, which suggests that winds in this area could provide an early warning for monitoring *P. physalis* entrance and dispersion (Macías et al. 2021). Overall, westerlies of ≥ 6 m/s in the strait were predominant during the weeks preceding 2010s high-occurrence events in the Mediterranean. However, this was not the case for March-April 2021 event, when westerlies occurred during winter. In the absence of strong winds, currents play a key role in distributing *P. physalis* (Headlam et al. 2020; Macías et al. 2021), so it would be interesting to explore wind-current interaction in shaping these events, as winter surface currents bring Atlantic waters towards the coasts of Algeria and Tunisia (Pinardi and Masetti 2000).

The ecology and phenology of *P. physalis* is largely unknown, and more research is needed to understand the factors affecting its abundance and distribution in the Atlantic Ocean and the factors influencing their drift to Mediterranean shores. This includes associated species, such as *Glaucus atlanticus*, which was recorded in 2021 summer in Valencia, Spain, for the first time in the Mediterranean since 1705 (Montesanto et al. 2022). We provide two additional records for the Mediterranean in August 2022 (Tunisia) and June 2023 (Algeria). Overall, the species reported in this study represent a potential risk for human health (Edwards and Hessinger 2000; Prieto et al. 2015), and are predatory species that may have ecological effects on the ecosystem (Lopes et al. 2016; Helm 2021). Therefore, the occurrence of these species should be registered and monitored to forecast and minimise their impact (Macías et al. 2021). In this context, low-cost methods such as simple weather tools and citizen science contributions, could be useful to citizens and managers to assess the risk of high-occurrence events, early detection of colonies, and large-scale monitoring of neustonic species (Chandler et al. 2017; Callaghan et al. 2022; Gueroun et al. 2022). Citizen involvement in the scientific process enhances social awareness and scientific literacy, contributing to the United Nations' Sustainable Development Goals (SDGs), particularly in resource-limited countries (Pateman et al. 2021). In the Mediterranean, UNEP/MAP Strategies endorse citizen science for biodiversity monitoring and conservation (UNEP/MAP 2016). Thus, citizen science projects should be bolstered to detect and monitor harmful species blooms, like those reported here and, to assess if the frequency and severity of these blooms are increasing as a consequence of climate change.

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Author Contributions S.C., J.S-V. and S.K.M. wrote the main manuscript text and prepared figures. A.D. conducted the statistical analyses and prepared figures. F.T, E.A., R.B., E.D. and Y.R.S. contributed to the collection of records, validation and curation of data. All authors reviewed the manuscript.

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Data Availability No datasets were generated or analysed during the current study.

Declarations

Ethical Approval and Consent to Participate Ethical approval is not applicable, and all authors declare consent to participate in this study.

Human and Animal Ethics This article does not contain any studies with animals performed by any of the authors.

Consent for Publication All authors declare consent to the publication of this study.

Competing Interests The authors declare no competing interests.

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