Research Article

Mediterranean Marine Science
Indexed in WoS (Web of Science, ISI Thomson) and SCOPUS
www.hcmr.gr
DOI: https://doi.org/10.12681/mms.41723

Winning in the era of global change: new findings on the invasive fireworm *Hermodice caruncolata* (Annelida) along the Italian coasts obtained using Citizen Science

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Contributing Editor: Sarah FAULWETTER

Received: 05 June 2025; Accepted: 15 September 2025; Published online: 20 October 2025

Abstract

Invasive species and other factors contributing to global change can interact, leading to potentially synergistic impacts on marine ecosystems and the services they provide. The ongoing spread of the invasive, thermophilic and stinging fireworm *Hermodice carunculata* (Amphinomidae) along the Italian coasts has attracted special attention from the scientific community and the public. In 2021, we established the citizen science project "Monitoraggio Vermocane" (Fireworm Monitoring) to fill key gaps in knowledge related to the ecology, reproductive biology, current range expansion and possible impacts of *H. carunculata*. Over three years, more than 600 records were provided by professional divers and sea users using social networks. Data analysis revealed that 1) *H. carunculata* scavenges frequently on fishery waste, which may attract fireworms to anthropized areas and promote their growth, increasing the likelihood of human/fireworm interaction. Fireworms may also act as opportunistic consumers and kleptoparasites on ecosystem engineer anthozoans, which are already threatened due to heat stress and mechanical damage. 2) Fireworm spawning is linked to the lunar cycle, occurring during the summer throughout the Central Mediterranean at a depth of 2-16 m. The body posture and movement, and the aggregation of worms, may optimize their reproductive effort. 3) The range of *H. carunculata* is still expanding along the Tyrrhenian coasts and in Sardinia. These findings suggest that *H. carunculata* is emerging as a potential "winner" of human-driven changes in the Mediterranean Sea. Further studies based on both experiments and participatory science are needed to better assess the risk and damage associated with its expansion.

Keywords: distribution records; Amphinomidae; climate change; scuba diving; invasive species.

Introduction

Most aspects of global change, such as climate change and increasing disturbance, favour invasive species and exacerbate their impacts on native biodiversity and properties of the receiving ecosystem (Dukes & Mooney, 1999). Although it is generally attributed to allochthonous species that extend their range in an uncontrolled way, the adjective "invasive" can also refer to native species that conquer and dominate a new adjacent or nearby habitat (Valéry *et al.*, 2008). This is the case for thermophilic species that are expanding their range in response to climate warming, which may then over-compete or prey on local species that are weaker or less adapted to temperature increase (McCann & Bourdeau, 2025). A notable example of this phenomenon in the Mediterranean is the thermophilic fireworm *Hermodice carunculata*, a carnivorous amphinomid polychaete, which is expanding northward. *H. carunculata* may pose a threat for its prey, including keystone, cold-affinity cnidarians whose defences can be compromised by increased temperature, such in the case of the boreal zoanthid *Parazoanthus axinellae* (Cachet *et al.*, 2015; Righi *et al.*, 2020; Azzola *et al.*, 2025).

Currently, *H. carunculata* can be considered invasive in some regions of the Mediterranean Sea, due to its expansion from the central-eastern sectors towards the western and northern areas of the basin and the presence of high-density hotspots (Simonini *et al.*, 2017; Righi *et al.*, 2020; Toso *et al.*, 2020). Unlike many invasive species that go largely unnoticed, the fireworm, with its relatively large size, showy livery and poisonous chaetae, is widely known by swimmers and divers (Krželj *et al.*, 2020). Moreover, likely due to its potential danger to humans and its impact on artisanal fishery, *H. carunculata* has attracted the attention of the media and therefore the non-scientific public in the last fifteen years (Tiralongo *et al.*, 2023). Indeed, a simple search on Google Scholar using the words "*Hermodice carunculat*a Mediterranean" provides at least 9 international articles published from 2021 to May 2025. Furthermore, a search with "vermocane" carried out using Google News provides more than 100 articles published in traditional or online newspapers from May 2024 to May 2025 (Fig. S1).

Given that *H. carunculata* is a relatively large and visually distinctive species, it can be considered suitable for involving citizens in scientific data collection (Krželj *et al.*, 2020). Citizen Science (CS) involves a much larger and more diverse group of people than the traditional scientific community, promoting the democratization of science, making it accessible and more aligned with public interest (Sandahl & Tøttrup, 2020; Bertolucci, 2023; Coppari *et al.*, 2024). It also allows the improvement of relations among scientists, communities and policy managers (Bonney *et al.*, 2009; Thiel *et al.*, 2014; Hermoso *et al.*, 2021), as well as conservation practices (Hyder *et al.*, 2015; Vann-Sander *et al.*, 2016; Cvitanovic *et al.*, 2018; Hermoso *et al.*, 2021). Emerging technology such as social platforms involves billions of users (Oliveira *et al.*, 2021; Statista, 2024) and can be successfully used to increase environmental knowledge and awareness (Ambrose-Oji *et al.*, 2014; Van Vliet *et al.*, 2014; Hallman & Robinson, 2015; Taylor & Sammons, 2019) and to involve the public in Citizen Science projects (Rocha *et al.*, 2017; Oliveira *et al.*, 2021; Krželj *et al.*, 2020).

The updating of the geographic, bathymetric, and temporal distribution of invasive benthic organisms is essential to track their dispersal pathways and to understand to what extent they represent a threat for native biodiversity (Galil, 2012). Information retrieved from the web (Righi *et al.*, 2020), social profiles created *ad hoc* (Krželj *et al.*, 2020) and questionnaires (Righi *et al.*, 2020, Krželj *et al.*, 2020) was used in two studies on *H. carunculata* in the Central Mediterranean basins, published in 2020. These papers enabled the reconstruction of the fireworm's range and expansion from the mid-19th century to 2020, which is consistent with the ongoing regional warming of the western Mediterranean, and confirmed the breadth of its diet. Today, given the emerging problems related to the expansion of the fireworm, it is important to acquire new data on its distribution, habits, reproduction and ecology (Toso *et al.*, 2020, 2022; Tiralongo *et al.*, 2023) and to improve its quality in terms of completeness and objectivity. Indeed, the intrinsic nature of data that has been passively collected from social media and the web (created spontaneously and not generated within a well-defined scientific program) exposes it to the effect of subjectivity: people share what they consider noteworthy, and leave out other information. For example, in the study by Krželj *et al.* (2020), some local dive center owners had consulted marine biologists because they perceived the rapid spread of fireworms to be a threat to organisms that are attractive to recreational divers, such as gorgonians and starfish (Krželj *et al.*, 2020). The data collected was often incomplete, lacking temporal and spatial references (Righi *et al.*, 2020). Moreover, current knowledge of key aspects of fireworm biology, such as the timing of reproduction, is limited to a few locations (Toso *et al.*, 2020). *Ad hoc* monitoring through collaboration with SCUBA divers would enable the assessment of *H. carunculata* distribution on a finer scale (Righi *et al.*, 2020; Krželj *et al.*, 2020).

Since 2021, we have been implementing the citizen science project "Monitoraggio Vermocane", which takes advantage of social networks to involve professional divers and sea users in the collection of new data on the ecology, reproduction and distribution of the invasive fireworm *H. carunculata* along the Italian coasts. In the present study, we have analysed and discussed the results obtained during the first three years (2021-2023) of the project. In particular we: 1. provide new knowledge on the autecology of *H. carunculata* and its interaction with benthic organisms; 2. gain new insights into the behaviour and timing of spawning of the species in the central Mediterranean; 3. define the current range of *H. carunculata* along the Italian coasts, by providing its northern edge in the Tyrrhenian Sea, where fireworms have spread rapidly in recent decades; 4. explore the winning traits and socio-economic impacts of *H. carunculata* in the context of human-driven changes affecting the Mediterranean Sea.

Materials and Methods

Recruitment of volunteers and data collection

The research was conducted from January 2021 to December 2023, following the recommendations of Oliveira *et al.* (2021), Hermoso *et al.* (2021) and Krzelj *et al.* (2020) in order to optimize the collection of naturalistic records using Citizen Science and social platforms. Given that the Tyrrhenian Sea seems to be the basin of greatest interest for research into the biogeography of *H. carunculata* in the Mediterranean (Righi *et al.*, 2020) and is almost surrounded by Italian territories, it was preferable to use Italian rather than English as the language used on social platforms to facilitate interactions with the public. Since the common name of *H. carunculata* in Italian is "Vermocane", two public profiles, both called "Monitoraggio Vermocane" (MV), were created on Facebook (https://www.facebook.com/MonitoraggioVermocane) and Instagram (https://www.instagram.com/monitoraggiovermocane/), which are the most popular social networks in the study area (Italy) and those preferred by divers (Righi *et al*., 2020; Krželj *et al.*, 2020). The fan pages were also linked to an email address (monitoraggiovermocane@gmail.com) which, together with the social networks' contact tools, was used to ask the volunteers for further information to validate incomplete records. Starting from January 2021, an initial network of participants was created, by contacting them using phone, email and social media and asking 40 dive centre owners and their representatives to participate (Table S1).

These professional divers were involved in writing clear guidelines to identify the fireworm and its prey, in order to collect environmental information (location, depth, temperature), and provide participants with the necessary guidelines to behave appropriately (e.g., do not collect/touch fireworms). The guideline texts and figures were mostly based on the authors publications on fireworm behaviour (Simonini *et al.*, 2018; Toso *et al.*, 2020), distribution (Righi *et al.*, 2020) and threat (Krželj *et al.*, 2020; Righi *et al.*, 2021).

The guidelines and objectives were publicized using social media posts (reposted every year) and informative posters and flyers that dive center owners could distribute to their customers.

The public was also informed about the painful stings that the polychaete may inflict if touched (Righi *et al.*, 2021). To gather new insights into the behaviour and timing of spawning of the species, posts containing images and videos of fireworm reproductive events were published, accompanied by a brief description to help the public recognize and report them. During spawning, male and female individuals elevate and oscillate the anterior part of their body, promoting the release of sperm and eggs, which do not appear to attract fish (Toso *et al.*, 2020). These posts were published regularly two weeks before the full moons of July, August, and September, with the aim of encouraging observations during the period when spawning was most likely to occur. Indeed, Toso *et al*. (2020), documented spawning events between three and ten days after the full moons of July and August 2019 near Porto Cesareo (Apulia, Italy).

Participants could submit reports directly via email, via MV's social media (by commenting on posts or messages on Messenger), or by posting them on their social profiles and informing MV (by directly tagging the text of the post or in the comments). Requests were made to provide site, date (mandatory), photos and/or videos, depth and sea temperature (recommended but optional). All messages, posts and comments were checked for data reliability and to extrapolate the record. When information was lacking, users were contacted directly to integrate the missing data and ask for further photos/videos or data.

To reach a larger number of citizen scientists and obtain a higher number of fireworm records, user-friendly questionnaires were administered using MV's social media and leaflets with QR codes distributed to dive centres and interviews with sea users. The structure and the "Google Form" survey method of questionnaires was left in accordance with Righi *et al.*, (2020). The answers to the questionnaire were extracted, classified and catalogued using the same approach as the reports collected via social media.

Insights obtained through Facebook's "Meta Business Suite" were used to obtain the number of followers for both the Facebook and Instagram pages. Based on these data, we estimated the number of people involved in the project that were using social networks, including passive post and comment readers, commenters and active data contributors. The contributors were classified based on the activity they were engaged in at the time of the fireworm sighting, that is, scuba divers (conducting long dives with the aid of scuba equipment), free divers (conducting short dives without scuba equipment), bathers (remaining in shallow waters near the shore), and fishermen (involving in artisanal fishing). This information was extrapolated from the report or requested to the contributor.

Ecological insights into **H. carunculata**

The information obtained was processed and collected in a dataset in accordance with the format applied by Righi *et al.* (2020). Each record was considered as a count and classified according to the season, substrate and sea depth. The classification according to season was carried out considering Summer (July-September), Autumn (October-December), Winter (January-March) and Spring (April-June) as categories. With regard to the substrate, the following categories were considered: Rocky (bare bottoms, rocky walls and bottoms dominated by photophilous or sciaphilous algae, caves and coralligenous structures) (Pérès & Picard, 1964; Bellan-Santini *et al.*, 1994); Sediment (soft mud/sand substrates); Wrecks; Seagrass (i.e., *Posidonia oceanica* beds). Reports including the depth were classified in the categories "0–2 m", "2–20 m", "> 20 m"; in addition, when fireworms were found on beaches or piers, they were classified as "Beached". Reports that could not be assigned to one category were considered as "not determined". Depth and temperature values were also examined considering the main descriptive statistics (mean, standard deviation, minimum and maximum).

When photographs were available, all relevant information (e.g., habitat, feeding behaviour) was obtained directly from the images and/or from the author of the report. When a predation event was documented, prey was identified to the lowest possible taxonomic level (e.g., species, genus) and then assigned to its Phylum (e.g., Echinodermata, Cnidaria). Cases of fireworms feeding on fish carcasses (naturally deceased fish, fishing discards, fish trapped in fishing gears) or fishing bait (e.g., anglers' baited hooks with waxworms) were also considered.

Finally, records were assigned to one of four broader groups of trophic resources: "Cnidarians", "Echinoderms", "Carcasses & baits" and "Other". The latter included all prey types that did not fall into the previous categories (e.g., Bryozoa, Mollusca).

Seasonal and habitat preferences and prey item consumption (broad category) frequencies were compared between the present study and Righi *et al.* (2020) by means of the Chi-square test ($\chi 2$) using the statistical software Past (Hammer *et al.*, 2001). The number and percentages of reports for which it was not possible to assign to a season, type of substrate or depth category ("not determined" reports) were provided for both studies.

Predation on gorgonians

Recent research suggests that fireworms forage on anthozoans when they are stressed and affected by tissue necrosis (Bosch-Belmar *et al.*, 2024; Azzola *et al.*, 2025; Bonacolta *et al.*, 2025). The previous study on the feeding habits of *H. carunculata* in the central Mediterranean highlighted that gorgonians were the most frequently consumed prey, but the low availability of photos and videos did not permit the assessment of gorgonian health status (Righi *et al.*, 2020). To provide observational data supporting a tendency of *H. carunculata* to forage opportunistically on unhealthy specimens, the best quality photos and videos of fireworms consuming gorgonians (with both the worms and the gorgonians in clear focus) were carefully analysed to distinguish three categories of damage: type A (very recent, consisting of bare branch or tips, likely caused by worm predation), type B (recent, with branches colonized by pioneer epibionts, such as filamentous algae and hydrozoans), and type C (old, with advanced recolonization by long-lived species such as bryozoans, sponges and algae) according to Iborra *et al.* (2022).

Insights into the reproduction of H. carunculata

Several participants reported photos/videos of spawning events together with date and geographical location. All the information provided by the volunteers or obtained by examining the photos/videos (i.e., the environmental traits like substrate type and exposure, depth and temperature), date and the worm behaviour (i.e., aggregation among individuals, posture and movement) were considered in order to understand this crucial phase of the fireworm life cycle better, taking into account the description of spawning reported by Toso *et al.* (2020). Coordination of spawning with lunar periodicity was estimated by calculating the days that elapsed between the date of the report and the date of the closest full moon.

Distribution of H. carunculata

Geographical coordinates of the finding were retrieved using Google Maps based on the data provided by social platforms to obtain a distribution map of the fireworm along the Italian coasts using the QGIS 3.38 Grenoble software (QGIS Development Team).

For the ecological insight analysis described above, when multiple sightings were provided by the same participant on the same date and location, they were treated as separate records. Otherwise, for distribution analysis, they were pooled and considered as one report. For example, three worms reported by the same person from Catania on August 20, 2022, in three different types of substrates were considered as a single report for distribution analysis (i.e., "Catania") but were treated as three separate observations (e.g., "seagrass", "wrecks", "rocks") for ecological analysis, as they were associated with different substrates. To analyze the geographical distribution of the species, the criteria proposed in the study by Righi *et al.* (2020) were adopted. All records from sites within 10 km of a locality already known for the presence of fireworms were attributed to that one. The remaining ones ("first reports") were considered as new localities. A locality is a commonly accepted toponym or with administrative value, such as an island or a peninsula, a town or a city (Righi *et al.*, 2020).

The reliability of reports from localities placed near or beyond the distribution limits of the species indicated by Righi *et al.* (2020) was always verified by consulting the dive centers operating in the area. In addition, the support of the public enabled the correction of previous errors, such as reports of fireworms from Northern Sardinia (Namely "Porto Torres" and "Lavezzi Island") between 2009 and 2014, where the species has never been observed by local divers and fishermen.

The localities were attributed to one of the Mediterranean basins of Italian interest, i.e., Tyrrhenian Sea, Sicily Strait, Ionian Sea, Adriatic Sea (IHO, 1953). Distribution frequency of records from basins were compared between the present study and Righi *et al.* (2020) by means of the Chi-square test ($\chi 2$) using the statistical software Past (Hammer *et al.*, 2001). Only reports from the Italian coast were included.

Results

Engagement of volunteers and data collection

Over the three years of "Monitoraggio vermocane" activity, a total of 275 posts was published on the Facebook page (128 in 2021, 87 in 2022, and 60 in 2023), and 141 on the Instagram page (62 in 2021, 38 in 2022, and 41 in 2023). Using the two social networks considered, a total of 1,173 people were reached, including active contributors providing data, commenters, and post and comment readers (80% via Facebook and 20% via Instagram). By the end of the first year (2021), the number of followers was 437 on Facebook and 143 on Instagram. After the second year (2022), follower counts had increased to 764 and 191, respectively. Two years after the project began (2023), the number of followers on Facebook and Instagram reached 938 and 235 respectively. Most of the reports (86%) were obtained through social channels (Facebook, Instagram), while the remaining 14% were collected through questionnaires. Active contributors were mostly scuba divers (76%), followed by free divers (8%), bathers (14%), and fishermen (2%).

Ecological insights into H. carunculata

From January 2021 to December 2023, 606 records of *H. carunculata* were collected. The sightings occurred mostly in summer (69%, Table 1), followed by spring (22%), autumn (7%) and winter (2%).

The type of substrate on which the fireworms were

Table 1. Ecological features of *H. carunculata* extrapolated from the records provided by the public in the present study ("Monitoraggio vermocane") and the data obtained by Righi *et al.* (2020). The number and percentages of the "not determined" reports are provided in italics. The results of chi-square test (χ2 statistic and its significance [*=p<0.05; **=p<0.01 ***=p<0.001) for the comparison of seasonal and habitat preferences between the present study and Righi *et al.* (2020) are provided.

	Present Study			**Righi *et al.*, 2020**	
	n	**%**		**n**	**%**
Season					
Winter	14	2%		21	3%
Spring	133	22%		149	21%
Summer	415	68%		417	59%
Autumn	44	7%		123	17%
Sum	606			710	
Not determined	*0*	*0%*		*147*	*17%*
Chi-square			31.51***		
Substrate					
Rocky	381	79%		577	84%
Sediment	74	15%		60	9%
Wreck	11	2%		16	2%
Seagrass	13	3%		30	4%
Sum	479			683	
Not determined	*127*	*21%*		*174*	*20%*
Chi-square			11.59**		
Depth					
Beached	4	1%		28	9%
<2 m	86	20%		103	33%
2-20 m	286	66%		128	40%
>20 m	57	13%		58	18%
Sum	433			317	
Not determined	*177*	*29%*		*540*	*63%*
Chi-square			56,68***		

found was recognized in almost 80% of cases. Fireworms were observed mainly in rocky habitats (79%), but also in sedimentary environments (15%, Fig. 1A), in seagrasses (3%) and on wrecks (2%).

The depth was specified in 71% of the reports. Except for four cases of beached worms, reports ranged from low tide level (0.2-0.5 m) up to 86 m (mean ± standard deviation: 12±10 m). About 2/3 of the records (286) came from depths between 2 and 20 m, while 20% (86) and 13% (57) referred respectively to specimens found close to the coast (0-2 m) or in environments deeper than 20 m (Table 1). The temperature was included in 25% of the reports and ranged from 14 to 30°C (22±4°C).

Regarding trophic behaviour (Figs 1, 2, Table 2), 128 reports of *H. carunculata* feeding on different resources were collected (21% of the total number of reports). In 30% of cases, the worms showed scavenging behaviour, consuming fish carcasses and fishing waste (which includes by-catch, fish remains, fish trapped in nets, Fig. 1A, B) and, more rarely, baits. Clusters containing dozens of fireworms were observed on the largest fish remains. These records were obtained from the seashore to a depth of 22 m.

Many predation events involved cnidarians (38%, Table 2) belonging to different groups: hydrozoan jellyfish (*Olindias phosphorica*) and polyps (*Eudendrium* spp.); scyphozoans (*Cotylorhiza tuberculata* and *Pelagia noctiluca* Fig. 1C); actinians (*Anemonia viridis*); scleractinians (*Astroides calycularis*, Fig. 1D); zoanthids (*P. axinellae*) and gorgonians (described in the next paragraph). Two of the most interesting, unusual and detailed reports (one from Sicily and one from Calabria) concerned kleptoparasitism events in which a fireworm was stealing and consuming a jellyfish (*P. noctiluca*) that had been captured by the coral *A. calycularis* (Fig. 1C). Predation on echinoderms was also quite common (23%, Table 2), involving sea urchins (*Paracentrotus lividus, Spatangius purpureus*), starfish (*Ophidiaster ophidianus* and *Hacelia attenuata*) and sea cucumbers (*Holothuria* sp.). Other prey (10%, Table 2) were molluscs with re-

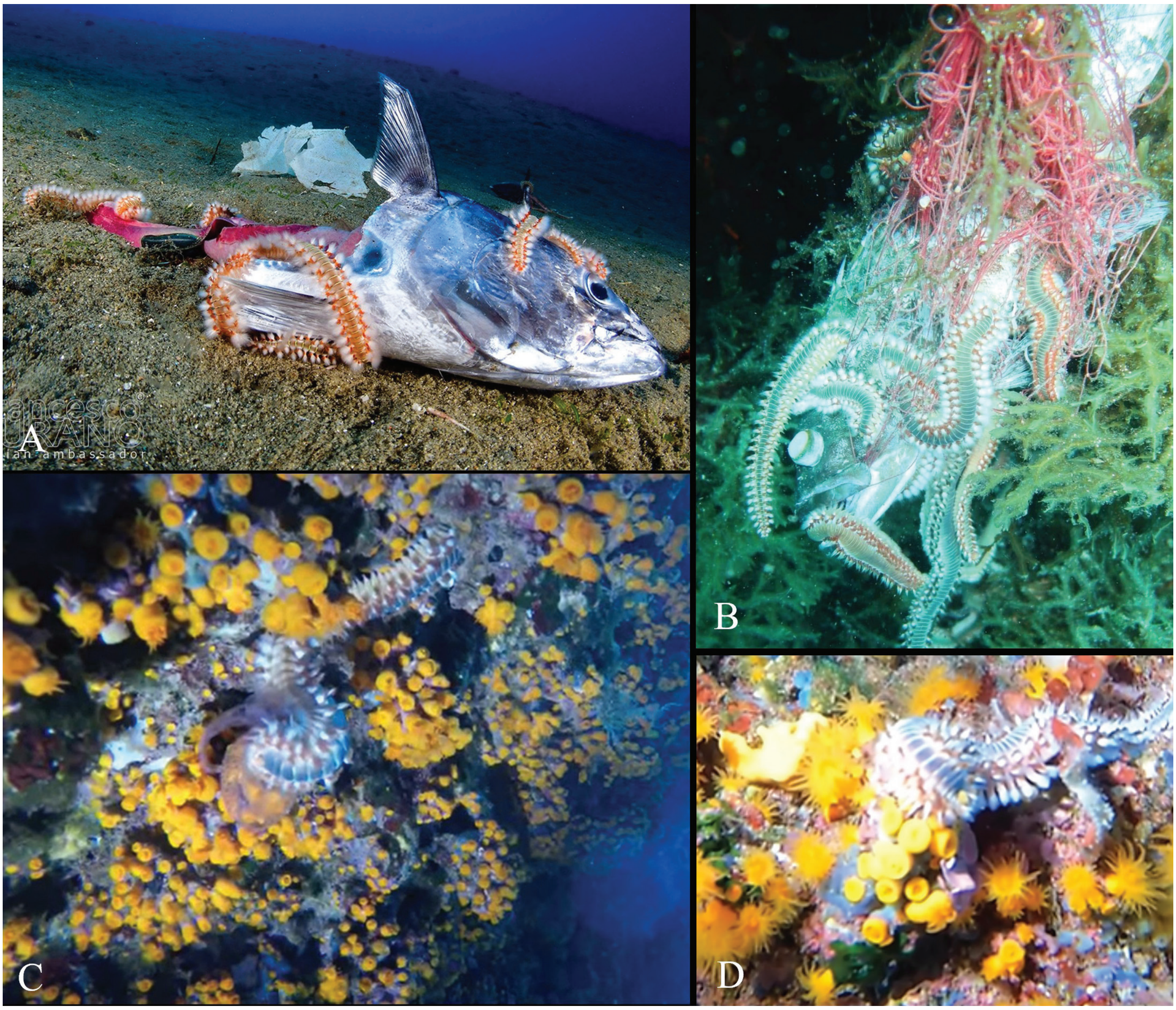

Fig. 1: Fireworm scavenging behaviour: (A) Many fireworms consuming fishing discards on sandy bottom (Pellaro, 06/10/2023) and (B) a fish trapped in fishing gear (Capo Vaticano, 07/07/2019). Fireworm kleptoparasitism: (C) A fireworm consuming a jellyfish (*Pelagia noctiluca*) captured by the polyps of the scleractinian *Astroides calycularis* (San Vito Lo Capo, 30/08/2022). Fireworm predation: (D) A fireworm preying on *A. calycularis* in a rocky habitat (San Vito Lo Capo, 02/09/2023). Links to social posts, including the author's name, of the images are reported in Table S3.

duced shells or without, tube worms (*Sabella* spp.) and bryozoans (*Myriapora truncata*). No predation activities on *H. carunculata* were reported: the only exception was a crab ingesting worm fragments, but no details on the interaction (i.e., worm health status, duration of the feeding event) between the two species were provided. Divers also reported two fish (a wrasse and a goby) that had abundant fireworm bristles in their mouths. They assumed that these were predation attempts, but there were no reports of fish consuming fireworms.

Predation on gorgonians

Gorgonian predation accounted for about 19% of all foraging reports (about 27% excluding baits and fish waste, Table 2). Photos and videos showed that, when foraging on gorgonians, fireworms usually engulfed the branch inside their body to considerable lengths (up to 5-10 cm), removing tissue and leaving only the bare axis. Fireworm predation affected at least five species i.e., *Paramuricea clavata* (Fig. 2A), *Eunicella cavolini* (Fig. 2B), *E. singularis* (Fig. 2D), *Leptogorgia sarmentosa* (Fig. 2C) and *Acanthogorgia hirsuta*.

Predation events were observed between 9 m (*E. singularis*) and 86 m in depth (*A. hirsuta*). In 60% of gorgonian predation reports (14/24), it was possible to assess the health status of the colonies thanks to the availability of good quality photos or videos (Fig. 2). Typically, only one specimen of *H. carunculata* was present per colony, except for two cases where two worms were foraging simultaneously on the same gorgonian. Only two gorgonians were healthy (with no bare skeleton or branches with signs of necrosis) (14%), while four (29%) showed only type A damage (Fig. 2C), indicative of very recent fireworm foraging. Most gorgonians (eight, corresponding to 57%) were unhealthy, exhibiting many branches colonised by epibionts (type B and/or C damage, e.g., Fig. 2A, B, D).

Table 2. Trophic resources exploited by *Hermodice carunculata* extrapolated from the record provided by the public in the present study (“Monitoraggio vermocane”) and the data obtained by Righi *et al.* (2020). The result of chi-square test (χ2 statistic and its significance [*=p<0.05; **=p<0.01 ***=p<0.001) for the comparison of preferences in the resource exploited (broad group) between the present study and Righi *et al.* (2020) is provided.

		Present study			**Righi et al., 2020**	
		n	**%**		**n**	**%**
Higher taxa	**Resources exploited**					
	Baits	9	7,0%		0	0,0%
	Fish carcasses	29	22,7%		109	44,1%
Cnidaria						
Hydrozoa	Hydrozoan polyps	2	1,6%		2	0,8%
Scyphozoa and Hydrozoa	Jellyfish	12	9,4%		14	5,7%
Actiniaria	Sea anemones	2	1,6%		2	0,8%
Zoantharia	Zoanthids	0	0,0%		7	2,8%
Octocorallia	Gorgonians	24	18,8%		36	14,6%
Scleractinia	Scleractinians	8	6,3%		3	1,2%
Annelida						
Polychaeta	Tube worms	9	7,0%		8	3,2%
Mollusca						
Polyplacophora	Chiton	0	0,0%		1	0,4%
Heterobranchia	Sea slugs	2	1,6%		3	1,2%
Octopoda	Octopus	0	0,0%		2	0,8%
Bivalvia	Bivalves	0	0%		6	2,4%
Echinodermata						
Holothuroidea	Sea cucumbers	6	4,7%		6	2,4%
Echinoidea	Sea urchins	5	3,9%		24	9,7%
Asteroidea	Starfish	18	14,1%		19	7,7%
Bryozoa	Bryozoans	2	1,6%		3	1,2%
Tunicata	Thaliaceans	0	0%		1	0,4%
Porifera	Sponges	0	0%		1	0,4%
Sum	Sum	128			247	
Broad group of trophic resources						
Carcasses & baits		38	30%		109	44%
Cnidaria		48	38%		64	26%
Echinodermata		29	23%		49	20%
Other organisms		13	10%		25	10%
	chi-square			8.60*		

Insights into the reproduction of H. carunculata

During this project, we obtained thirteen spawning reports (Fig. 3). The examination of photos and videos showed that reproducing worms gathered on rocky ledges on the bottom, raising and oscillating their anterior portion towards the surface (instead of crawling on the bottom). Gamete emission caused the water to become cloudy in the immediate vicinity of worms. No fish were observed approaching the gamete clouds.

The spawning reports enabled the examination of the aggregation tendency in 38 specimens of *H. carunculata*. Most of these fireworms (87%) were tangled in clusters containing from 2 to 7 individuals (4±2); the other specimens stayed alone, but two of them (5%) were close to a large cluster (about 1-2 m of distance), while the remaining three (8%) seemed to be alone.

All spawning events occurred during the summer season within nine days of the full moon.

In 2021, four spawning events were reported between July (Fig. 3A) and August (Fig. 3B): one came from the Ionian Apulia (July 26, full moon on July 24, Fig. 3A) and three from western Sicily on July 25 (Fig. 3A) and August 24 and 25 (full moon on August 22, Fig. 3B).

In 2022 (Fig. 3C, D), five spawning events were documented from Sicily and Ionian Apulia in July (12, 16 and 20 July, full moon 13 July, Fig. 3C), and from northern Sardinia and western Sicily in August (12 and 14 August, full moon 12 August, Fig. 3D).

In 2023 (Fig. 3E, F), three reproductive events were

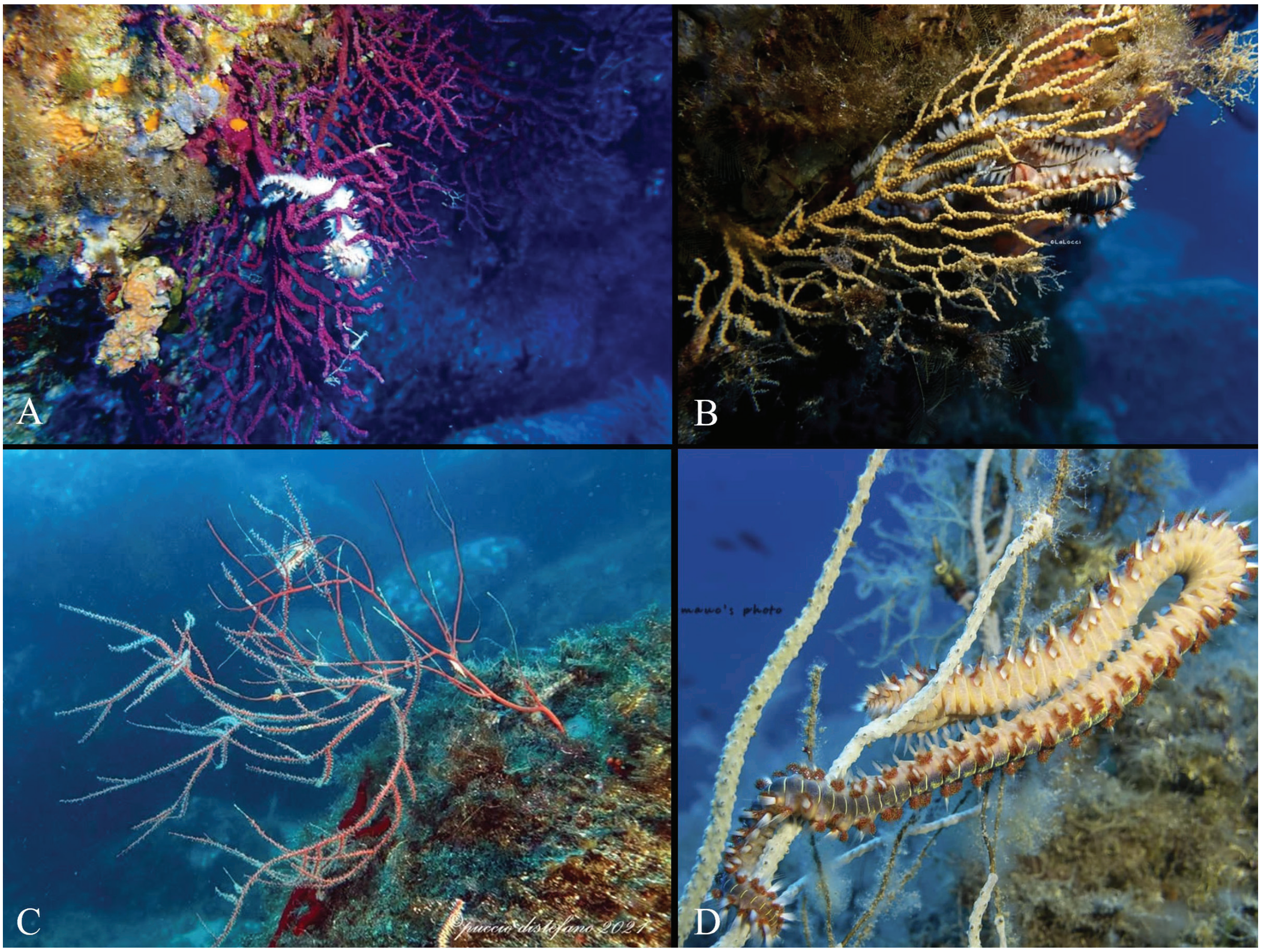

Fig. 2: Examples of predation by *Hermodice carunculata* on gorgonians: (A) *Paramuricea clavata* showing type A and B damage (Villasimius, 09/2022); (B) *Eunicella cavolini* showing type A, B and C damage (Villasimius, 01/11/2022); (C) *Leptogorgia sarmentosa* showing only type A damage (Acireale, 01/08/2022); (D) *Eunicella singularis* showing type B and C damage (Villasimius, 07/07/2021). Links to social posts, including the author's name, of the images are reported in Table S3.

documented: the first two in August (from western Sicily and Pantelleria (Sicily Strait) on 2 and 4 August respectively, full moon 1 August, Fig. 3E), the last one in September (from Ionian Apulia and western Sicily, 2 and 9 September respectively, full moon 31 August, Fig. 3F).

Seawater temperature was provided in four reports and ranged from 22°C (September 2023) to 26°C (July and August 2021). The depth was present in 7 reports and ranged from 2 to 16 m (7±5 m).

Distribution of **H. carunculata**

From January 2021 to December 2023, 457 single reports of fireworms were obtained (Table S2). Overall, the reports came from 76 locations distributed from the southwestern coast of Sardinia and the Tuscan Archipelago (Western Mediterranean) to the Ionian Sea and Southern Adriatic Sea (Eastern Mediterranean) (Fig. 4, Table 3).

Of the 76 localities from which reports were received, 21 (about 28%) were new localities where the presence of *H. carunculata* had not been previously documented. Of those found in the Italian peninsula and in Sicily, 10 were within the previous range, while one (Formiche di Grosseto, Tuscany) was the most northerly site to be found in the Tyrrhenian Sea (Fig. 4). Most of the new reports (11) came from Sardinia: the three northernmost (Isola Mortorio, Capo Figari, Tavolara) and the two easternmost (Golfo di Palma and Isola Piana) were located outside the previous distribution area (Fig. 4).

Almost two-thirds of the reports came from the Tyrrhenian area (60%); the remaining mainly referred to sites located along the Ionian coasts (29%), while reports from the Adriatic and the Strait of Sicily were 6% and 5%, respectively.

Comparison with previous studies

In the work by Righi *et al.* (2020), the season was only determined in 83% of the reports: summer was also the season in which reports were most frequent (59%), but the seasonal distribution was more balanced than that observed in this study, with a higher frequency of reports in autumn (Table 1).

Concerning the type of substrates, the differences between the present study and Righi *et al.* (2020) are main-

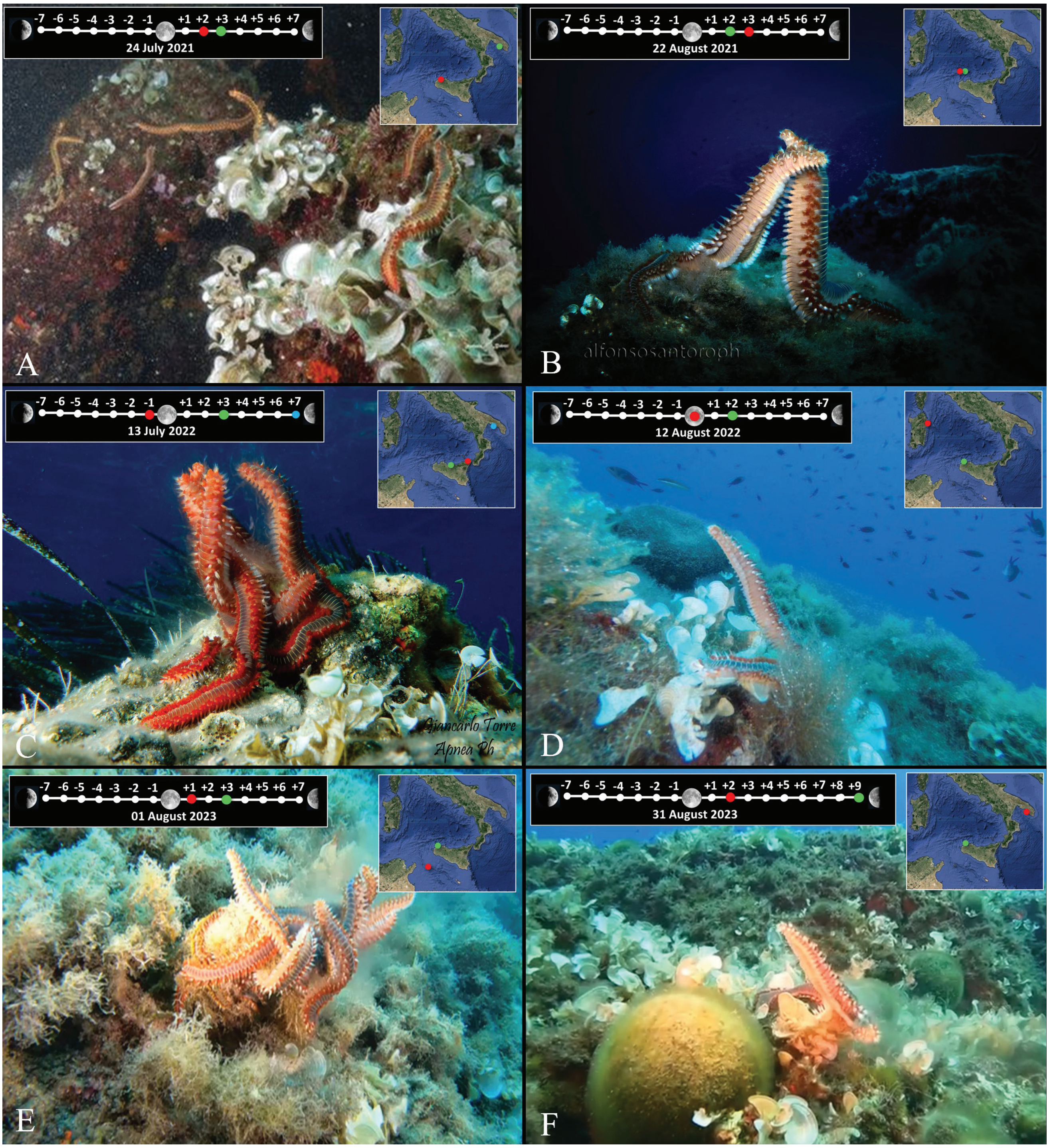

Fig. 3: Representative *Hermodice carunculata* breeding events observed from spring 2021 to fall 2023. (A) July 2021; (B) August 2021; (C) July 2022; (D) August 2022; (E) August 2023; (F) September 2023. Each image represents a separate event and includes a timeline showing when it occurred relative to the full moon date (top left, fourteen-day timeline, centred on the full moon date) and a map showing the localities and dates (coloured dots) in which breeding events occurred under the same moon cycle time frame (red dots denotes the localities of collection of each photo, green and cyan dots indicate other localities in which the spawning occurred in the same lunar cycle). Links to social posts, including the author's name, of the images are reported in Table S3.

ly attributable to a different distribution of the reports between the two main categories (Rocky and Sediment, Table 1).

In Righi *et al.* (2020) information on depth was lacking in 63% of the reports, and the frequency of sightings at low depth was higher than those found in the present study (Table 1). Moreover, information on temperature was present in less than 5% of the reports.

The comparison of the trophic habits of *H. carunculata* (in terms of frequency of consumption of broad categories of resources) between the present study and Righi *et al.* (2020) showed an increase in reports of prey (cnidarians and echinoderms) and a reduction in those of fish carcasses (Table 2).

Comparing the frequency of *H. carunculata* in the Mediterranean basins surrounding Italy between the pres-

Table 3. Frequency of *Hermodice carunculata* in the Mediterranean Sea basins surrounding the Italian Peninsula deduced from the records provided by the public in the present study and the data extrapolated from Righi *et al.* (2020). Only reports from the Italian coast are included. The result of chi-square test ($\chi 2$ statistic and its significance [*=p<0.05; **=p<0.01 ***=p<0.001) for the comparison of frequency among the basins between the present study and Righi *et al.* (2020) is provided. The number and frequency of records from the area "Sicily+ Strait of Messina+ Ionian Apulia" (including the records from Sicily, the Aeolian, Pelagian and Aegadian archipelagos, Pantelleria and Ustica islands, the Calabrian coast from Scilla to Saline Ioniche, and the Apulian coast from Porto Pirrone to Santa Maria di Leuca) are also provided.

	Present study (2021-23)			Righi *et al.*, 2020	
	n	%		n	%
Basins					
Tyrrhenian Sea	274	60%		178	34%
Strait of Sicily	24	5%		67	13%
Ionian Sea	131	29%		244	37%
Adriatic Sea	28	6%		33	6%
Sum	457			522	
chi-square			70.66***		
Sicily + Strait of Messina + Ionian Apulia	304	66%		328	63%

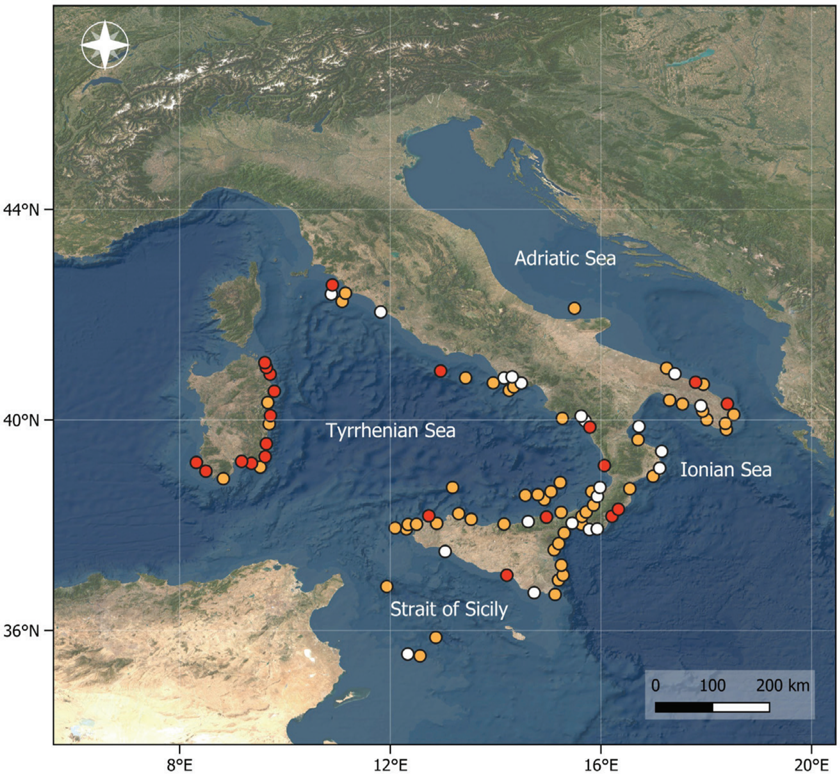

Fig. 4: Distribution of *Hermodice carunculata* in Italy. Localities in which the presence of the fireworm has been documented in both Righi *et al.* (2020) and in the present study (orange dots); only in Righi *et al.* (2020) (white dots) and for the first time in the present study (new localities, red dots).

ent study and Righi *et al.* (2020), the main differences concern mainly the Tyrrhenian area (high frequencies in this study) and the Ionian area (low frequencies in this study) (Table 3). Localities in which the fireworm presence has been documented in both Righi *et al*., 2020 and in the present study represented over 70% of the whole (n = 55) (Fig. 4). These overlapping locations were mainly distributed along the Ionian Apulia, the Strait of Messina, and the Sicilian coast. These areas accounted for about 66% and 63% of the sightings in the present study and in Righi *et al.* (2020), respectively (Table 3). Twenty-one localities (about 30%) were only reported in Righi *et al.* (2020) (Fig. 4): they were in areas where the fireworm was reported in the present study (Fig. 4). The remaining ones were the new localities documented for the first time in this study, which are described above.

Discussion

Engagement of volunteers and data collection

The initial involvement of dive centre owners, along with the request for specific information, such as depth and temperature, enabled scuba divers to become the most active participants and the main contributors of *H. carunculata* sightings. The high number of reports received via Facebook and Instagram confirms the effectiveness of the social media-based approach in engaging and training participants (Langeneck *et al*., 2022). Further evidence lies in the continuous increase in followers, more than doubling on the Facebook page and increasing by 65% on Instagram between the end of the first and third years of the project. They actively participate in the initiative by supplying their useful photo and video records. The direct involvement of divers and the relatively long duration of the project allowed us to focus on an area of greater interest and to collect more informative data than the previous study, by exploiting Web Ecological knowledge and Social networks to investigate Mediterranean *H. carunculata* populations (Krželj *et al*., 2020; Righi *et al*., 2020).

Ecological insights into **H. carunculata**

This study further highlights that fireworm sightings in the Mediterranean come mainly from infralittoral hard bottoms, although the worm has been recorded on sedimentary bottoms especially in certain places, such as in the Strait of Messina. Here, photographs and videos often showed dense populations on mixed bottoms, dominated by coarse sand or pebbles affected by bottom currents (Fig. 1A). *H. carunculata* in the Strait of Messina is frequently found on "patches" of hard substrate (natural or artificial), probably using them as a refuge from which to crawl in search of food on sediments. This could be linked to the polychaete's preference for hard bottoms, as well as a bias resulting from the lack of data on diving activity in mixed substrates from other areas.

Contrary to the research of Righi *et al.* (2020), in this study, information on depth was provided for most records (Table 1). Observations of *H. carunculata* in very shallow waters near the coast (0-2 m, especially less than 0.5 m) were collected only during the warm season (seawater temperature ranging from 23 to 27°C) in Sicily, Calabria and Apulia by people staying in highly frequented areas, such as coastal ponds, fishing spots and piers used by traditional fishermen. Actively foraging specimens were observed from the surface down to a depth of 86 m and from January to November, with temperatures ranging from 14 to 28°C. The massive involvement of divers allowed us to collect a lot of information from the 2-20 m depth range (Table 1), where more than 70% of predation events were observed.

The public reported cases of saprophagy, predation (including opportunistic predation) on a wide range of organisms and two cases of kleptoparasitism.

About a quarter of the reports concerned worms feeding on live organisms, most commonly cnidarians. It is possible that the public provided an overestimation of the real predation rates by sharing the events considered to be the most amazing. It is indeed plausible that recreational divers paid more attention to events perceived as unusual or harmful to iconic organisms (e.g., fireworms consuming a gorgonian), rather than to immobile or slow moving fireworms (Krželj *et al.*, 2020). Most of the prey were already known in the literature, such as the gorgonians *P. clavata* (Mistri & Ceccherelli, 1994), *Eunicella* spp. (Righi *et al.*, 2020) and the sea star *H. attenuata* (Krželj *et al.*, 2020).

Besides, predation on the sea urchin *P. lividus* was reported (Simonini *et al.*, 2017), even if it has been observed only in the central-eastern basins so far: the lack of reports from the Tyrrhenian area suggests a possible specialization of trophic habits among populations of worms colonizing different geographical areas (Righi *et al.*, 2020). Notable "novelties" include predation events on the relatively rare or deep-sea gorgonians *L. sarmentosa* and *A. hirsuta.* Most of the fireworm prey are important Mediterranean keystone and/or bioconstructor species. Moreover, all these species are of particular interest to divers and attract their attention. Laboratory and field experiments are needed to assess fireworm impact on shallow rocky bottom communities and evaluate if fireworms' voracious feeding habits can compromise the attractiveness of popular dive destinations (Righi *et al.*, 2021; Simonini *et al.*, 2021; Bosch-Belmar *et al.*, 2024; Azzola *et al.*, 2025).

Kleptoparasitism is a type of predator-predator interaction in which one animal steals resources from another that has expended effort to acquire them (Rothschild & Clay, 1957; Bavestrello *et al.*, 1996). In many cases, the food owner engages in a counter-attack on the kleptoparasite (Bhattacharjee *et al.*, 2024). This project provided reports of benthic fireworms acting as kleptoparasites, consuming jellyfish stolen from *A. calycularis* without the need to invest time and energy in searching for and immobilizing such planktonic prey. The reaction of the coral polyps is merely a defensive tentacle contraction induced by contact with the fireworm. Laboratory experiments have shown that even short interactions with fireworms prompts the retraction of coral polyp tentacles, a response that persists beyond the interaction itself, reducing feeding efficiency and altering metabolic activity (Simonini *et al.*, 2017; Bosch-Belmar *et al.*, 2024). Given the ability of fireworms to consume *A. calycularis* both in the field and in the laboratory, we cannot exclude that klepto-predation (in which the predator consumes both its own prey and the prey it has captured, Willis *et al.*, 2017) may occur.

Predation on gorgonians

As observed by Righi *et al.* (2020), also in the present study most of the reports of predation by *H. carunculata* concerned gorgonians. Global and local stressors, such as heatwaves (Garrabou *et al.*, 2019) and physical injuries due to lost fishing and scuba diving activity (Ponti *et al.*, 2018; Betti *et al.*, 2019; Di Camillo *et al.*, 2025), may pose a threat for ecosystem engineers like gorgonians (Rossi *et al.*, 2017). Multiple physical injuries and repetitive stress would lead to the fast colonisation of damaged branches by fouling organisms and to a reduction of feeding and reproductive surfaces, with consequences on benthic-pelagic coupling (Cerrano *et al.*, 2005; Coppari *et al.,* 2019; Iborra *et al.*, 2022). In the present study, predation on gorgonians was mostly recorded on colonies showing branches with signs of damage, suggesting that fireworms may preferentially prey on unhealthy and injured gorgonians. Although further evidence should be provided by considering i) the prevalence of damaged octocorals in the studied areas together with ii) monitoring of both healthy and compromised colonies, and with iii) laboratory tests, our findings suggest that fireworms, through their feeding activity, could contribute to the decline of gorgonians synergistically with other anthropogenic stressors.

The rapid warming of the Mediterranean Sea is increasing the likelihood of thermal anomalies that favour the spread of thermophilic species (Marchesi *et al.*, 2025) and, at the same time, induce stress in benthic cnidarians (Giuliani *et al.*, 2005; Kružić *et al.*, 2016). The increased abundance of *H. carunculata* could further reduce the population of benthic cnidarians by consuming damaged polyps. Given the observational nature of the data, manipulative experiments under controlled conditions are required to evaluate whether model gorgonians (e.g., *E. singularis* and *E. cavolini*), whether healthy or subjected to experimentally induced stress (e.g., mechanical damage or thermal stress), can be differentially harmed by *H. carunculata*.

Insights into the reproduction of H. carunculata

Coordination in synchronous spawning is maintained via environmental cues, such as lunar periodicity, photoperiod and temperature, and it is associated with chemical signals that induce gamete release in annelids and other marine invertebrates (Giangrande, 1997; Watson *et al.*, 2003). For example, the Mediterranean date mussel *Lithophaga lithophaga* breeds in late summer, with its most significant spawning events occurring, under calm sea conditions, between the full moon and its last quarter (Žuljević *et al.*, 2018). It is known that warmer waters favour high population densities and sexual reproduction in *H. carunculata* (Schulze *et al.*, 2017; Righi *et al.*, 2019, 2020). Given that fireworms can survive after spawning (Toso *et al.*, 2020) and could live up to eight years (Simonini & Ferri, 2022), *H. carunculata* is considered an iteroparous species. Toso *et al.* (2020) reported two spawning events of *H. carunculata* in shallow waters (5 m) along the Ionian coast of Apulia in July and August 2019 a few days after the full moon. The reports examined in the present study confirm previous observations and allow generalizations in either space or time. Reproductive events were observed over a relatively wide range of depth (2-16 m) over a large stretch of the Mediterranean coastal areas between 9° E and 18° E,, spanning from the Tyrrhenian Sea to the Ionian Sea. The spawning was always linked to the lunar cycle, occurring a few days before or after the full moon during the summer (July-September). In each year, two distinct spawning events (mid-July and late August or early August and early September) were observed.

In many species of vagile marine invertebrates, adults climb objects prior to spawning and/or assume a posture that places their gonopores into the water column (Lotterhos *et al.*, 2010). In all reports, spawning fireworms were "dancing", emitting gametes while oscillating the anterior part of the body (Toso *et al.*, 2020). The "dance" was performed on parts of the seabed (e.g., rocks) that were raised above the surrounding area and may be favoured by undertow flow. The higher water flow above the seafloor surface would increase the rate at which the gametes released would be carried away from adults (Lotterhos *et al.*, 2010).

Aggregative behaviour may dilute predation rates on adults and eggs (Himmelman *et al.*, 2008; Molloy *et al.*, 2012). The present study evidenced that aggregation of fireworms is common during spawning and that, as reported by Toso *et al.* (2020), fish are not attracted by the massive gamete release. Actually, when the eggs are small and develop into planktotrophic larvae, such as in the case of *H. carunculata* (Toso *et al.*, 2020), fish predation on gametes may be low (Babcock *et al.*, 1992). It can thus be assumed that the aggregative behaviour of fireworms enhances the effectiveness of synchronized spawning, favouring an increase in reproductive output, by increasing mate-encounter rates and improving fertilisation success (Himmelman *et al.*, 2008; Molloy *et al.*, 2012).

Such information would have been very difficult to obtain without the collaboration of many divers, who, unlike the other participants in the project, explore the seabed using underwater cameras at the depths at which reproduction occurs. Further research on fireworms is needed to shed light on traits such as the developmental stages from the trochophore larva to metamorphosis, juvenile survival and population dynamics (Toso *et al.*, 2020, 2022).

Distribution of H. carunculata

Despite the differences in data collection methods, the distribution of *H. carunculata* obtained in the present study along the Italian Peninsula is consistent with previous reports. Combining the new records with the previous ones it appears that fireworms may be found south of 41° N from the Pontine Archipelago to the outskirts of Bari in Apulia. Some of the new localities are quite interesting from a biogeographical point of view. There have been numerous reports from western Sicily and south-eastern Sardinia, which have only been colonised by fireworms in the last 20 years (Righi *et al.,* 2020). The new sightings collected in this study suggest an extension of *H. carunculata's* range to the northern and western parts of the Sardinia.

Recently, de la Ballina *et al.* (2025) collected records of *H. carunculata* by combining benthic monitoring programmes, local ecological knowledge, and publicly available information, aiming to fill gaps in knowledge regarding the distribution of fireworms in the western Mediterranean Sea. The authors reported a northward shift in *H. carunculata* distribution, with the northernmost record (Cap de Creus, north-east Catalonia) extending up to 2.2° beyond previously documented limits. The northernmost record reported in the present study, Formiche di Grosseto (Tuscany; approximately 42.34° N) is at nearly the same latitude as the Spanish record (Cap de Creus, 42.24° N). Formiche di Grosseto is located just 20 km north of the previously documented occurrence in the Tyrrhenian sea. The low distance from the last report (Righi *et al.*, 2020) suggests that physical and biotic factors along the Tuscany coasts could at least slow down the dispersion of the polychaete, as predicted for other invasive species (Mitchell & Dominguez Almela, 2025). In contrast, the expansion of the worm along the northern and western coasts of Sardinia is evident. The new reports from Sardinia and continental Italy do not seem to be occasional colonization events, as they are located quite close (about 20-40 km) to the northernmost distribution border recorded in 2019 (Righi *et al.*, 2020) and, together with those from Spain, could therefore represent a further expansion in *H. carunculata* range. However, this northward spread in the Mediterranean Sea appears to be gradual and could be driven by critical environmental constraints, such as seawater temperatures, since larval development of *H. carunculata* is blocked at < 22°C (Toso *et al.,* 2020). Even today, approximately two-thirds of the reports come from the Ionian Apulia, the Strait of Messina, Sicily and surrounding islands, where the presence of *H. carunculata* has been well documented since the 1990s (Righi *et al.*, 2020)

At lower latitudes, on the eastern side of the Tyrrhenian basin, the existence of a discontinuity in the distribution area of *H. carunculata* is confirmed between the southern Tuscan Archipelago and the Pontine Archipelago/Gulf of Naples, more than 300 km away in a SE direction (Righi *et al.*, 2020). This could depend on the scarcity of suitable seabed for the establishment of the species in the coastal area that extends from the mouth of the Tiber to the Phlegraean Peninsula, where the seabed is mainly composed of fine sands and coastal muds, occasionally interrupted by rocky promontories (Mazza *et al*., 2016). However, the scarcity of data in this area could also be due to the low detectability of juvenile stages, which may colonize soft substrates as well, and the limited attention divers usually pay to these environments, which are often overlooked during dives (Di Camillo *et al*., 2025 and references therein).

Similarly, on the western Adriatic coastline, despite the presence of artificial hard substrates (Bulleri & Airoldi, 2005), *H. carunculata* remains largely unrecorded. Besides the type of substrate, low winter temperature (below 10° C) and the northern Adriatic's relatively low and variable salinity (Vilibić *et al.*, 2019), may further limit settlement of planktonic larvae and the survival of adults (Righi *et al.*, 2020). The current system of the Adriatic Sea may also play a role in limiting the species' northward expansion along Italy's eastern coastline. The general surface circulation in the Adriatic basin brings Levantine and Ionian warm-waters northwards along the Croatian eastern coast, up to the Northern Adriatic, where they are affected by the cold Bora wind effect before moving southward along Italy's west coast (Bergamasco & Malanotte-Rizzoli, 2010; Millot &Taupier-Letage, 2005; Righi *et al.*, 2020). In the central Adriatic, this circulation pattern appears to support the presence of *H. carunculata* along the Croatian coastline (Righi *et al.*, 2020), while concurrently limiting the northward dispersal of *H. carunculata* planktonic larvae from southern populations and thereby contributing to the observed biogeographic discontinuity.

Many reports came from areas like the Ionian coast of Apulia and the Strait of Messina- Aeolian Islands, where fireworms have become invasive in recent years. However, it is not possible to draw definitive conclusions about changes in the species' abundance based solely on citizen science data, as both the number and origin of reports may be influenced by several factors, for instance, greater curiosity in areas where the fireworm is a "new" presence and reduced interest in regions where its occurrence is considered "normal." However, increased density and associated issues in southern regions have been documented through quantitative or impact-focused studies conducted in areas where the species has become invasive. For example, ecological surveys have reported a recent population increase in the Ionian Apulia region (Toso *et al.*, 2022), a rise in the number of individuals found in fishing nets (Celona & Comparetto, 2010; Tiralongo *et al.*, 2023), and negative impacts on fishing activity along the southeastern coast of Sicily (Ionian Sea) (Tiralongo *et al.*, 2023).

The data collected is essential to predict the most suitable habitats and environmental conditions for the stable presence of the species and to guide future monitoring efforts toward potentially vulnerable areas. Currently, further investigations are underway especially in the northernmost sectors of the Tyrrhenian Sea, facing the coastal areas of Tuscany and Sardinia. Several diving centers present in this area have been contacted to stimulate greater interest and request the sending in of reports, essential to monitor the expansion of the range of *H. carunculata*.

Socio-economic impacts of **H. carunculata**

The growing attention achieved by the fireworm in the last five years is due to several reasons. *H. carunculata* can feed on fish trapped in nets or on baited hooks, damaging local artisanal fisheries (Tiralongo *et al.*, 2023). Furthermore, the worm feeds on fishing discard (present work Fig 1A,B, and Krželj *et al.*, 2020; Righi *et al.*, 2020;

Toso *et al.*, 2022), where it is likely attracted by olfactory traces (Simonini *et al.*, 2021; Tiralongo *et al.*, 2023). The scavenger behaviour of fireworms has been described since the 1920s (Aegean Sea, Issel, 1926); however, in recent years, a remarkable increase in the amount of fish waste has been produced around the world, creating huge economic and environmental concern (Coppola *et al.*, 2021). Regarding the Italian marine fishery, in the Mediterranean Sea it has been estimated that the discarded fraction represents 7% of gross catch, and that the discarding practice gradually increased until the beginning of the 21st century (Kelleher, 2005; Caruso *et al*., 2020). Given that increasing carrion biomass is predicted to enhance scavenger abundance (Baruzzi, *et al.*, 2018), it can be expected that, on a local scale, an increase in fishing waste can lead to the rise in fireworm populations in the shallow waters of anthropized coasts. Policies aimed at improving fishery management, by-catch and discard reduction should be encouraged to mitigate the rise in fireworms, especially in coastal tourism hotspots subjected to their invasion (Tiralongo *et al.*, 2023).

Hermodice carunculata is relatively easy to detect underwater, and the abundance of scientific publications, reports, and social media posts may have heightened public awareness among divers and beachgoers. Recently, a local newspaper reported a case involving a man from Ancona (Northern Adriatic Sea) whose skin injuries were diagnosed as burns caused by contact with a fireworm. However, to date, there are no confirmed records of this polychaete along the coasts of Ancona, based on both the present study and personal observations. The growing notoriety of the fireworm has had mixed effects: on one hand, it helps inform sea enthusiasts about the potential risks of contact; on the other, it may contribute to excessive alarmism.

Another potential social consequence of the growing concern surrounding fireworms is the unplanned management of this invasive species by local stakeholders, particularly dive center staff, as well as by citizens. Until the ecological impact of heavy predation by *H. carunculata* on flagship species and habitat-forming organisms remains largely unassessed, frequent observations of the worm feeding on charismatic species may prompt spontaneous and poorly planned eradication efforts.

Conclusions

The findings from the first three years of the citizen science "Monitoraggio vermocane" project suggests that the fireworm *H. carunculata* is emerging as a potential "winner" of human-driven changes in the Mediterranean Sea (Toso *et al.*, 2024). However, future impacts of fireworm increase on receiving marine ecosystems are still uncertain. According to Tiralongo *et al.* (2023), gaining spatio-temporal insights into the distribution and abundance of *H. carunculata* in the Mediterranean is crucial to anticipate and mitigate its potentially increasing impact. We strongly believe that further studies based on participatory science could help to gain insight into key life history traits, and identify and quantify the threats posed by *H. carunculata* to host communities and traditional artisanal fishery, which are expected to worsen in the context of global warming (Toso *et al.*, 2022; Tiralongo *et al.*, 2023). Conducting a quantitative field study on the impact of fireworms on Mediterranean benthic communities is essential in order to obtain evidence of their impact and plan successful strategies to control their spread, together with dive centers, fishermen, local population and tourism stakeholders.

Acknowledgements

We would like to give a warm thanks to all the diving centers and their staff who kindly support the "Monitoraggio Vermocane" project. We are grateful to all the volunteers who provided us records to assess fireworm distribution, ecology and reproduction. We also thank the two anonymous reviewers whose helpful suggestions improved the manuscript. This work was supported by grants from the University of Modena and Reggio Emilia (Bando Public Engagement) and National Recovery and Resilience Plan (NRRP), Mission 04 Component 2 436 Investment 1.5 - NextGenerationEU, Call for tender n. 3277 dated 30/12/2021 (Award Number 0001052437 dated 23/06/2022).

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Supplementary Data

The following supplementary information is available online for the article:
Fig. S1: List of articles retrieved in May 2025 via Google Scholar using the keywords "*Hermodice carunculata* Mediterranean" and via Google News using the fireworms italian common name ("vermocane").
Table S1. Dive centres contacted by "Monitoraggiovermocane" project and their coordinates.
Table S2. Overall dataset of finding localities of *H. carunculata* obtained from the "Monitoraggio vermocane" project in the three years (2021-2023). "N" indicates the order of the reports.
Table S3. Authors and links to social posts of the reports which are showed in Figures 1, 2 and 3.