The Portuguese Man-of-war, One of The Most Dangerous Marine Species, Has Always Entered The Mediterranean Sea: Strandings, Sightings And Museum Collections

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Abstract

A search from different kinds of sources has been carried out to review the incidence of *Physalia physalis*, the Portuguese man-of-war, in the Mediterranean Sea; scientific and grey literature, social media, zoological museums were accessed. The records of the species were considered validated if documented with images or collected specimens. It was possible to date the putative first record of *Physalia physalis* in the Mediterranean Sea, thanks to a couple of colonies preserved in a historical collection, originating from the Gulf of Naples in 1914. Some massive strandings occurred in localities of the Alboran Sea, area of entrance from the Atlantic from where the species spread mainly along the Sicilian waters, in the central Mediterranean Sea. The records from the Italian maritime regions were then subdivided into three categories of risk according to the season of occurrence. These categories were created to assign a level of danger for swimmers to the sightings of *Physalia physalis*. The increasing sightings of such a poisonous organism in coastal waters can represent a risk to human health, and also to all those activities linked to the marine tourism sector. The involvement of citizens and touristic structures for the early detection of *Physalia physalis* can play a key role in preventing encounters with the species, allowing marine tourist facilities to operate within a range of reasonable security.

Introduction

The presence or even the blooms of marine jellyfish, the gelatinous animals which have a planktonic lifestyle, can have several negative impacts on ecosystems, on the economy (e.g., tourism, fisheries, aquaculture) and human health (De Donno et al. 2014; Bosch-Belmar et al. 2017). About this latter aspect, it is well known that specifically the cnidarians, commonly named jellyfish, can generate serious wounds and poisoning to humans, and in some cases the death (Burnett and Gable 1989; Burke 2002). However, since this gelatinous zooplankton is not usually targeted by fisheries and not easily surveyed or collected by researches activity, data on dispersal and impact on human life are scarce or sometimes lacking (Condon et al. 2012; De Donno et al. 2014; Rossi et al 2019; Gravili and Rossi 2021). Hence, we cannot state with absolute certainty for several species that a general increase of their abundance is occurring or will occur in a specific region. In this regard, Citizen Science and local public networks can be of great help in collecting data on a large spatial-temporal scale in order to better understand the dynamics of jellyfish populations (Baumann and Schernewski 2012; Fleming et al. 2013).

One of the most dangerous species in the Mediterranean Sea is the Portuguese man-of-war, *Physalia physalis* (Linnaeus, 1758), a pleustonic colonial organism rarely observed in the Mediterranean basin, whose direct observations mainly concern stranded specimens (Berdar and Cavallaro 1980; Deidun 2010; Boero 2013; Prieto et al. 2015; Castriota et al. 2017; Mghili et al. 2020; Deidun et al. 2020). This species, belonging to the Cnidarian group – order Siphonophores, is part of the floating community of ocean organisms that live at the interface between water and air (Boero 2013; Munro et al. 2019). Though the whole body seems a single individual, it is a colony in which small individuals (zooids) perform different functions such as floating, feeding, defence and reproduction (Lane 1960). The structure of the colony is complex; on the whole, it can be described as composed of two portions: a portion visible floating on the ocean surface – pneumatophore – and a not visible tentacular portion expanding below the water surface – the complex of zooids (Munro et al. 2019).

Physalia physalis is easily recognized by its bluish pneumatophore, and by an air bladder developed from one of the zooids that can reach 30 cm in length (Bardi and Marques 2007; Munro et al. 2019), surmounted by a crest that acts like a sail that helps to navigate and float on the surface of the sea (Lane 1960; Iosilevskii and Weihs

2009). The tentacles of this species, may be up to 30 m long and containing more than 750,000 stinging cells each (Munro et al. 2019), contain the “physaliatoxin” (Bardi and Marques 2007) that is the cause of its painful sting, which causes a series of symptoms, from local skin necrosis to neurological and cardiorespiratory problems that can cause death (Labadie et al. 2012). Furthermore, unlike other cnidarian species, the nematocysts of the Portuguese man-of-war seem can penetrate surgical gloves (Pierce 2006). *Physalia physalis* behaves like a predator, plays an important ecological role and influences the abundance of populations of small animals, in particular juveniles of fishes and larvae that it captures with tentacles (Purcell 1984). On the other hand, the Portuguese man-of-war can be preyed upon by fishes, turtles, lepadomorph barnacles and glaucid nudibranchs (Wangersky and Lane 1960; Bieri 1966; Thompson and Bennett 1970; Arai 2005), and other taxa not disclosed yet (Arai 2005).

Physalia physalis is a cosmopolitan species, distributed from tropical to temperate waters roughly comprised from 51°N to 38°S (Shannon and Chapman 1983; Kirkpatrick and Pugh 1984; Haddad et al. 2002; Elston 2007; Pontin et al. 2011; Oliveira et al. 2016). The locomotion of *P. physalis* is affected by winds. The species is surface-dwelling thanks to the chamber filled with air and carbon monoxide which represents a sail (the pneumatophore extending above the water’s surface) thus the colony moves with the prevailing wind (Mapstone 2015).

It is interesting to underline that the colonies of *P. physalis*, which move towards coastal areas, where they find optimal trophic conditions, and float along the shoreline, as a consequence of the direction and energy of prevailing winds and surface currents, originate from unknown marine georeferenced points (Graham et al. 2001). Thus, the continuously updating of records is much relevant to foresee the dispersal routes.

Up to date, the first documented record of *P. physalis* for the Mediterranean Sea dates back to 1980 (Berdar and Cavallaro 1980). The species has been subsequently reported sporadically, in the western and central basins, mostly around Sicily and Malta islands (Deidun et al. 2010; Boero et al. 2013; Deidun et al. 2020). The latest records in Sicily date back to 2019 in the Aegadian Sicilian Islands (Deidun et al. 2020).

Gathering the baseline information on this species records over time and space constitutes an important task for the elaboration of management programs aimed to alert the local human population and touristic structures. *Physalia physalis* represents an important species to be aware of, and for which dissemination of data about its presence should be improved.

Here we introduce a review of sightings, strandings and museum records of the species for the Mediterranean Sea, and the first documented Mediterranean records, originating from the southern Tyrrhenian basin. Relevant biodiversity information can be extrapolated from materials and data collected in the past and preserved in the Natural History Museums, which can provide overlooked data and, in many cases, still unpublished (Tedesco et al. 2020; Lo Brutto et al. 2021). The sightings and strandings summarized herein highlight the potential role of the zoological museums and the citizens' participatory science. The data from social media and local Citizen Science projects can have a key role if well managed; the information is often uploaded on the web but not archived in the scientific literature or summarized in any report. The case *P. physalis* is herein reported to fill such gap.

Methods

A survey on the presence of *Physalia physalis* in the Mediterranean Sea was carried out. Information from scientific and grey literature, from the web and social media, was extrapolated and analyzed.

As the Italian maritime sectors reported the most frequent records, a further search of historical museum specimens in Italy was integrated to find out old data never published. In particular, information was acquired from the “Darwin Dohrn” Museum of the Anton Dohrn Zoological Station of Naples and the Museum of Zoology “P. Doderlein” of the University of Palermo (MZPA), Italy.

For each kind of source, only information documented with images or collected specimens was selected to consider the data validated. The records were assigned to the main Mediterranean sectors based on the sampling locality; from west to east: Alboran Sea, Western Mediterranean, North-Western Mediterranean, Central Tyrrhenian Sea, Southern Tyrrhenian Sea, Channel of Sicily, Strait of Messina.

The records from the Italian maritime regions were subdivided into three “categories of risk” according to the season of occurrence. The records of *P. physalis* detected in February-March were included in the *low-risk* category; the records occurred in April-May in the *medium-risk* one; the records happened in June-August in the *high-risk* category. These categories were created to designate a level of danger for swimmers in a particular area, thus it was assumed that the sightings of *P. physalis* in the summer period (June-August) could be considered the most dangerous (*high-risk*), according to the higher number of swimmers than the remaining months of the year; while *medium* and *low-risk* were associated to a lower frequency of human activities accordingly. The Italian records belonging to the three categories of risk were counted and grouped according to the biogeographical sectors proposed by Bianchi (2004). A final map showed such clustering.

Results

More than 550 colonies of *Physalia physalis* were detected within the Mediterranean Sea, in a timescale comprised between 1914 and 2021 (April). Three colonies were found in museum collections, 530 colonies were counted from scientific literature, and information about 14 colonies was extrapolated from the web. Most of the colonies were reported stranded. The highest incidence was recorded in the Alboran Sea, across a limited area, from the Strait of Gibraltar and the Almeria-Oran Front (Tintore et al 1988); while the central Mediterranean area was the one where *P. physalis* mainly spread (Table 1). None information was provided from the Eastern Mediterranean, Adriatic Sea and Aegean and Levantine basin.

All data are shown in Table 1; the records are listed according to a chronological order, and each locality is associated to a marine sector indicated by a point in the map of the Fig. 1 (see the ID numbers). The marine sectors where *P. physalis* was been scored are the following: Maroccan waters – Alboran Sea (corresponding to the ID number 1 on the map of Fig. 1), Alboran Sea (ID 2), Balearic Sea –Western Mediterranean (ID 3), the coastline of Corsica – North-Western Mediterranean (ID 4 and 5), the coastline of Sardinia – Western Mediterranean (ID 6), Tunisian waters – Channel of Sicily (ID 7 and 8), Northern Tyrrhenian Sea (ID 9), Aegadian Archipelago – Southern Tyrrhenian Sea (ID 10), Pelagie Archipelago – Channel of Sicily (ID 11), southern Tyrrhenian Sea (ID 12), Central Tyrrhenian Sea (ID 13), Maltese Archipelago – Channel of Sicily (14), Strait of Messina (15) (Table 1 and Fig. 1).

Table 1

Records of *Physalia physalis* in the Mediterranean Sea, pointed out in the map of Fig. 1. The records are listed following a chronological order; year and month, when noticed, are specified. The locality and the marine sectors are indicated, the last according to the biogeographical division of the Mediterranean Sea and Italian waters.

Year	**Month**	**Locality**	**Mediterranean Marine Sector**	**ID on Map**	**Documented**	**Number of colonies**	**Reference**
1914	Unknown	Gulf of Naples (Italy)	Central Tyrrhenian Sea	13	Yes	2	Present paper
Antecedent 1980	Unknown	Gulf of Palermo (Italy)	Southern Tyrrhenian Sea	12	Yes	1	Present paper
1980	February	Coast of Messina (Italy)	Strait of Messina	15	Yes	1	Berdar and Cavallaro 1980
2001	May	Golden Bay (Malta)	Maltese Archipelago Channel of Sicily	14	Yes	1	P. J. Schembri *pers. comm.*
2009	February-March	Coastline of southern Spain (Spain)	Alboran Sea	2	Yes	57	Prieto et al. 2015
2009	February	Golden Bay (Malta)	Maltese Archipelago Channel of Sicily	14	Yes	1	P. J. Schembri *pers. comm.*
2009	April	Mgarr ix-Xini; Cirkewwa (Malta)	Maltese Archipelago Channel of Sicily	14	Yes	2	P. J. Schembri *pers. comm.*
2009	July	Ghar Lapsi (Malta)	Maltese Archipelago Channel of Sicily	14	Yes	1	P. J. Schembri *pers. comm.*
2009	March	Capo Peloro (Italy)	Strait of Messina	15	Yes	2	Castriota et al. 2017
2009	April	Lampedusa Island (Italy)	Pelagie Archipelago Channel of Sicily	11	Yes	1	Castriota et al. 2017

Year	Month	Locality	Mediterranean Marine Sector	ID on Map	Documented	Number of colonies	Reference
2009	August	Crystal Lagoon, Comino (Malta)	Maltese Archipelago Channel of Sicily	14	Yes	1	Deidun 2010
2010	February-April	Spanish Mediterranean coast (Spain)	Alboran Sea	2	Yes	>> 200	Prieto et al. 2015
2010	March-June	Cirkewwa; St. ThomasBay; Xlendi (Malta)	Maltese Archipelago Channel of Sicily	14	Yes	3	Deidun 2010
2010	March	N-E coast of Sicily (Italy)	Strait of Messina	15	No	1	Boero 2013
2010	March-August	Torre dei corsari; Funtanamare; Island San Pietro; Villaputzu (Italy)	coastline of Sardinia Western Mediterranean	6	No	4	Boero 2013
2010	March-August	Gozo Island (Malta)	Maltese Archipelago Channel of Sicily	14	No	2	Boero 2013
2010	June-August	Corsica Island (France)	coastline of Corsica North-Western Mediterranean	4–5	No	2	Boero 2013
2010	July	Porto Ercole (Italy)	Northern Tyrrhenian Sea	9	No	1	Boero 2013
2010	July	Sicily (Italy)	Southern Tyrrhenian Sea	12	No	1	Boero 2013
2011	February-March	Spanish Mediterranean coast (Spain)	Alboran Sea	2	Yes	17	Prieto et al. 2015
2011	March	Sa Maison (Malta)	Maltese Archipelago Channel of Sicily	14	Yes	1	Deidun et al., 2020

Year	Month	Locality	Mediterranean Marine Sector	ID on Map	Documented	Number of colonies	Reference
2012	February-March	Balearic Islands (Spain)	Balearic Sea Western Mediterranean	3	Yes	2	Prieto et al. 2015
2012	March	Ghajn Tuffieha (Malta)	Maltese Archipelago Channel of Sicily	14	Yes	1	Deidun et al. 2020
2014	March	Capo Peloro (Italy)	Strait of Messina	15	Yes	1	Castriota et al. 2017
2014	April	Xlendi (Malta)	Maltese Archipelago Channel of Sicily	14	Yes	1	Deidun et al. 2020
2014	April	Levanzo Island (Italy)	Aegadian Archipelago Southern Tyrrhenian Sea	10	Yes	1	Deidun et al. 2020
2018	March	Strait of Gibraltar (Marocco)	Maroccan waters Alboran Sea	1	Yes	8	Mghili et al. 2020
2018	April	M’diq, Fnideq, Martil, Azla (Marocco)	Maroccan waters Alboran Sea	1	Yes	169	Mghili et al. 2020
2018	May	Martil, M’diq, Fnideq (Marocco)	Maroccan waters Alboran Sea	1	Yes	46	Mghili et al. 2020
2018	May	Ghasri valley (Gozo); Valletta Grand Harbour (Malta)	Maltese Archipelago Channel of Sicily	14	Yes	2	Deidun et al. 2020
2018	May	Favignana Island (Italy)	Aegadian Archipelago Southern Tyrrhenian Sea	11	Yes	1	Deidun et al. 2020

Year	Month	Locality	Mediterranean Marine Sector	ID on Map	Documented	Number of colonies	Reference
2019	January and April	Ghajn Tuffieha; North Comino Channel (Malta)	Maltese Archipelago Channel of Sicily	14	Yes	2	Deidun et al. 2020
2020	May	S-W coastline of Sardinia Island (Italy)	coastline of Sardinia Western Mediterranean	6	Yes	1	Deidun et al. 2020
2021	February	Balestrate, N-W Sicily Island (Italy)	Southern Tyrrhenian Sea	12	Yes	1	Present paper
2021	February-April	Maamoura (Tunisia)	Tunisian waters Channel of Sicily	8	Yes	2	Social network
2021	March	Lampedusa Island (Italy)	Pelagie archipelago Channel of Sicily	11	Yes	2	Social network
2021	March-April	Nabeul-Chebba (Tunisia)	Tunisian waters Channel of Sicily	8	Yes	2	Social network
2021	April	Rades; Amilcar Beach; Sidi Bossaid; Bizerte; Carthage (Tunisia)	Tunisian waters Channel of Sicily	7	Yes	6	Social network
2021	April	San Pietro Island (Italy)	coastline of Sardinia Western Mediterranean	6	Yes	1	Social network
2021	April	Capo Peloro (Italy)	Strait of Messina	15	Yes	1	Social network

The first Mediterranean records of Physalia physalis

Due to the scarce scientific literature documenting the presence of *Physalis physalis* in the past, two of the oldest museum zoological collections in Italy, which preserve specimens collected in the Tyrrhenian area, were explored. The aim was to track down the first records of *P. physalis* in the Mediterranean Sea.

The oldest documented colonies in the Mediterranean Sea were collected in the Gulf of Naples in 1914. Two colonies are stored at the “Darwin Dohrn” Museum of the Anton Dohrn Zoological Station in Naples (Voucher code: HYD001) (Fig. 2). Further, by consulting the archive of the Museum of Zoology "Pietro Doderlein" of the University of Palermo, it was also possible to date a colony of *P. physalis*, collected along the North-Western coast of Sicily Island (southern Italy), in a period antecedent to 1980, presumably around 1960 (Silvano Riggio *pers. comm.*). The colony was found stored in a glass jar and is in a good state of conservation (Voucher code MZPA-IM-545).

Recent records

The recent records herein assumed are the ones reported from 1980 to nowadays; 1980 is the year of the presumptive first Mediterranean record, as highlighted by Berdar and Cavallaro (1980), however not confirmed by the museum collections above showed. The specimens preserved in the zoological collections did not further corroborate a record which was presumptively thought first on the North-Western coast of Sicily. The colony stranded on the 17th February 2021 (Balestrate, Gulf of Castellammare, 38°2'52.76"N – 12°59'52.15"E) was documented by an image (Fig. 3) and is here stated as new information. It was found still alive and showed the typical bluish colour of the species; it measured approximately 20 cm in total length. Considering that the sail of *P. physalis* can reach 30 cm in total length, the colony can be considered of medium-large size (Wilson 1947; Prieto et al. 2015). In the same year (2021), from February to April, *P. physalis* strandings occurred along the coast of Tunisia and Lampedusa Island (Channel of Sicily sector), in the Strait of Messina and the waters of Sardinia Island (Western Mediterranean sector) (Table 1, Fig. 1). The sightings were photographed and published on the web and social networks.

The records of *P. physalis* successive to the 1980 start in 2001. There is a gap of twenty years, from 1980 to 2000.

In 2001, the presence of this species was documented in Malta Island, although local fishermen affirmed that they had encountered the species previously (Calleja 2009). In Maltese waters, this species has been frequently registered: in May 2001, from February to August 2009, from March to June 2010, and in the period 2011–2020 (Patrick J. Schembri *pers. comm.*; Deidun 2010; Deidun et al. 2020). In this latter period (2011–2020), two records were also reported from the Aegadian archipelago – Southern Tyrrhenian sector, and one from the Island of Sardinia – Western Mediterranean sector (Deidun et al. 2020) (Table 1, Fig. 1).

In February-March 2009, 57 colonies were registered in the Alboran Sea along the Spanish coast (Prieto et al. 2015) and in the successive months in the Channel of Sicily and in the Strait of Messina (Mare Nostrum Italia 2013).

In 2010, probably the first human fatal outcome related to *P. physalis* was recorded in Sardinia (Focus 2010); 2010 was the year with the highest number of colonies documented (more than 200). The Western Mediterranean basin experienced several swarms, recording hundreds of colonies in different sites on the Spanish coast (Alboran Sea sector) and sightings in the North-Western Mediterranean sector, the Tyrrhenian Sea and the Strait of Messina (Table 1).

In the following years, however, the number of sightings decreased significantly, in fact, only 17 colonies were recorded in the same Spanish monitored sites in 2011 and two in 2012 (Prieto et al. 2015).

In 2018, between March and April, colonies of *P. physalis* were registered for the first time on the Mediterranean coast of Morocco – Alboran Sea sector, again more than 200 colonies (Mghili et al. 2020).

The flow of *P. physalis* from the Atlantic Ocean toward the western Mediterranean basin seemed to be attributed to an unusual combination of meteorological and oceanographic factors during the winter period (Poulain et al. 2012; Prieto et al. 2015). In the spring of 2009 and 2010 (Prieto et al. 2015) and 2018 (Mghili et al. 2020) intense strandings were recorded in the Alboran Sea, probably due to the action of the Western Alboran Gyre (WAG) and Eastern Alboran Gyre (EAG) (Poulain et al. 2012). Such surface currents of the Alboran Sea can behave also as physical barriers to the flow towards the Western Mediterranean, as suggested by Prieto et al. (2015), limiting the easternmost circulation of a large number of *P. physalis* colonies. Only a few colonies that escape the front manage to circulate by the benefit of the surface currents present in the Mediterranean Sea (Poulain et al. 2012). By creating a map of the *P. physalis* records documented in the last century, and superimposing it with the trajectories of the surface currents that drive the colonies (Poulain et al. 2012), it has been shown a general pattern of occurrence of the Portuguese man-of-war within the Mediterranean Sea (Fig. 1).

Records of Physalia physalis **in the Italian maritime regions**

The records of *Physalia physalis* were grouped in four Italian biogeographical sectors: Sardinian waters, Channel of Sicily, Tyrrhenian Sea, Strait of Messina. The clustering was arranged to identify those marine areas most affected by *P. physalis* sightings and strandings. Furthermore, the validated records of *P. physalis* were subdivided into three categories of risk (Fig. 4) according to the season of occurrence and the level of danger for swimmers.

The Sardinian waters recorded eight colonies, two belonging to the *low-risk* category, three to *medium-risk* and three to *high-risk* class (Fig .4). The Channel of Sicily showed the largest number of colonies sighted and stranded, 31 colonies of which ten were at *low-risk*, seventeen at *medium-risk* and four at *high-risk*. In the Tyrrhenian marine sector five colonies occurred, of which the only one at *low-risk*, two at *medium-risk* and two at *high-risk*. In this marine sector, the colonies of the Naples and Palermo museums were excluded because without data of the month. The Strait of Messina registered six colonies, of which five at *low-risk* and one at *medium-risk*.

Discussion

Physalia physalis is among the most dangerous species of cnidarians that threaten public health. This is because the sting of this species is very painful and the venom present in nematocysts can cause health complications for people attacked. In some documented cases, these incidents have had fatal outcomes (Burke 2002; Labadie et al. 2012). *Physalia physalis* can be harmful also in an indirect way, as prey of neustonic nudibranchs; some planktonic molluscs ingest the cnidarian and undischarged nematocysts as a defensive strategy (Thompson and Bennett 1969). The nematocysts maintain toxicity in the predators (Thompson and Bennett 1969; Ottuso 2009). The same harmfulness has been detected in the stranded *P. physalis* individuals on a beach, even after several days of dehydration (Tiballs 2006).

The World Health Organization (WHO) included *P. physalis* in the dangerous aquatic organisms for human health within the “Guidelines for safe recreational water environments” and suggested avoiding bathing in waters where Portuguese man-of-war is concentrated (WHO 2003). The assessment of the risk of contact with the Portuguese man-of-war within the Mediterranean Sea to develop policies for controlling and managing the well-being in water recreation needs a wide spatial and temporal scale of data. Further, the launch of a series of activities, through scientific dissemination campaigns, can allow the local authorities in charge to plan effective actions regarding the protection of public health and tourism activities not as isolated measurements for managing risks (De Donno et al. 2014; Montgomery et al. 2016).

This is particularly relevant within the Mediterranean Sea where dispersal of some cnidarian species need major attention (Rossi et al 2019) and where a great portion of the population still ignore the real hazard of most of the species, even though the high number of sightings and strandings recently detected through the media and social networks have helped to deepen the knowledge of the group.

Thus data were herein collected from different sources: social networks – scientific literature – museum zoological collections, as current and historical information on the distribution of the Portuguese man-of-war in the Mediterranean had not been organized yet and presented in a single article.

Under this operational framework, it was possible to track the putative first record of *P. physalis* in the Mediterranean Sea. The oldest documented capture of *P. physalis* occurred in the Gulf of Naples in 1914. Furthermore, it was possible to date a colony of *P. physalis*, presumably beached, on the North-Western coast of Sicily in a period antecedent to 1980 (Silvano Riggio *pers. comm.*), even older than the record by Berdar and Cavallaro (1980) in the Strait of Messina.

The role of museums was fundamental for reconstructing the past distribution of *P. physalis*. A new scenario on its presence in the Mediterranean Sea has been depicted, up to now suspected by the scientific community (Boero 2013). *Physalia physalis* has always entered the Mediterranean Sea.

The occurrence of *P. physalis* in the Mediterranean had been considered rare till the last decades, due to the lack of documented records in the literature (Castriota et al. 2017). Only in recent years, an increase of *P. physalis* sightings in the central Mediterranean Sea was reported. The reasons are attributable to the advancement of technological innovations (smartphones), which make sightings validated with photographs or videos, in the past not allowed, as the case of the Maltese fishermen who were not able to provide evidence of sightings (Calleja 2009).

From 2001 to 2020, several *P. physalis* strandings have been documented in the Mediterranean Sea (Patrick J. Schembri *pers. comm.*; Deidun 2010; Focus 2010; Boero 2013; Mare Nostrum Italia 2013; Prieto et al. 2015; Castriota et al. 2017; Deidun et al. 2020; Mghili et al. 2020) and lead us to assess the flow of the colonies in the Mediterranean Sea. The route and the extent of flow depend on the particular climatic-oceanographic conditions which regulate the entry from the Atlantic Ocean towards the Mediterranean, as argued by Poulain et al. (2012).

The data showed massive strandings (hundreds of colonies) recorded in the Alboran Sea (Prieto et al. 2015; Mghili et al. 2020), probably due to the action of the strong gyres in shallow water (Poulain et al. 2012), which behave like a physical barrier, as suggested by Prieto et al. (2015). The Atlantic water in the Alboran Sea describes two anticyclonic (clockwise rotating) gyres that dominate the surface flow pattern: a quasi-permanent anticyclonic gyre in the west (Western Alboran Gyre, WAG) and a more variable circuit in the east (Eastern Alboran Gyre, EAG) (Fig. 1) (Millot 1999). In such a situation, the vein flowing from Spain to Algeria, named 'the Almeria-Oran jet' (Millot 1999), stops a large number of colonies, preventing their eastward dispersal, except some colonies that find a favourable oceanographic route and move towards the Western and Central Mediterranean.

As the circulation features of the Alboran sector is largely controlled by meteorological conditions (Macías et al. 2008), some concerns regard climate change which could alter the role of natural barrier in the future, allowing a greater entry of *P. physalis* from the Atlantic Ocean. Under such a hypothetical scenario of an increasing number of colonies of *P. physalis*, we should limit human activities eventually exposed to risks in the central Mediterranean.

The pattern described in the map of Fig. 1 gives an idea of how the Portuguese man-of-war circulates in the Mediterranean. The records follow the surface currents and cover a limited geographical range may be due to biological constraints, as it is probable that *Physalia physalis* completes its life cycle in the Mediterranean Sea.

The tracking of this species in the Mediterranean Sea should not be overlooked, as the species threaten human health. For this reason, we selected some areas of risk by grouping the records of *P. physalis* in the most concerned four Italian maritime sectors: Sardinian waters; Channel of Sicily; Tyrrhenian Sea; Strait of Messina. The marine sectors most involved by *P. physalis* passage were identified and associated with levels of danger for swimmers according to the seasons of occurrence of the colonies (Fig. 4). The highest number of colonies were recorded in the Channel of Sicily, probably also thanks to the active monitoring that has taken place in recent years. The area showed records belonging to the three categories of risk, *low- medium- and high-risk* category; it means that the species occurs from February to August. The Strait of Messina seems to be the area less involved by the passage of the Portuguese man-of-war.

The recent expansion of Citizen Science projects and the use of social media for the detection of "strange-looking species" or charismatic species may have certainly contributed to increasing the number of observations in nature, including *P. physalis.* As a consequence, the presence of the species seems to have suddenly increased only in recent years.

In this regard, we have observed, especially in the last decade, how Citizen Science is experiencing an upsurge of interest and was demonstrated to be particularly effective for data collection and maritime monitoring (Devictor et al. 2010; Dickinson et al. 2010). In the Mediterranean Sea, several Citizen Science projects are currently active and led to the early detection and monitoring of uncommon or non-indigenous species (Giovos et al. 2019; Tiralongo et al. 2019; Tiralongo et al. 2020). These projects have often benefited from the involvement of the public through social media (Azzurro and Tiralongo 2020; Al Mabruk et al. 2021). Citizen Science could be an efficient tool for information campaigns to introduce the Portuguese man-of-war to the population and better track the early detection of the species, as already done for other harmful organisms (Andaloro et al., 2016).

The results suggest that a national multidisciplinary summer surveillance program in the central Mediterranean Sea coast is required to provide alerts to the public, to better identify patients at risk for developing severe clinical symptoms, and hopefully to improve the quality of health care. Local authorities should set up a monitoring and alert system, with the participation of territorial organizations, and the contribution of the scientific community, as proposed in other seas (Labadie et al. 2012). In this regard, engaging tourists as citizen scientists can be a useful and low-cost method for the monitoring of this and other dangerous species in general on a large spatial-temporal scale (Schaffer and Tham 2019). Continuous monitoring could beneficial for marine tourist facilities.

In general, the importance of obtaining time-series data to monitor biodiversity changes in the Mediterranean Sea is herein demonstrated and acquire relevant role respect the more frequent extreme events and temperature anomalies.

Declarations

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Authors contributions

All authors conceived the project, analysed the data, and reviewed the manuscript. RB drafted the manuscript and SLB contributed to its final review and editing.

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Figures

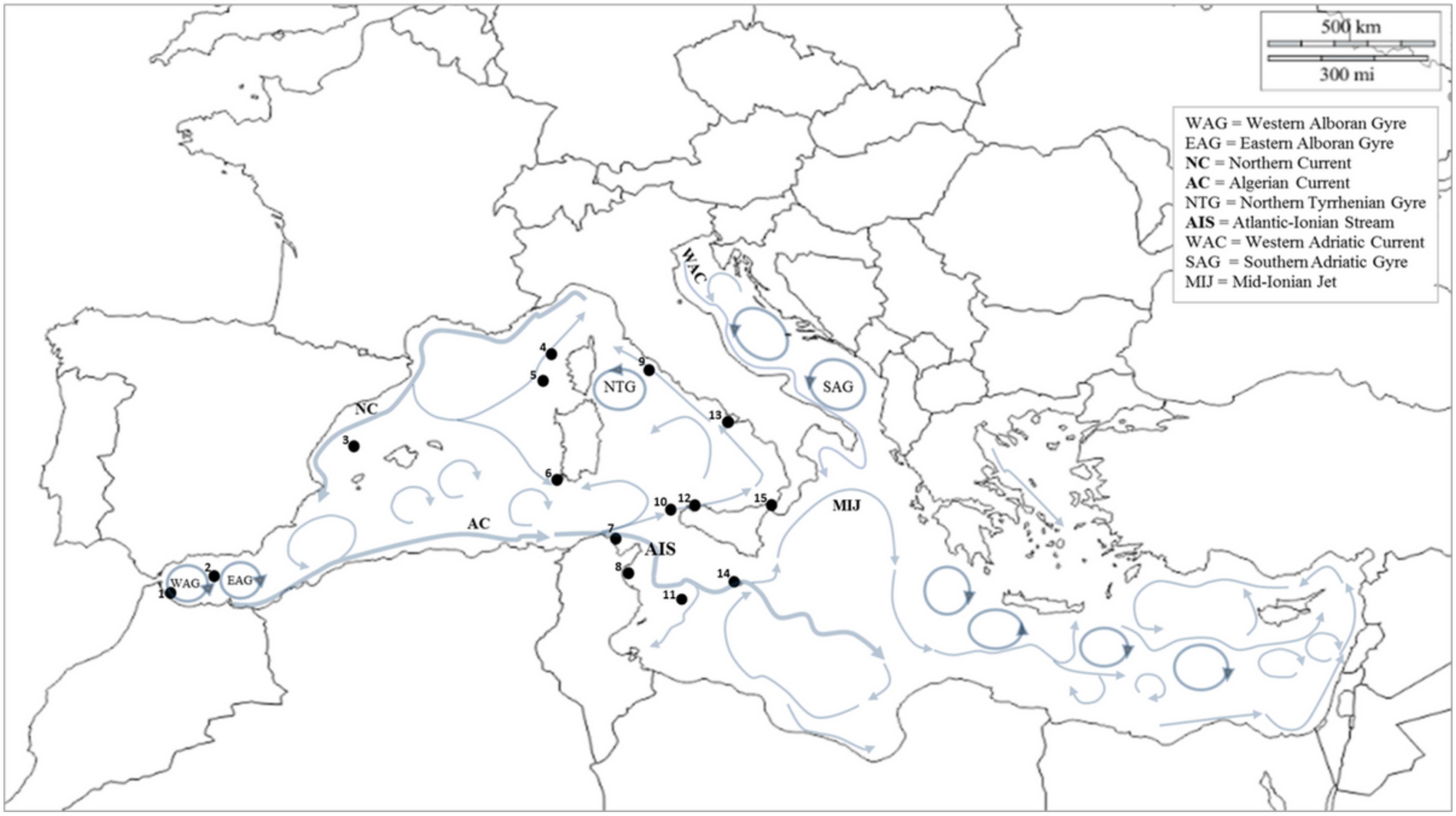

Figure 1

Map of Physalia physalis records in the Mediterranean Sea (1914 – 2021). The black points with the ID number indicate the area where P. physalis was found. The localities reported in Table 1 are associated with the ID number of such areas according to a neighbouring criterion. The arrows indicate the model of the main surface currents present in the Mediterranean Sea, according to Millot (1999) and Poulain et al. (2012).

Figure 2

The two colonies of Physalia physalis collected in the Gulf of Naples (Italy) in 1914, preserved at the “Darwin Dohrn” Museum of Naples (photo by Akira Kihara, Science Center, Hosei University, Tokyo; ©2007 Zoological Collection Database @Stazione Zoologica "Anton Dohrn").

Figure 3

The colony of Physalia physalis recorded in the north-western coast of Sicily, southern Tyrrhenian basin (2021), photo by Rosario Badalamenti.

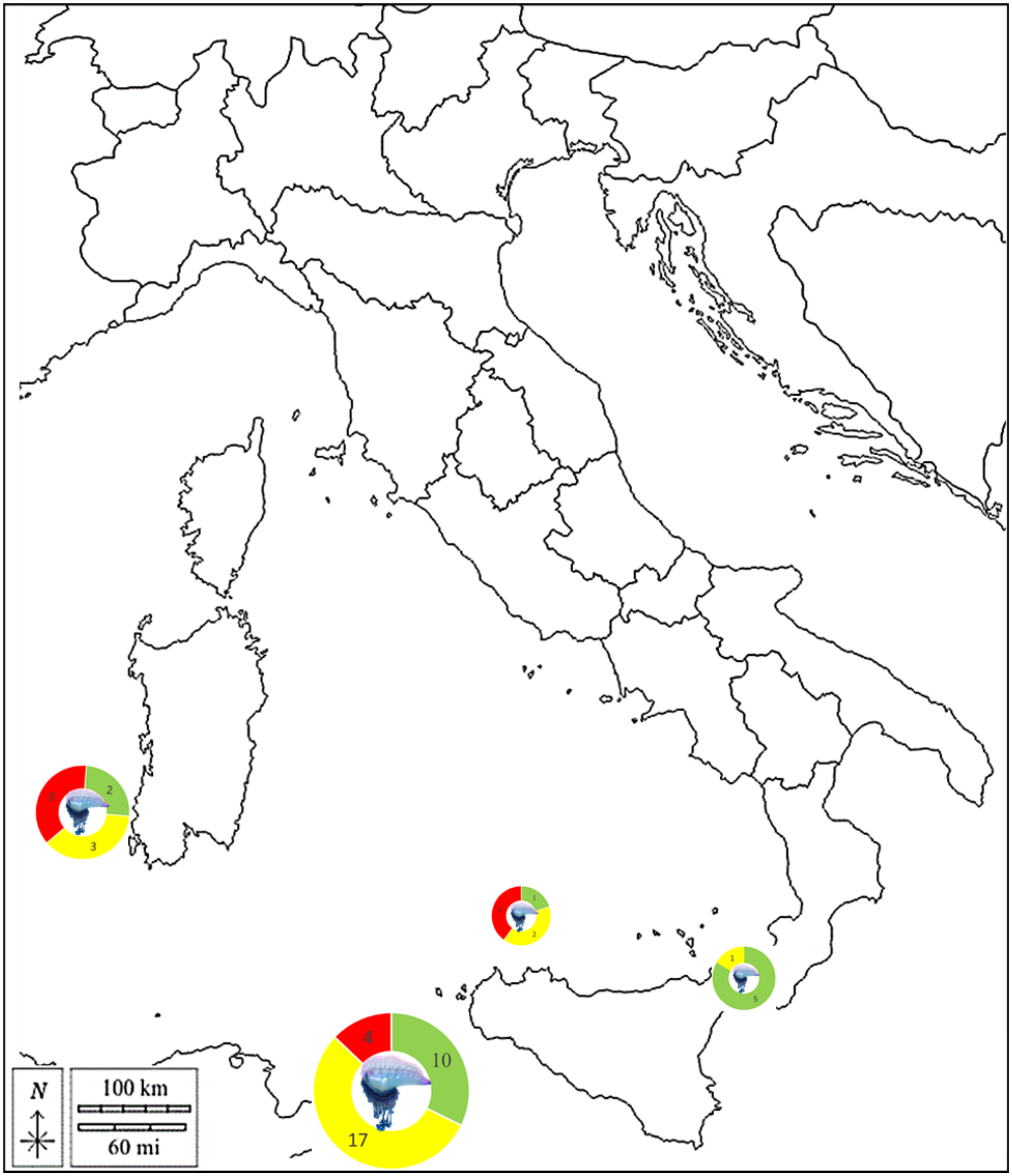

Figure 4

A schematic clustering of the records of P. physalis in the Italian maritime zone; the records were aggregated in four different sectors (from west to east, Sardinian waters; Channel of Sicily; Tyrrhenian Sea; Strait of Messina), and categorized to a level of risk for swimmers. Green indicates the number of colonies sighted in the period February-March (low-risk); yellow is the number of colonies sighted in the period April-May (medium-risk); red is the number of colonies sighted in the period June-August (high-risk).