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Citizen Science Effectively Monitors Biogeographical and Phenological patterns of Jellyfish.

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Abstract

Jellyfish encounters will undoubtedly increase as humans increase their involvement in the marine environment. Despite the direct health risks and socio-economic impediments that jellyfish pose around the globe, little is known about their current population dynamics. In order to reduce the negative impacts caused by jellyfish and increase knowledge on their population dynamics, we developed a citizen science application (MedusApp) to gather information on the biogeographical patterns of jellyfish on the Spanish Mediterranean Coast. Between 2018 and 2021, reports showed that *Pelagia noctiluca*, *Rhizostoma pulmo*, *Cotylorhiza tuberculata*, and *Rhizostoma luteum* were the most sighted jellyfish species. Over time, three of the four most frequently encountered jellyfish showed gradual increases in sightings (*R. pulmo*, *C. tuberculata*, and *R. luteum*), but *P. noctiluca* showed a quasi-annual distribution in reports. Based on our results, *R. luteum*'s distribution appears to be expanding its distribution northward and establishing itself in the Western Mediterranean basin (4.1% of sightings in 2021). The effective manner in which Medusapp collected data on the temporal and spatial distribution of jellyfish, will allow us to couple abiotic data and ultimately provide insight into the ecological drivers of jellyfish populations for broad spatial scales. Following on from the data acquired, jellyfish management policies can be improved and updated to minimise negative biological and socioeconomic impacts.

Keywords

Jellyfish, Mediterranean, Citizen Science, Spatial and temporal distribution, *Pelagia noctiluca*, *Rhizostoma luteum*

1. Introduction

Sitting between three continents and home to more than 420 million people, the Mediterranean Sea is an important and highly biodiverse body of water (Cuttelod et al., 2009; Bianchi and Morrià, 2019). It has an important economic role among the twenty-one countries that have access to it (Bleu et al., 2008). Jellfyfish (used in this study refers to those organisms of the phylum Cnidaria subphylum Medusozoa (Richardson et al., 2009)), have complex life cycles (generally planktonic and benthic phases), both sexual and asexual reproduction, and are classified as top predators that can affect fisheries through bottom-up and top-down control (Hale, 1999; Licandro et al., 2010). Jellyfish are also considered keystone predators (Mills and Mills, 1995), and as such affect humans in various ways, whether economically (Lucas et al., 2014) socially (Purcell et al., 2007) and ecologically (Pitt et al., 2009). Some of the detrimental impacts of jellyfish include stings to humans, few of them being fatal mainly in the tropical areas due to box-jellyfishes (Lippmann et al., 2011); increased pressure on fisheries and fish catch (Brodeur et al., 2011; Kim et al., 2012); negative economic effects on tourism (Ghermandi et al., 2015); disrupted electricity supply due to blockage of nuclear power plant intakes (Graham et al., 2014); and clogging cooling uptakes in vessels (Mianzan et al., 2005). The importance of monitoring jellyfish populations in the Mediterranean Sea is underscored by the fact that studies have linked the abundance and geographical expansion of jellyfish in the Mediterranean with increased temperatures and longer durations of phytoplankton blooms (Goy et al., 1989; Molinero et al., 2005; Lejeusne et al., 2010; Salgado-Hernanz et al., 2019). In short, anthropogenic pressures may increase the population densities of gelatinous species, lengthen their seasons, expand their distributions, and exacerbate difficulties for tourism, fisheries and other coastal industries (Purcell et al., 2012).

One of the negative impacts associated with jellyfish populations in the Western Mediterranean was recently studied by Báez et al. (2022), who states that jellyfish have a significant negative economic and biological impact on sardine and anchovy fisheries at both wild populations and fisheries landing levels. Furthermore, the effect of jellyfish on human health in the Western Mediterranean has been quantified using lifeguard data, which found that in 2012, 66.4% of injuries on beaches in Spain originated from jellyfish stings (Bordehore et al., 2016). Economic and health concerns surrounding jellyfish will undoubtedly continue to increase (Gibbons and Richardson, 2013) due to the continued expansion of human activities into the coastal zone via blue growth (OECD, 2016). Understanding the dynamics of jellyfish populations will therefore be paramount, as jellyfish bloom size, frequency, duration, and extent are apparently increasing in some regions of the world (Brotz and Pauly, 2012; Condon et al., 2013). The difficulties of sampling and monitoring jellyfish (Graham et al., 2003; Richardson et al., 2009; Brotz et al., 2012)., coupled with their ecological importance having been overlooked in the past (Verhaegen et al., 2021), has led to data on jellyfish species and abundance being scattered and scarce especially on large spatial and temporal scales (Brotz et al., 2012). With a greater need to understand global patterns of jellyfish distribution, new ways to gather quantitative or semi-quantitative data on jellyfish – species, location, time, abundance and size – are needed (Purcell, 2009). Ultimately, the limited scientific knowledge of spatial and temporal trends in jellyfish populations has hindered the capacity to design successful management strategies (Richardson et al., 2009; Prietro, 2018).

1.1 Citizen science

Citizen science uses volunteer participation of people to enhance scientific data and understanding in both terrestrial and marine studies and has proven to be an effective system for monitoring the spatial and temporal distribution of species such as whale sharks or the Atlantic blue crab (Araujo et al., 2017; Encarnação et al., 2021). Well-implemented citizen science projects can supply invaluable data whilst simultaneously expanding citizens' ocean literacy. Furthermore, citizen awareness of environmental changes and understanding of scientific issues has the potential to influence management policies and implementation strategies (Bonney et al., 2009; Kullenberg and Kasperowski, 2016; McKinley et al., 2017). Recently, citizen science has also proven to complement jellyfish studies in particular (Poursanidis and Zenetos, 2014; Deidun and Sciberras, 2017; Nordstrom et al., 2019). Several projects have been carried out in the Mediterranean, such as Jellywatch by the Mediterranean Science Commission, Meteomedusae by Boero, (2013) in Italy and Meduzot by Edelist et al. (2020) in Israel, which have led to novel discoveries regarding jellyfish distribution. There is currently a lack of large-scale data on jellyfish population dynamics on the Spanish Mediterranean coast – except for Catalonia, where a citizen science project called iMedJelly was implemented in 2013 and is still ongoing. Through iMedJelly, Canepa et al. (2014) observed jellyfish population dynamics and concluded that slope index and SST were the most important environmental variables for the distribution of jellyfish.

1.2 Aims

Building on the remarkable success of citizen science data collection on jellyfish in the aforementioned studies, this study aims to report on the results of a citizen science initiative -MedusApp- along the Spanish Mediterranean coast from 2018 to 2021. In light of the lack of management policies focusing on jellyfish, herein we document the most abundant jellyfish sighted on Spanish beaches, the most abundant jellyfish by their individual numbers, their appearances and disappearances and determine shifting trends in spatial and temporal resolutions by using MedusApp's sighting reports. To minimise the socio-economic effects of jellyfish, this study ultimately fills in gaps in the biogeography of jellyfish in the Western Mediterranean, so that authorities can implement species specific management measures.

2. Methods

2.1 MedusApp

MedusApp is a citizen science mobile application that focuses on obtaining large-scale data to examine biogeographical and phenological patterns in jellyfish populations. The app was conceived in 2018 as a result of the LIFE NAT08/0064 "CUBOMED" project, and it is available for iOS and Android phones. To increase user signups, the app was promoted via national news articles, radio interviews and television news broadcasts, which strongly contributed to the propagation and participation of users on MedusApp. Jellyfish sightings mostly came from the Spanish Mediterranean coast, which accounts for 3684km and covers the Alboran and Balearic Seas and part of the Western Mediterranean. MedusApp has been made to work on a global scale and has received 79 sightings from 21 other countries; however, this study only examines sightings made from Spanish waters. MedusApp initially focused solely on the presence of jellyfish, but after two years it was updated to request that citizens also report the absence of jellyfish on beaches; as a result, in 2020 MedusApp moved towards a presence/absence model in an attempt to become semi-quantitative and include 'zeroes' in the data. MedusApp is a tool that offers users five main utilities: 1) reporting jellyfish sightings and absences (point mode), additionally the app can identify the species in a photograph through an artificial intelligence function developed by the MedusApp team; 2) transects of jellyfish sightings or absences. Both types after a rapid human-based validation are then uploaded to a near real-time map; 3) reporting sting incidents and pictures of the damaged skin (which results are not within the scope of this paper), this information is not public and goes directly to the MedusApp medical doctors (V. del Pozo and M. Fernandez-Nieto, from Fundación Jiménez Díaz, Madrid); 4) providing users with a step-by-step first aid guide to treating the sting depending on which species caused it, and; 5) a guide to jellyfish that focuses on the most common species found in the Mediterranean, with information on the seasonality, frequency and distribution of each species and the danger they pose to bathers.

The jellyfish sightings are validated by a team of gelatinous zooplankton specialists after a user sends a sighting. This step is essential in any citizen science project. The validation process consists of removing misidentified sightings or fake pictures, identifying the species if unknown, filtering out duplicates and requesting more information from the user. The additional information requested about each sighting includes an in-situ photograph of the jellyfish, the relative abundance of jellyfish at the site on a scale of 0–6 (0 = unknown; 1 = 1 individual; 2 = 2–5; 3 = 6–10; 4 = 11–99; 5 = 100–1000; 6 = > 1000), the size of individual bell diameters on a scale of 0–5 (0 = unknown; 1 = 0–5 cm; 2 = 5–10 cm; 3 = 10–15 cm; 4 = 15–25 cm; 5 = > 25 cm) and, if known, the species from a list of 25 possible jellyfish. There is no true definition of what constitutes a bloom, and this can change markedly over different periods, locations and species. This study, therefore, assumes that sightings with a rank of 5 or 6, meaning any sightings with more than 100 jellyfish, constitute blooming events.

2.2 Software/Data analysis

The data collected in the MedusApp database was firstly revised for any duplicate sightings that may have been produced, cleaned and transferred to a workable spreadsheet. Data and graphical figures were processed and exported in SigmaPlot V.14.0, whilst maps on spatial distributions were produced in QGIS 3.22.0.

3. Results

3.1 MedusApp activity

MedusApp gathered data from January 2018 to November 2021 (though the application is currently still working); in that time the application was downloaded a total of 151,314 times; it was opened 891,682 times; a message indicating that the user was within 5 km of a reported jellyfish was shown 668,334 times; and 919 reports of jellyfish sting incidents were submitted. A total of 5,421 reports were received, of which 4,377 were accepted. The verified reports accounted for 3,561 sightings of jellyfish which is estimated to represent 255,676 individual jellyfish (this is calculated by obtaining the midpoint of each abundance rank, and for a rank of 6, 1000 jellyfish are assumed), and 354 absences of jellyfish. From the sightings, a total of 21 jellyfish species were reported, where 13 species were scyphozoans, 7 hydrozoans, and one cubozoan (figure 1). In 2018 there were 783 sightings, then 647 sightings, 773 sightings, and 2,174 sightings for 2019, 2020, and 2021, respectively. The seasonality of sightings occurred mainly in the summer season, with 3,382 sightings (95%) occurring from the first of June to the end of August, while the winter months (December to February) totalled 50 sightings.

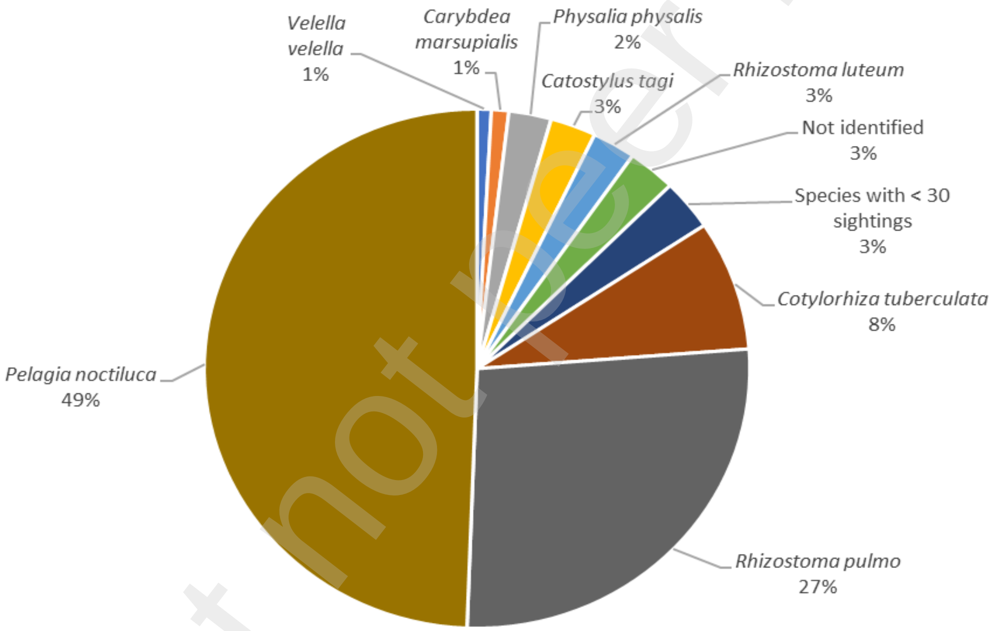


Figure 1. 21 different jellyfish species were sighted on MedusApp. Species with <30 sightings, is composed of a total of 13 species.

3.2 Spatial and Temporal distribution

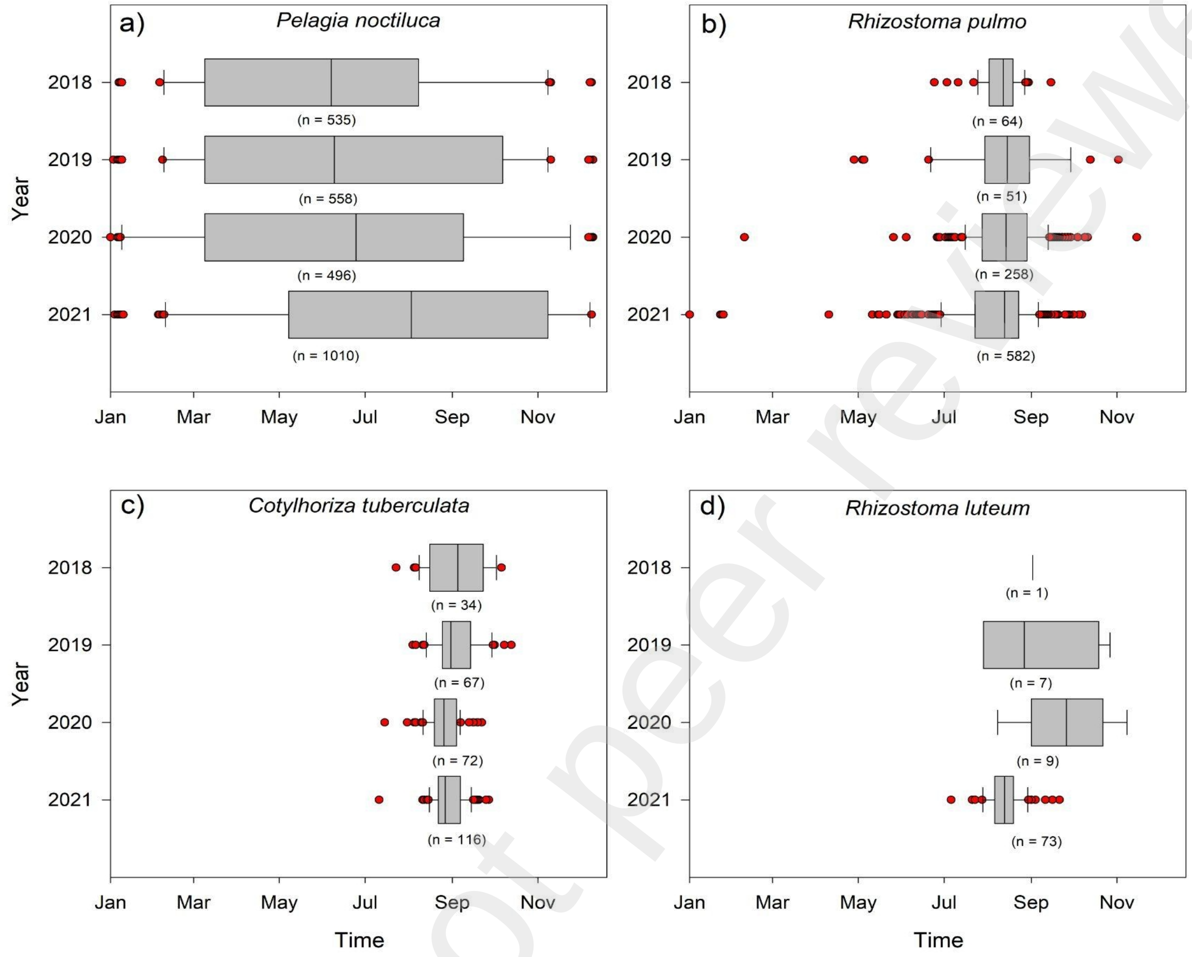


Figure 2. Box plots depicting the seasonality of jellyfish sightings over a four-year period. Circles indicate outliers and 'n' is the number of sightings for each box. a) *Pelagia noctiluca*; b) *Rhizostoma pulmo*; c) *Cotylhoriza tuberculata*; d) *Rhizosotma luteum*.

3.2.1 Pelagia noctiluca

P. noctiluca was the most sighted jellyfish with 1762 sightings (49%), of which 226 were bloom-level sightings; individuals in blooms alone are estimated to account for 131,050 jellyfish. The sightings of *P. noctiluca* varied over time, with 2018 and 2021 showing a high abundance of sightings of 540 (61,033 jellyfish) and 699 (57,342 individuals), respectively and, 2020 showed the lowest peak in abundance with 152 sightings (11,876 individuals).

Sightings of *P. noctiluca* occurred throughout the year with each month receiving a minimum of 5 sightings (figure 2a). The mean number of sightings shifted to later in time from the 7 of June to the 3 of August; in contrast, the estimated abundance of jellyfish has shifted to earlier in the year. There were 2,379 individuals from January to June in 2018 and 58,654 from July to December, compared to 12,377 (January to June) and 44,965 (July to December) in 2021. Nevertheless, there are no statistically significant differences in *P. noctiluca* seasonality (H(3)= 0.718, p=0.896). The spatial distribution of *P. noctiluca* also varied during the four years, with a northward shift for 2 years (2019 and 2020) (figure 3). In 2018, 89.7% of sightings of *P. noctiluca* were found in the southern region of Spain (latitudes under 37.5 degrees), with small patches of sightings reported from central Spain. In 2019, *P. noctiluca* in the southern region of Spain only amounted to 14.8% of total sightings, whereas central Spain and the Balearic Islands saw 81.3% of sightings (latitudes between 37.51 and 40 degrees). The same northward shift of *P. noctiluca* sightings was seen in 2020, when most of the sightings came from the Catalonian coast (33.5% at 40.01–42 degrees latitude) and central Spain (63.8%), with only 2.7% occurring in the southern region. However, in 2021, the northward trend stopped, and *P. noctiluca* was reported across all regions of Spain. As with sightings, the abundance of individuals shows the same spatial shift.

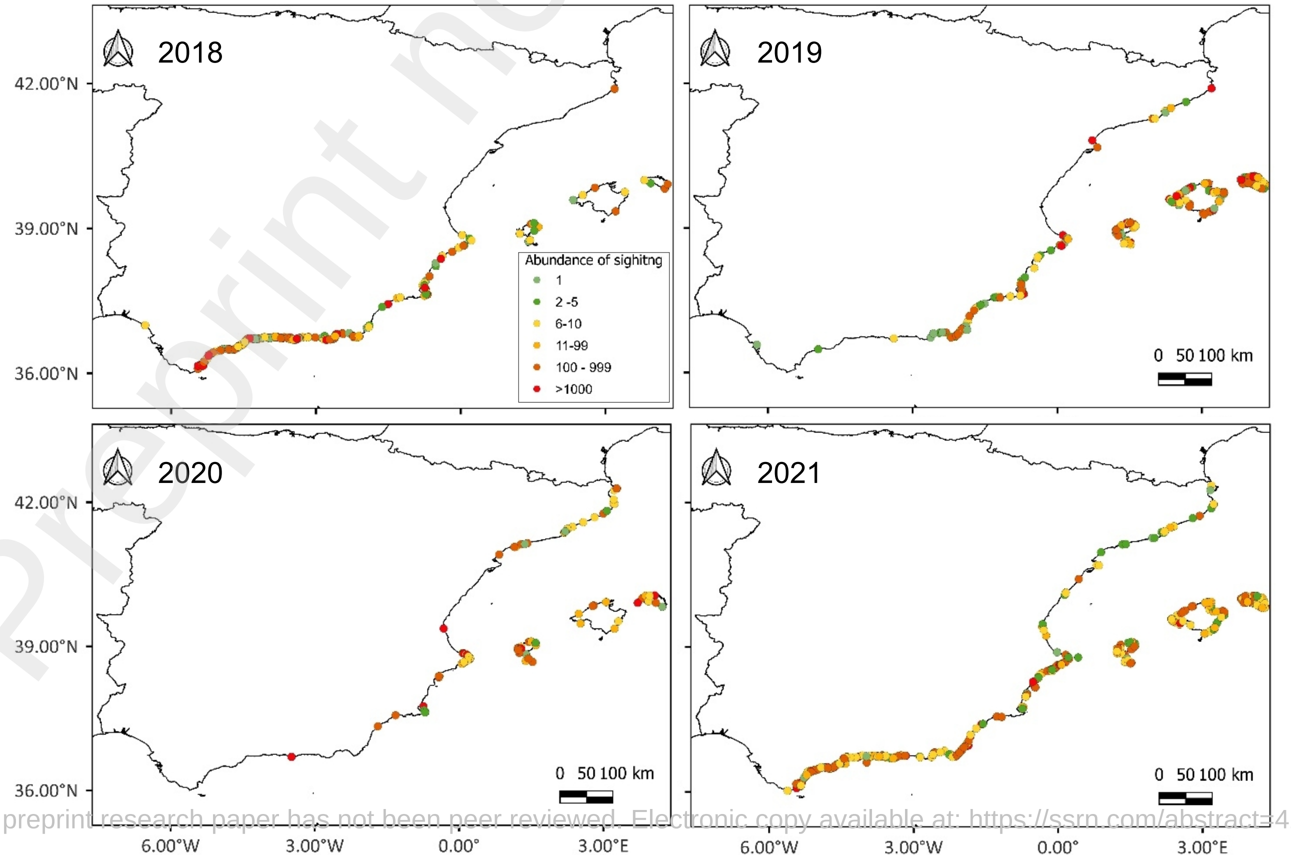
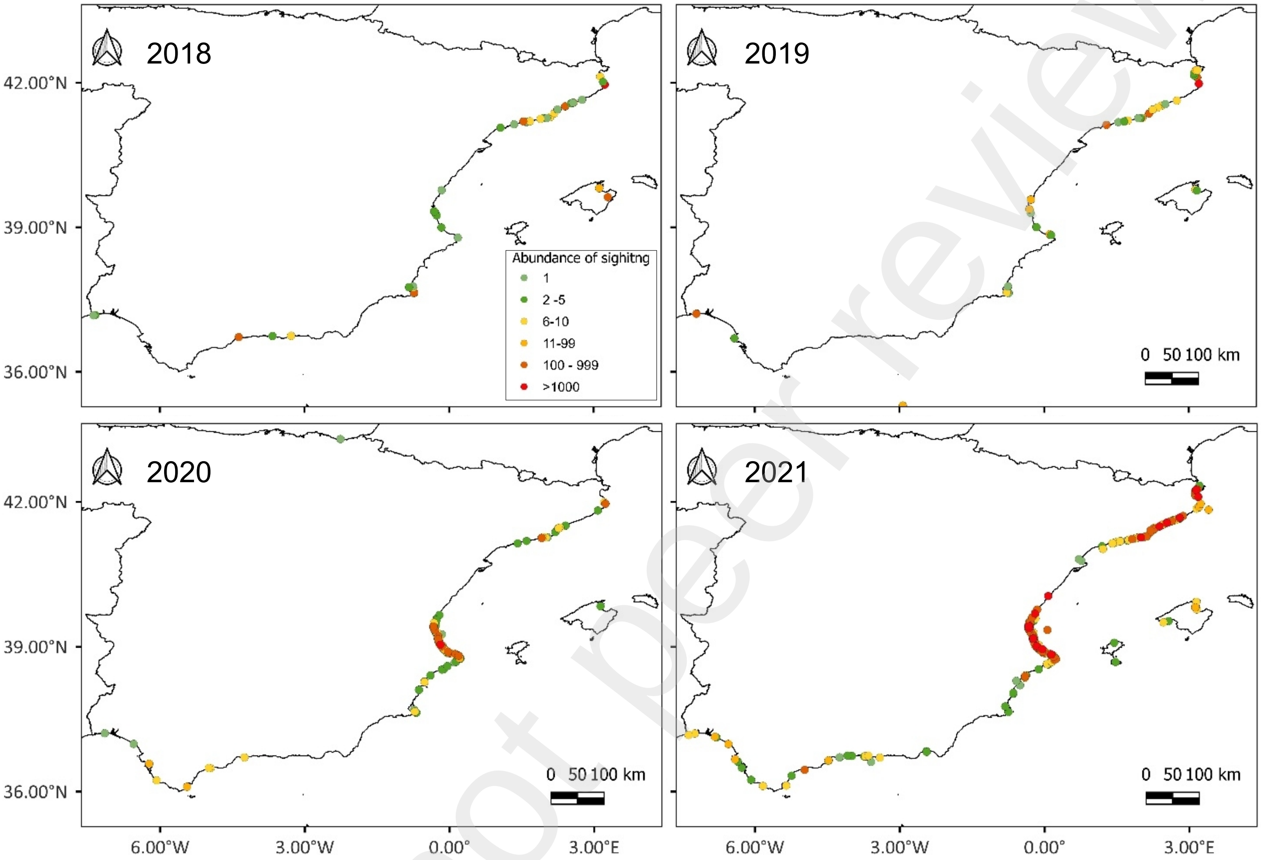


Figure 3. Spatial and temporal distribution of *Pelagia noctiluca* along the Spanish Mediterranean coast for 2018, 2019, 2020 and 2021. The colour of the circles indicates how abundant (rank) each sighting is.

3.2.2 Rhizostoma pulmo

MedusApp collected 960 sightings (estimated abundance of 29,251individuals) of *Rhizostoma pulmo*, making it the second most abundant jellyfish in terms of sightings. *R. pulmo* showed a significant increase in sightings from 66 made in 2018, 52, 259 and 582 for



2019, 2020 and 2022, respectively. The same continuous increase can be seen in the estimated abundance of jellyfish, with 1,070 in 2018, 1,541 in 2019, 4,154 in 2020 and 22,486 in 2021. *R. pulmo's* seasonality was consistent; with most occurrences appearing between 2 of July to the 29 of September, while 9.1% were observed outside of those dates. (figure 2b). The mean abundance of sightings was within four days across the four years (11–15th August) (figure 2b). As far as spatial distribution is concerned, *R. pulmo* was consistently found in the Catalonia (55.8%) and Valencian provinces (68.3%), with the Valencian province experiencing a higher concentration of populations (map of the provinces of Spain can be found in supplementary figure 1).

Figure 4. Spatial and temporal distribution of *Rhizostoma pulmo* along the Spanish Mediterranean coast for 2018, 2019, 2020 and 2021. The colour of the circles indicates how abundant (rank) each sighting is.

3.2.3 Cotylorhiza tuberculata

Cotylorhiza tuberculata was the third most reported species in MedusApp with 376 sightings and an abundance of 9,115 jellyfish. It underwent a consistent increase every year, starting from 35 sightings in 2018 and ending with 116 in 2021; however, in the number of abundance abundance there is an increase from 724 (2018) to 1,885 (2019) followed by a decrease 837 (2020) and then a sharp increase to 5,669 individuals (2021) *C. tuberculata's* seasonality began in mid-August and ended in late October. *C. tuberculata* showed a condensed and stable seasonality, with all sightings being found within 95 calendar days (11 of July to 13 of October) (figure 2c). The same stability in seasonality also applies to *C. tuberculata's* spatial distribution (figure 5), in 2018, the few observed sightings (n = 35) were spread across the Spanish coast, with at least one sighting in every province except two: Cadiz and Huelva. The following three consecutive years, *C. tuberculata* saw the same spatial distribution but recorded more sightings around the Valencia and Alicante province.

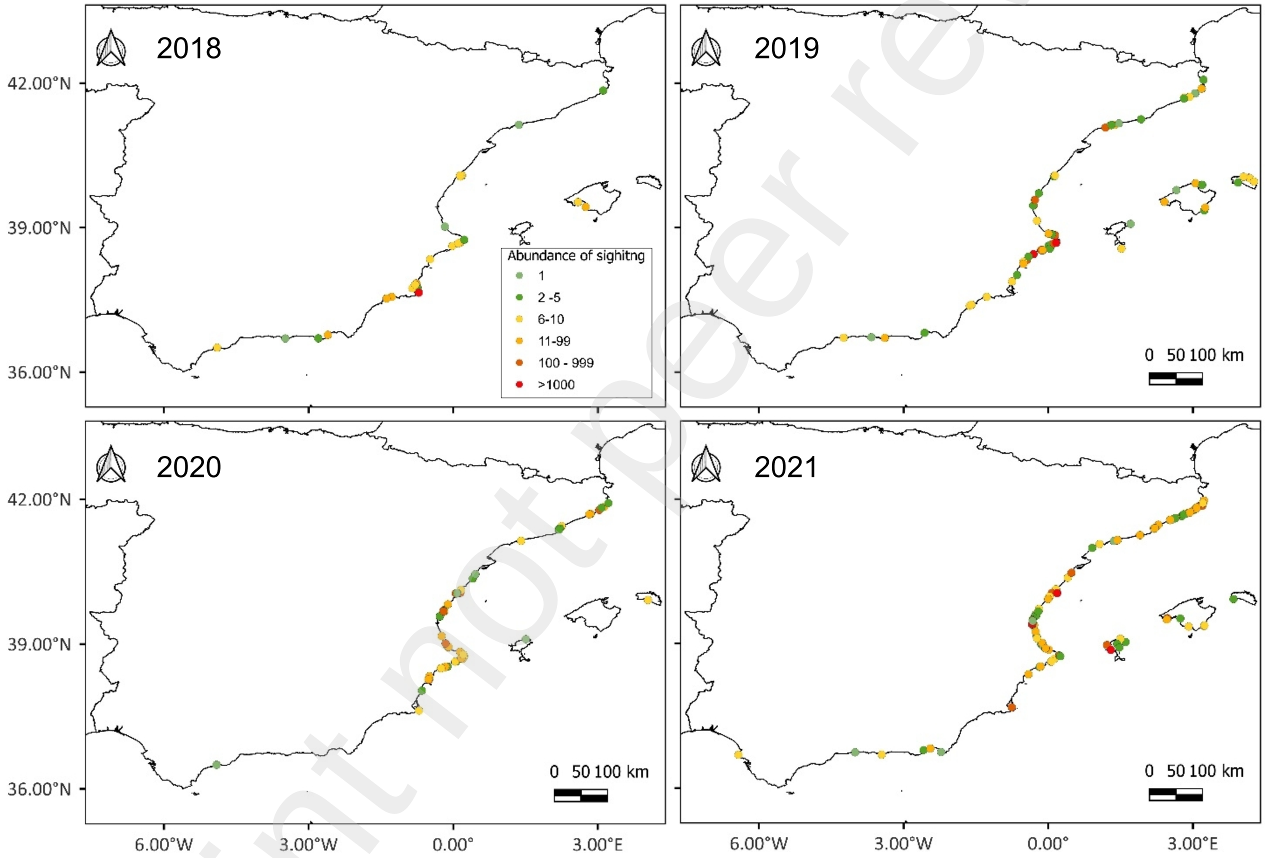


Figure 5. Spatial and temporal distribution of *Cotylorhiza tuberculata* along the Spanish Mediterranean coast for 2018, 2019, 2020 and 2021. The colour of the circles indicates how abundant (rank) each sighting is.

3.2.4 Rhizosotma luteum

Rhizostoma luteum was the fourth most abundant jellyfish in terms of sightings, with 90 sightings overall which accounted for an estimated abundance of 303 individuals (54% of sightings were ranked as 1 in abundance); however, 81.3% of the sightings occurred in 2021. In 2018, only one sighting was reported (corresponding to one individual), followed by 7, 9 and 73 (7, 77, and 222 individuals) sightings for 2019, 2020 and 2021, respectively. There are no trends in the seasonality of the reports, with varied appearances and disappearances occurring between July and November (figure 2d). The spatial distribution of *R. luteum* occurred mostly around the southern coasts of Spain, near the strait of Gibraltar and the Atlantic Ocean. However, in 2021, 5 sightings came from as far north as the Balearic Islands (figure 6).

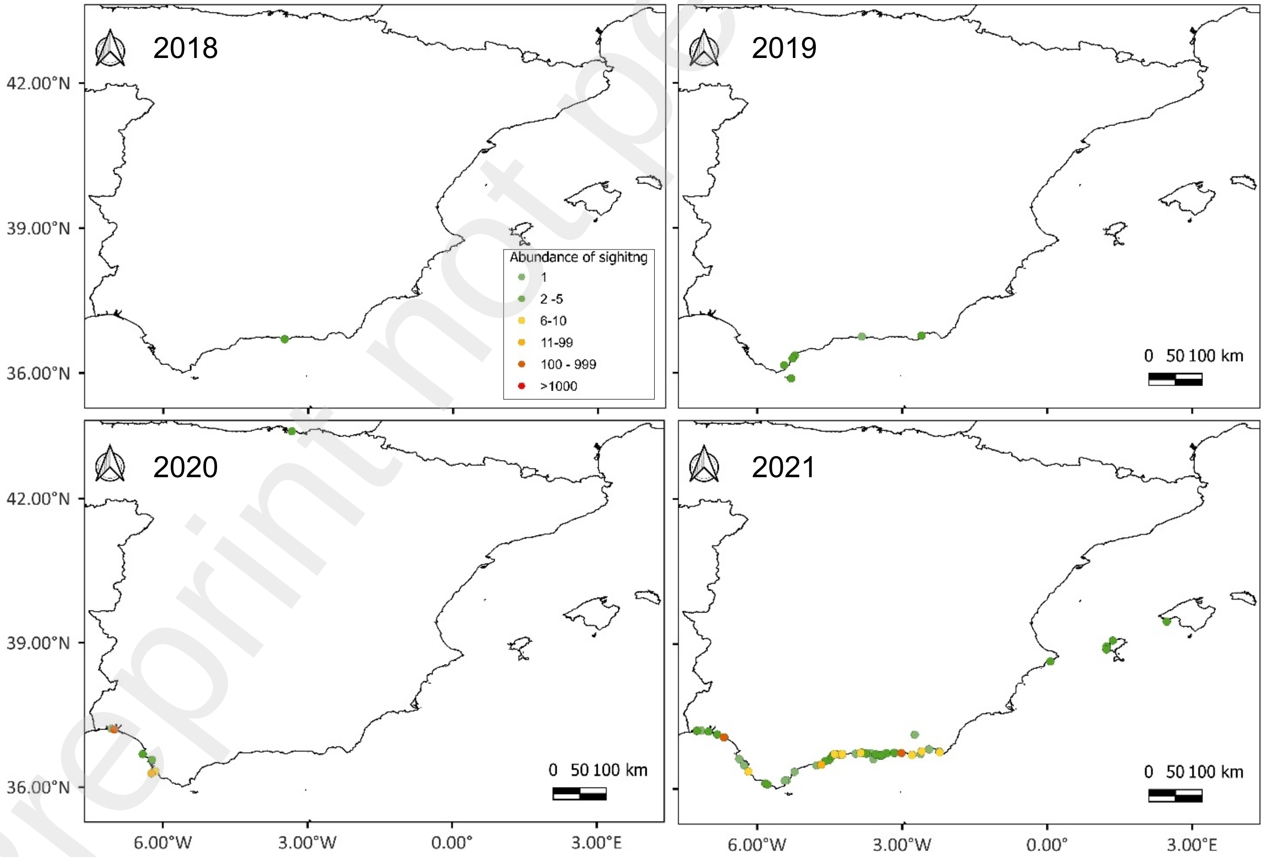


Figure 6. Spatial and temporal distribution of *Rhizostoma luteum* along the Spanish Mediterranean coast for 2018, 2019, 2020 and 2021. The colour of the circles indicates how abundant (rank) each sighting is.

4. Discussion

This study has successfully used a citizen science data collection method to supply a broad understanding of the phenological and biogeographical distributions of important species of jellyfish in the Western Mediterranean Sea. The data presented is on a national spatial scale, having covered 3684 km of coast; however, the data can also be analysed on local scales to see the effect of local hydrodynamic effects. The Mediterranean Basin is not uniform in terms of hydrodynamics and jellyfish population dynamics, and changes can be drastic from north to south and west to east (Leoni et al., 2021). Results obtained from citizen science projects focused on different countries will not reflect jellyfish populations on the Spanish coast; appropriate management policies must therefore be designed based on knowledge obtained directly from the coast in question. The data presented in this study covers a relatively small time period – only four years – when compared to the data needed to observe long term (decadal oscillations) of jellyfish populations (Condon et al., 2013), short time sampling may show local or regional short-term changes. Nonetheless, the nature of the data in this study will be fundamental to understanding the dynamics of jellyfish populations on a large spatial scale and could be essential to implementing appropriate management policies to attenuate negative human-jellyfish interactions. With regards to the Western Mediterranean, several studies (Kogovšek et al., 2010; Mariottini and Pane, 2010; Brotz and Pauly, 2012) have identified six main taxa of jellyfish: *Pelagia noctiluca*, *Rhizosotma pulmo*, *Cotylorhiza tuberculata*, *Chrysaora hysoscella*, *Aurelia spp* and *Velella velella*. The results obtained from MedusApp are consistent with these previous studies, with the exception of the inclusion of *R. luteum* as a prominent jellyfish in recent years.

4.1 Pelagia noctiluca

P. noctiluca was the highest reported species, constituting 49.4% of the total sightings on MedusApp. Studies have claimed that *P. noctiluca* could be the most important Mediterranean species of jellyfish due to its high abundance of blooms, the widespread distribution it manifests, its ecological role in the food web and its risk to human wellbeing (Mariottini et al., 2008; Licandro et al., 2010; Canepa et al., 2014). Based on our results, *P. noctiluca* occurs along the entire Spanish Mediterranean coast. *P. noctiluca* was reported 1762 times, 12.8% of which were bloom level events, which can disrupt coastal areas (Canepa et al., 2014). Canepa et al. (2014) explains in further detail how *P. noctiluca* bloom events negatively affect five human industries – tourism, fisheries, aquaculture, energy, and ecosystem functioning – through 12 different impacts. Our findings revealed bloom level sightings to be prominent in the provinces of Malaga, Granada, Almeria, Murcia, Baleares and Alicante provinces, which are characterised by high beach tourism rates and 147 aquaculture facilities (Visor Acuicultura, 2022). Based on 227 bloom-level sightings, we infer that the western Mediterranean aquaculture and tourism will suffer losses due to large agglomerations of *P. noctiluca*. To the best of the authors' knowledge, these losses have not yet been quantified.

P. noctiluca has been reported by other citizen science projects, and similarly to the results presented here, Gatt et al. (2018) found that *P. noctiluca* was the most abundant reported species between 2011 and 2015 in Malta, via Spot the Jellyfish. *P. noctiluca* was also the most abundant species in Tunisia in the 'Decouvrons Les Meduses' (2013–2015) project. On the Spanish coast, Canepa et al. (2014) highlighted that the distribution of *P. noctiluca* correlated with marine canyons, something that other studies have previously concluded (Rosa et al., 2013; Benedetti-Cecchi et al., 2015). Canepa et al. (2014) found that the distribution of *P. noctiluca* was primarily in the northern parts of the Catalonian coast, in correlation with the location of the Palamós and Cap de Creus submarine canyons. Although the life cycle of *P. noctiluca* has the potential to be greatly enhanced within submarine canyons (Benedetti-Cecchi et al., 2015), we found no such correlation between *P. noctiluca* sightings and the locations of submarine canyons along the Spanish coast. MedusApp identified the distributions to be ubiquitous along the catalonia province. Looking at the entirety of the

Spanish coast, our results hinted towards a northward shift of the populations of *P. noctiluca* for two years in a row which could be in part due to climatic variabilities, such as the NAO or the NHT. *P. noctiluca* populations, however, are not significantly affected by fluctuations in the NAO, as shown by Daly-Yahia et al. (2010). Therefore, it is likely that other smaller climatic variability, or hydrological and anthropogenic factors, have an influence on their abundances.

4.2 Rhizostoma pulmo

Rhizostoma pulmo was the second highest reported jellyfish on MedusApp, with our results showing a substantial increase of *R. pulmo* sightings over four years. A similar finding was made by Leoni et al. (2021), which used historical data and saw that since the early 2000s, *R. pulmo* populations have been increasing in southern European seas. Although a longer period of data is necessary to distinguish any decadal oscillations, it has been suggested that changing environmental conditions in the Mediterranean could be enhancing the capabilities of *R. pulmo* to reproduce and grow in a body of water that is heavily impacted by anthropogenic inputs (Leoni et al., 2021). The increase of sightings and abundances has not affected the seasonality or the duration of appearances of *R. pulmo*, with the mean abundance of sightings being within four days. *R. pulmo* was found primarily in the provinces of Valencia and Barcelona, but also showed small scale sightings along the entire Mediterranean coast. The concentration of *R. pulmo* around the centre of the Catalonian coast, in Barcelona province, is consistent with other reports from Fuentes et al. (2011) and Marambio et al. (2021). The majority of sightings and bloom levels came from Valencia province, which could be connected to the effects of temperature on the scyphistomae and ephyrae of *R. pulmo,* due to the favourable abiotic conditions in the area*.* Purcell et al. (2012) conducted laboratory experiments and found that *R. pulmo* produces more ephyra at higher temperatures (21°C) than lower ones (14°C); but they also found that the survival rate of polyps was higher at lower temperatures of 14°C than at 21°C. Consequently, the water temperatures prior to strobilation (January–March) around the Valencian coast tend to be around 13–14°C, and at the time of ephyra production (April–May), temperatures are around 18-20°C, which suggests that the Valencian coast offers an optimal temperature-time range for the reproduction and growth of *R. pulmo*. Our results show that *R. pulmo* is the most abundant, and therefore a potentially problematic, species of jellyfish for the Valencian province. Management measures should therefore focus on the seasonality and characteristics of this species to minimise negative interactions that affect the wellbeing and livelihoods of humans. In small areas of beaches, for example, jellyfish nets could be deployed at the time of peak sightings (13 of August) to protect people who are vulnerable or scared of jellyfish.

4.3 Cotylorhiza tuberculata

Although *C. tuberculata* is the third most reported species, the number of sightings (376) is far below those for *P. noctiluca* (1762) and *R. pulmo* (960). The sightings confirms the literature that *C. tuberculata* appear and disappear later in the bathing season due to strobilation occurring at a narrow temperature range (Prieto et al., 2010; Astorga et al., 2012). Cold waters prevent strobilation (Kikinger, 1992) and a minimum of 20–22°C is needed for strobilation to occur, temperatures which are reached in June along the coast of the Spanish coast (Puertos, 2022). *C. tuberculata* benefits greatly from anthropogenic environments (Astorga et al., 2012), the main factors contributing to the propagation of *C. tuberculata* are an increase of hard substrate surfaces to which the planulae can attach and increased polyp budding rates under rising temperatures (Holst and Jarms, 2007). The ability of this species to attach to any surface is demonstrated in our results with the ubiquity of *C. tuberculata's* sighting distribution along the entirety of the coast and in almost all provinces. *C. tuberculata* has also been linked with enclosed areas within coastal zones, as this provides an ideal habitat for its life cycle. One of the best examples known is in the Mar Menor lagoon (Prieto et al., 2010). Our results show that in 2018, *C. tuberculata* showed a high concentration of abundances in the Mar Menor; however, even though the species has shown the capability of completing its life cycle within the lagoon (Muñoz-Vera et al., 2015), our results show that in the following three years, *C. tuberculata* was absent from the lagoon. The absence of sightings from the lagoon is not explained by an absence of MedusApp users, as other species (*P. noctiluca*) were reported in the lagoon during the absence of *C. tuberculata*. Instead, sightings see a slight northward shift from the Mar Menor up the coast and finally concentrate around the Valencia province, roughly 100 km north of the Mar Menor. With the continued development of the coast leading to the proliferation and availability of artificial hard substrates (Serrano et al., 2013) along the coast of Spain, *C.*

tuberculata could potentially increase its presence or permanently shift its distribution further north outside of the Mar Menor region. With *C. tuberculata* potentially moving out of the lagoon, this might give *Aurelia spp*. the opportunity to recolonise the lagoon (Pérez-Ruzafa et al., 2018). Fishery authorities in the province of Murcia should therefore be aware of the appearances and abundances of *Aurelia spp*. and monitor the potential shift in species and associated impacts.

4.4 Rhizostoma luteum

R. luteum, the worldwide distribution of which was compiled by Kienberger and Prieto (2018), can be found off the coasts of Portugal (Rodrigues et al., 2020), on both sides of the Strait of Gibraltar, the Atlantic coast of Morocco (Prieto et al., 2013) and the west coast of Africa from the Mauritanian coast to Great Fish Bay in southern Angola (Kramp, 1959). Being an east Atlantic species and reaching the Mediterranean Sea through the Strait of Gibraltar (Kienberger et al., 2018), *R. luteum* is considered an alien species in the Mediterranean by several authors (Boero et al., 2016; Langeneck et al., 2019). 2021 was a particularly prolific year for *R. luteum* with 73 sightings accounting for 222 individuals. The number of sightings made from the Spanish coast alone in 2021 (77 sightings), without considering those from Portugal or North Africa, has already exceeded those reported in 2015 (39 observations) and 2014 (33) by Kienberger and Prieto (2017). In 2021, five individuals of *R. luteum* were sighted in Balearic waters, each with photographic evidence. These sightings constitute some of the most north-easterly locations to date, with only four other reports, as far as the authors are aware, at similar latitudes in the Mediterranean: one in Cabrera in 2016; Formentera in 2017; Ibiza in 2017 (Kienberger, 2019); and one dead individual reported from Mallorca via iNaturalist (iNaturalist, 2019). Although strong westerly winds have likely influenced jellyfish strandings on the western coast of Andalusia (Prieto et al., 2013), they do not appear to be the main factor that drove these individuals to Ibiza, since the winds recorded at buoys located just south of the Balearic Islands blew in the opposite direction, to the south (supplementary figures 2-3). With regards to water temperature, the Balearic region showed a higher temperature than in the Alboran Sea during both months of *R. luteum* sightings (supplementary table 1). However, considering that *R. luteum* comes from the Atlantic and that it inhabits areas where temperatures can drop to 14°C in winter

(Kienberger et al., 2018), it is improbable that the specimens have actively moved to Ibiza following a temperature gradient. There is no buoy from Puertos del Estado (State-owned Spanish Port System) within 80 km of Ibiza with data concerning currents, so although currents could be a plausible explanation for the presence of *R. luteum* around Ibiza, we lack sufficient data on them or their swimming ability against and with currents. More sightings and a more comprehensive spatiotemporal study (including a wider data grid if possible) are needed to clarify why *R. luteum* expanded its geographic range in 2021, and to elucidate whether the records presented in this paper are anecdotal or, on the contrary, will become common in the future. Considering that *R. luteum* is moderately venomous (in an analogous manner to *R. pulmo*, according to Kienberger et al., 2017) and has been reported as a potential bloomer (Langeneck et al., 2019), a mass occurrence event in the Balearic Islands (an eminently sun-and-sand tourist destination) would be highly undesirable, both socioeconomically and environmentally.

4.5 Citizen science

The results obtained from the citizen science project MedusApp comprise one of the largest and most comprehensive biogeographical and phenological describers of jellyfish patterns along the Spanish Mediterranean coast. Jellyfish can affect important socioeconomical aspects of human life, and their widespread distribution is a direct and indirect factor challenging the blue growth of Spain. As a result, investing in citizen science programs that monitor the distribution of jellyfish may become an effective approach to designing appropriate jellyfish management measures (Haklay, 2015; McKinley et al., 2017). Furthermore, the type of data collected can be used to create predictive models of jellyfish and function as an early warning system to help bathers, fishers, and aquaculturists avoid negative socioeconomic impacts (Angel and Freeman, 2016; Kingsford et al., 2018). MedusApp is a tool that has the capability to contribute to scientific knowledge, society and economic progress; whilst being aligned with 'Establishing Horizon 2020' act (EU Regulation No - 1291/2013; Eur-lex.europa.eu, 2013), which highlights the importance of involving all levels of stakeholders in protecting, monitoring and understanding biodiversity and the marine environment.

Citizen science is a technique which is faced with a multitude of limitations and hindrances (University of the West of England, 2013), nonetheless the technique is being widely used and improved at a rapid pace (Fraisl et al., 2022). One of the specific limitations MedusApp faces is the fact that high spatial resolution can be hindered by considerable challenges due to uneven reporting of jellyfish in different provinces (e.g. Bernard et al., 2011). There is no database which can identify which regions or areas have downloaded the app, therefore sampling effort is not taken into account. Additionally, the marked seasonality of beach and sea tourism in Spain causes the maximum number of sightings to occur during the Summer months (June-August). Even though few reports still emerge from the rest of the year, these might not reflect the true abundances of holoplanktonic species, such as *Pelagia noctiluca*, which are present all year round. Another limitation which MedusApp may be subject to is that an influx of users in a given year may result in an underestimation of jellyfish abundances in previous years. Currently, it is impossible to determine exactly how many MedusApp users attend the beach, but it is possible to view profiles that are still active and those that are not. Throughout the study period, MedusApp observed that the number of active accounts remained similar which helps mitigate an underestimation in previous years. The next milestone for MedusApp and similar projects, will be to involve a level of standardisation perhaps in the form of official government numbers on beach goers.

5. Conclusion

Citizen science has proved yet again to be a useful and powerful tool for monitoring and detecting the phenological and biogeographical distribution of species in marine habitats. MedusApp has undoubtedly contributed to knowledge about spatial and temporal distributions of jellyfish in the Western Mediterranean. MedusApp obtained semi-quantitative data for jellyfish species abundance for 3684 km of coastline (200 Spanish municipalities) and has supplied national coverage for spatial and temporal distributions of important Mediterranean species of jellyfish, as well as evidence of a new potential geographical expansion of *R. luteum*. Moreover, the results indicate an increase in sightings and individuals for three prominent jellyfish species in the Western

Mediterranean Sea over the past four years. By tracking environmental factors during jellyfish blooms, citizen science tools will enable better monitoring, preparedness, and identification of the best intervention techniques.

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Contributions

J.Y. Dobson: Formal analysis, Data Curation, Visualisation, Investigation, Writing- Original draft preparation, Reviewing and Editing. **E.S. Fonfría**: Conceptualisation, Data curation, Investigation, Writing- Reviewing and Editing. **R. Palacios**: Conceptualisation, Data curation, Software. **E. Blasco**: Conceptualisation, Data curation, Software. **C. Bordehore**: Conceptualisation, Data curation, Supervision, Writing - Review and Editing.

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Conflicts of interest/Competing interests

Not applicable

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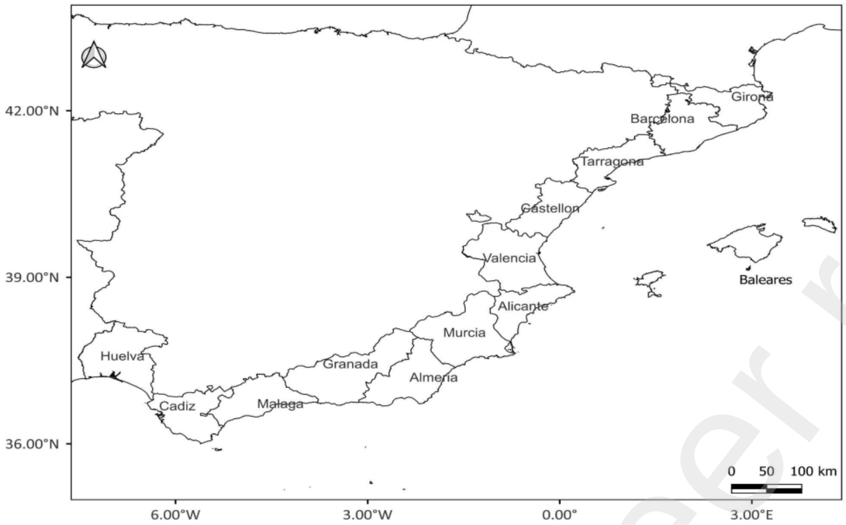
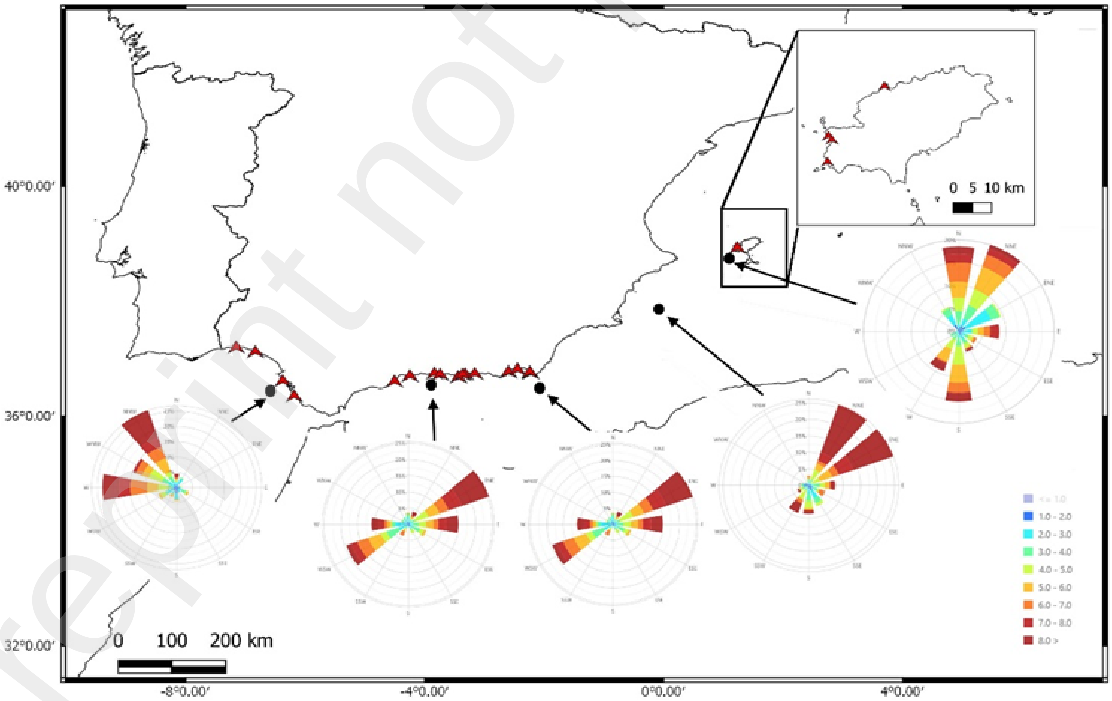
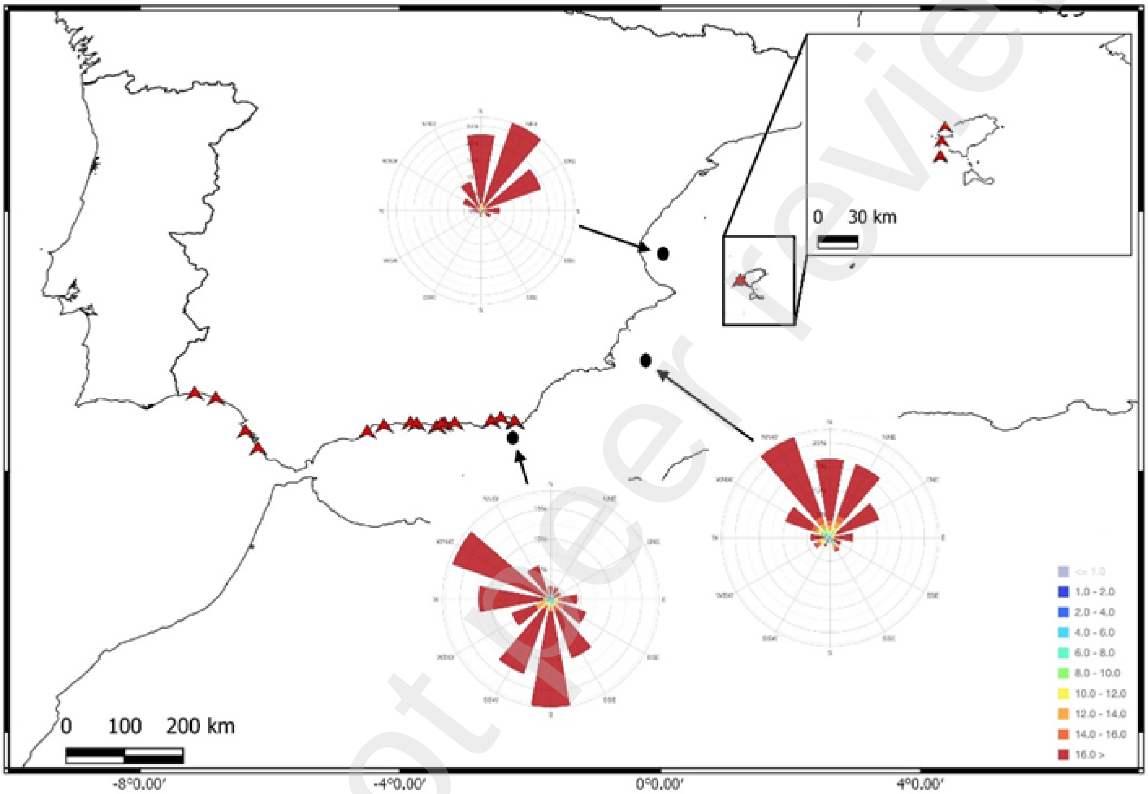
Supplementary information:



Supplementary Figure 1. A map of Spain with the provinces outlined.



Supplementary Figure 2. Red triangles indicate *R. luteum* sightings. Wind direction and speed (9 categories, m·s^{-1}) for the period 1st August to 16th August 2021 recorded from the buoys (from left to right): Punto Simar 1054046, Punto Simar 2036078, Punto Simar 2056079, Punto Simar 2084096, and Punto Simar 2098107 deployed by Puertos del Estado (www.puertos.es).



Supplementary Figure 3. Red triangles indicate *R. luteum* sightings. Current direction and speed (10 categories, cm: s-1) for the period 1st August to 16th August 2021 recorded from the buoys (from left to right): Punto Simar 2080092, Punto Simar 2056079 and Boya de Valencia deployed by Puertos del Estado (www.puertos.es).

Supplementary Table 1. Seawater temperature data (total month mean) obtained from Puertos del Estado (www.puertos.es).

Buoy Location	**Coordinates**		**Temperature (total month mean)**	
	Latitude	**Longitude**	**July**	**August**
Málaga	36.69	-4.42	20.2	19.9
Cabo de Gata	36.57	-2.34	23.4	24.3
Cabo de Palos	37.65	-0.31	24.5	26.2
Valencia	39.51	0.2	25.3	26.4