

Article

# Enhancing Diversity Knowledge through Marine Citizen Science and Social Platforms: The Case of *Hermodice carunculata* (Annelida, Polychaeta)

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**Abstract:** The aim of this research is to set a successful strategy for engaging citizen marine scientists and to obtain reliable data on marine species. The case study of this work is the bearded fireworm *Hermodice carunculata*, a charismatic species spreading from the southern Mediterranean probably in relation to global warming. To achieve research objectives, some emerging technologies (mainly social platforms) were combined with web ecological knowledge (i.e., data, pictures and videos about the target species published on the WWW for non-scientific purposes) and questionnaires, in order to invite people to collect ecological data on the amphinomid worm from the Adriatic Sea and to interact with involved people. In order to address future fruitful citizen science campaigns, strengths and weakness of each used method were illustrated; for example, the importance of informing and thanking involved people by customizing interactions with citizens was highlighted. Moreover, a decisive boost in people engagement may be obtained through sharing the information about citizen science project in online newspapers. Finally, the work provides novel scientific information on the polychete's distribution, the northernmost occurrence record of *H. carunculata* in the Mediterranean Sea and new insights on predatory behavior on other living benthic species.

**Keywords:** climate change; invasive species; spatiotemporal distribution; marine benthos; Mediterranean; social networks

## 1. Introduction

In order to measure variations in biodiversity [1], to track spatiotemporal distribution of thermophilus species [2] and to set indicators for benthic invertebrates within the concepts of essential biodiversity variables (EBVs, [3]) and essential ocean variables (EOVs, [4]), it is indispensable to fill data gaps through monitoring activities and collection of occurrence records.

Marine conservation initiatives involving volunteers (marine citizen science) thrived in the last decade [5] and were mainly focused on marine litter, invasive species, seabirds, marine mammals and turtles [6,7]. Citizen scientists may contribute to conservation by detecting target species [8], taking samples or by collecting biodiversity data following standardized protocols [9]; in any case the involvement of citizens greatly speeds up and improves the acquisition of information allowing the extension of the geographical scale and the temporal range of studies with a relatively limited investment [10–13]. In addition to collecting biodiversity data (occurrence, abundance and other eco-ethological information), one of the main outcomes of citizen science projects is the enhanced knowledge and consciousness of the public about marine environment [14–17]. Attractive topics and a strong motivation are necessary to foster participation in citizen science projects [18,19].

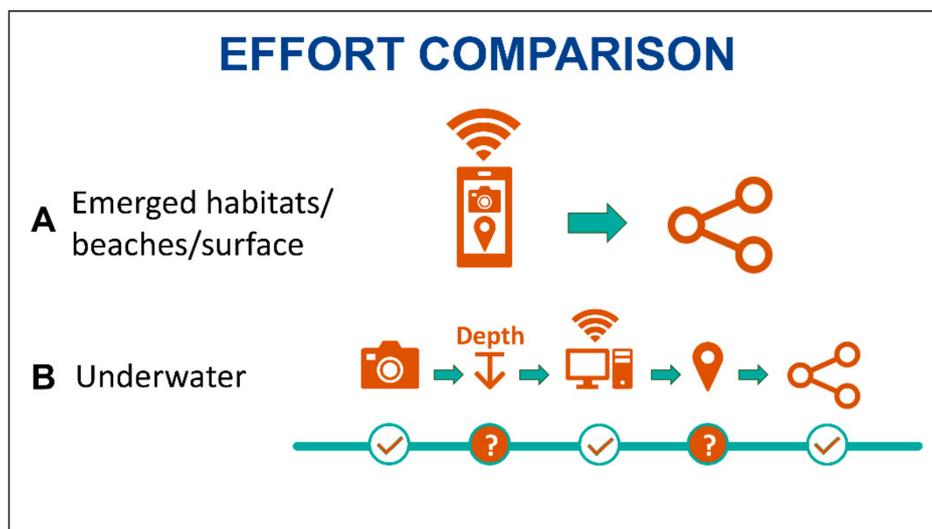
People contribute to conservation programs for several reasons: self-interest, curiosity, fun, opportunity to learn alongside scientists, the elation of making a breakthrough and the warm glow that comes with protecting the environment [20–24].

The possibility to be involved in planning citizen science projects or solving challenging environmental issues could stimulate the participation of most creative volunteers [5,25–27] and increase public involvement [28].

Coastal and marine ecosystems are under-considered by citizen science in comparison to terrestrial ecosystems [14,29]—even if oceans cover approximately 70% of the Earth.

According to [30], participants in citizen science belongs to “a slightly male-biased, overwhelmingly white and well-educated population” while, marine citizen scientists include explorers of both coastal and submerged habitats which probably have a very different profile [16].

Participation of scuba divers and snorkelers in citizen science programs is still not enough exploited [8,31,32] because submerged aquatic environments are more difficult to explore [6], and because a diving license and a costly gear are required. Nowadays smartphones include cameras and Internet connection integrated in one tool; therefore, it is easy and fast to acquire and to share pictures or videos from the coast or from a boat by a smartphone. On the contrary, it takes much more time to take pictures with underwater (UW) cameras, to download them to a personal computer and finally to share them (Figure 1). Moreover, UW findings should be integrated at least with information about depth to be considered an occurrence record. This suggests that the engagement of UW citizen scientists could require a higher effort to motivate people.



**Figure 1.** Comparison of steps for taking/sharing records collecting from the (A) surface and (B) submerged sites. The process requires only two steps using smartphones from the surface and five steps for submerged habitats. This analysis highlights that information about depth and coordinates is generally missing, and that scientists should attempt to fill these gaps during the engagement of scuba divers.

Thanks to advances in information tools, social platforms are largely applied to improve marketing strategies [33,34], but also to develop technology-mediated citizen science projects [35,36] and to share data [37,38].

Blending science, citizen participation and emerging technologies could advance biodiversity knowledge and raise public awareness about environmental issues [39]. social platforms in particular facilitate communication between scientists and citizens [40,41].

For these reasons, in this research a combination of new tools was tested in order to address a successful strategy to engage marine citizen scientists and to obtain reliable data on marine species. To achieve research objectives, different information sources were used: some emerging technologies

(mainly social platforms), information retrieved from the world wide web (WWW) and questionnaires. We invited people to participate in data collection (mainly related to geographical distribution) about a target species: the bearded fireworm *Hermodice carunculata* (Pallas, 1766) (Annelida: Polychaeta), an amphi-Atlantic species also common in the Mediterranean Sea [42]. This is a striking and likely venomous worm [43], unpalatable and scarcely preyed upon [44]. Thanks to its opportunistic feeding behavior and its ability to tolerate a variety of environmental conditions, this polychaete could take advantage of environmental changes and expand its range of distribution [44]. *H. carunculata* is spreading from the southern Mediterranean basin probably in relation to global warming; however, there are very few studies on its spatial distribution and ecology in the *Mare nostrum* [45–49] and about the effects of its predation on Mediterranean benthic communities [50].

Cryptic species in general are not suitable for involving citizens in scientific data collection, due to their difficult detection [8]. Due to its features, *H. carunculata* can be considered as a ‘charismatic’ species [51]; therefore, data on its distribution and behavior could be collected with the help of scuba divers and bathers that can easily identify it.

The selected study area in this research is the Croatian coast (including islands) where local diving centers perceive this species as fast-spreading and because there are still few information about the polychaete distribution and behavior in this area.

Summarizing, research questions were:

- Can social platforms support the building of a scientifically sound dataset on marine species?
- Which are the effects that these projects can have on volunteer contributors?
- Is the information from the WWW an effective tool to build datasets on species distribution and abundance?
- How the profiling of volunteers can support the development of conservation projects based on citizen science?
- Could the proposed strategy contribute to the development of an early warning system [52] of new incursions of the polychete?

Strengths and weaknesses of each used tool were illustrated and solutions to minimize eventual bias in data collection were proposed.

## 2. Materials and Methods

### 2.1. Background on Marine Citizen Science in the Mediterranean Sea

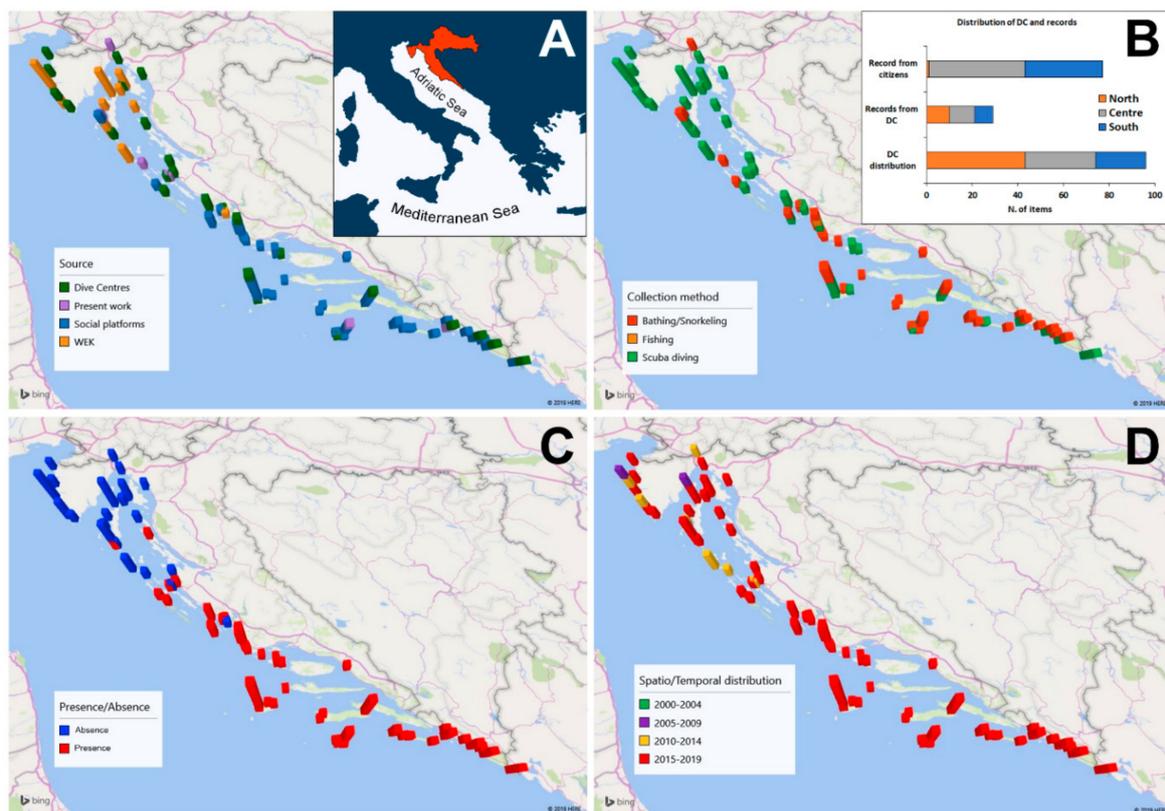
A bibliographic search was carried out using the Elsevier’s Scopus database ([www.scopus.com](http://www.scopus.com)) with the aim to quantify research-based citizen science conducted in the Mediterranean Sea. In the first step, queries ‘citizen AND science AND Mediterranean’ were used in searching within titles, abstracts, keywords and 120 documents were obtained; then, results were refined limiting the search on articles published during the last five years (2015–2019) and excluding three subject areas (‘arts and humanities’, ‘economics’, ‘biochemistry, genetics and molecular biology’). There were 67 refined documents. To discard other off topic articles, all articles were downloaded from the WWW and checked in order to obtain a final set of 45 papers (available as Table S1) that were analyzed with aim to show number of published articles per year, main target species/habitats, principal methods to involve citizens.

### 2.2. Records of *Hermodice carunculata*

Occurrence records of the polychaete were obtained by combining different methods: (i) by engaging dive centers/citizens through Facebook (see next paragraph for details), (ii) by scuba diving activities performed by the authors along the Croatian Archipelago (Lošinj, Ist, Molat, Susak, Preko, Vis, Lastovo, Šipan, Dubrovnik) between 2006 and 2019 from 0 to –45 m; (iii) by exploiting videos published on the web for fun (i.e., the web ecological knowledge or WEK, sensu [31]).

WEK was considered because not many records of the worm presence were obtained in the from the northern coastal Counties; therefore, in order to confirm the absence of the polychaete in the northern part of the studied area, 30 amateur videos taken by scuba divers from Rovinj to Dugi Otok and published on the world wide web (YouTube) were examined following the protocol suggested by [31].

All the gathered records are listed in a dataset following [9], available as Table S2. Records are also showed in Figure 2A–D.



**Figure 2.** Record distribution and characterization. (A) Number and distribution of records discriminating between records from dive centers (DCs), social platforms, web ecological knowledge (WEK) and data obtained by scuba diving from the present work; (B) records distinguished by the method of collection; the bar histogram in the inset shows the proportion between records obtained from citizens and those gathered by DCs; moreover, the bars indicate that most dive centers are located in the north, while people participating in this work mainly come from the central and the southern part of Croatian coast; (C) number and distribution of presence/absence records; (D) spatiotemporal distribution of records.

### 2.3. Engagement of Dive Centers/Citizens through Facebook

A list of 116 dive centers located in Croatian coast (Eastern Adriatic Sea, Figure 2A, inset) was obtained in part from [www.ronjenjehrvatska.com](http://www.ronjenjehrvatska.com) and in part from Google Maps. Later on, each name of these dive centers (hereinafter: DCs) was digitized in the Facebook search engine (<https://www.facebook.com>) in order to verify if the center had a fan page. All the DCs with a fan page and recent posts (i.e., posts after 1 January 2019) were considered as ‘active’ and in total, 95 active DCs were selected.

A Facebook fan page (AmbienteMarino) was created with aim to inform and engage the owners of DCs present in the study area and all other potential citizen scientists. The first advantage of a fan page is that the number of followers is unit unlimited; moreover, fan pages offer people the possibility of interacting with administrators and with other citizens publishing pictures, adding comments,

formulating questions, participating in surveys, etc. Facebook insights made it possible to obtain information about organic reach (i.e., data given from Facebook for free). These data were also useful for targeting the audience. Insights generally refer to temporal intervals of one day, one week or 28 days; in this study data collected in a 28-day temporal window, from 18 August 2019 to 14 September 2019, were considered.

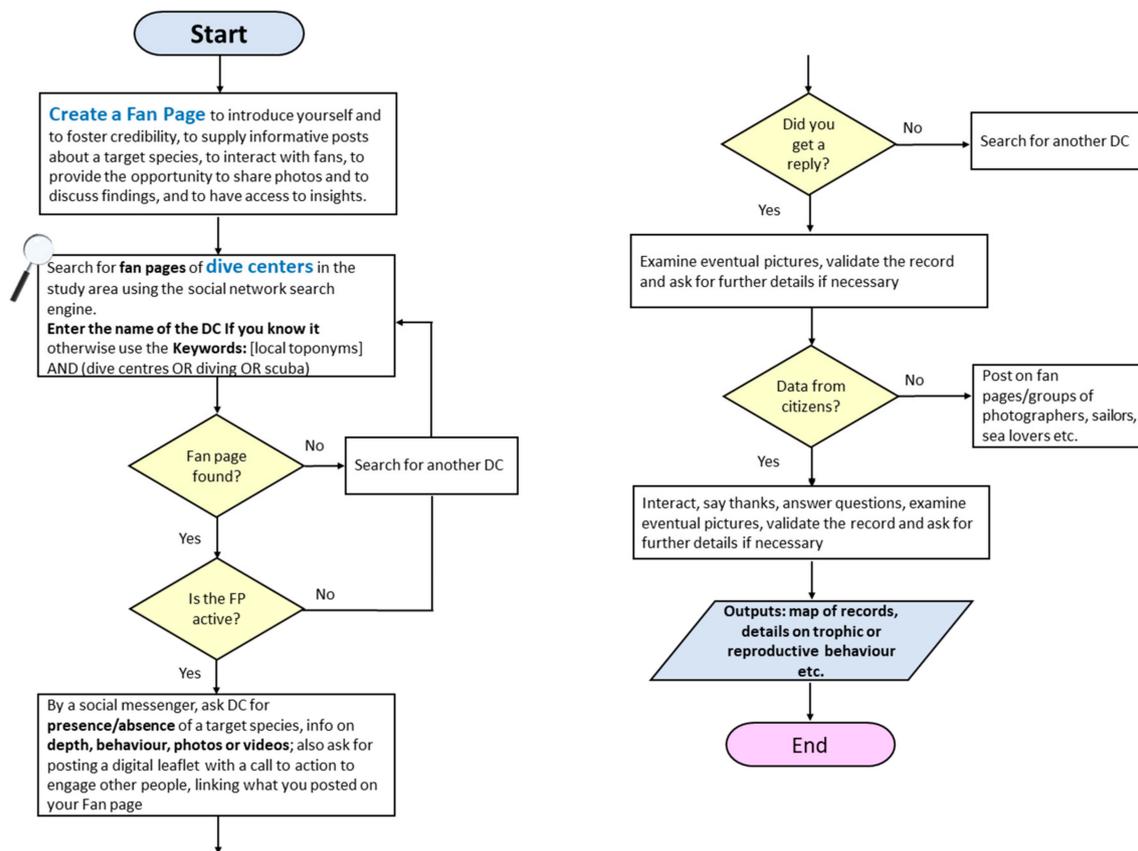
Administrators of AmbienteMarino sent a message via Facebook messenger to each DC's fan page asking about the presence of the worm in the DC area, but also documented photos or videos of the worm preying other organisms. Both 'presence' and 'absence' of the worm were considered as a record in the DC's area.

Each contact was registered in order to test the efficacy of engagement on Facebook. Date and time of contact, date and time of reply, eventual data, photos or videos obtained by the DCs were recorded.

In the second half of August, some online Croatian newspapers and TV reported the case of a woman injured by touching a fireworm. The URL of AmbienteMarino's fan page was linked to comments below each article in order to gather more followers and data.

People had two possibilities to interact with authors: (i) through Facebook or (ii) by sending an e-mail to the address associated with the fan page (ambientemarinoinfo@gmail.com).

The utilized protocol for retrieving data are synthesized in the flow chart in Figure 3.



**Figure 3.** Protocol to engage potential citizen scientists through the social network Facebook. Flow chart illustrating steps applied in this study is shown.

#### 2.4. Search Volume of Terms Related to *Hermodice carunculata*

In order to verify if the public involvement through social platforms turned up interest in fireworms, after 14/09/2019, search volume of terms 'vatreni crv' (i.e., fireworm in Croatian language) were tracked in Google trend (trends.google.it) for the period 2015–2019 and in the Country 'Croatia'. Google Trend shows relative search volumes normalizing data to the time and location of a query and scaling data on a range of 0 to 100 (for details see [53]).

## 2.5. Questionnaire

In order to reach the target audience, a very short anonymous questionnaire consisting of 8 questions was set by the ‘SurveyMonkey’ platform and shared by social networks and social messengers, to the people living along the Adriatic coast (in Croatia and in Italy). The survey was submitted to different clusters (i.e., Facebook groups of scuba divers, sailors, tourists, environmental awareness and to WhatsApp groups, including personal ones). The number of respondents for each cluster is unknown.

Aim of the survey was to get information about the activities that take place in the marine environment, marine animal injuries and awareness of citizen science.

## 2.6. Behavior of *Hermodice carunculata*

Photos sent by DCs and citizens, together with those collected by authors, were observed to validate each record and to gather information about behavior of the polychaete.

Additionally, one of the polychaetes found on a colony of the gorgonian *Paramuricea clavata*, in waters of Vis Island, was collected and successively placed into an aquarium in order to wait for expulsion of dejections. Later on, the dejections were examined by microscopy in order to obtain more information about the worm feeding behavior. The polychaete was released in the same location few hours later.

## 3. Results

### 3.1. Background on Marine Citizen Science in the Mediterranean Sea

Exam of the 45 analyzed articles revealed that the number of citizen science-based studies in the Mediterranean Sea increased from 1 to 16 per year from 2015 to 2019 (Figure 4A–E).

Most papers (42%) focus on (i) non-indigenous species (NIS) or invasive alien species (IAS), such as gastropods (*Aplysia dactylomela*, *Siphonota geographica*), algae (*Caulerpa cylindracea*), jellyfish (*Phyllorhiza punctata*) and numerous species of fish; (ii) marine litter (16%); (iii) endangered species (13%) such as sharks, limpets and the bivalve *Pinna nobilis*; only 5% of the studies are about habitat-forming corals (Figure 4A). Number of studies focusing on NIS/IAS (Figure 4B) is higher in 2018 and 2019 (7 and 6, respectively), as well as those about endangered species.

About 60% of the considered papers (Figure 4C) resort to scuba diving for data collection (sometimes in combination with snorkeling and/or fishing), with an evident increase in use of these tools over time (from 0 to 11 studies from 2015 to 2019, Figure 4D). On the other hand, studies engaging only fishermen (11%) diminished. Records of biodiversity along beaches and beach clean-up activities represent about 7%. Biodiversity sighting from boats was slightly utilized (only 2% of the studies).

Figure 4E highlights an increasing use of social platforms, WEK (web ecological knowledge) and LEK (local ecological knowledge), [52,54,55] (from 0 to 6 studies from 2015 to 2019) in marine citizen science.

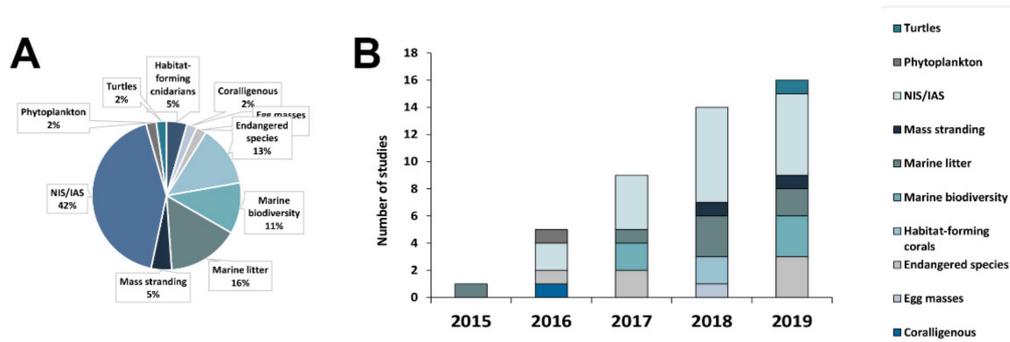
### 3.2. Records of *Hermodice carunculata*

A total of 138 records of presence/absence of *Hermodice carunculata* along the Croatian coasts was gathered; 20% from DCs contacted by Facebook, 54% by citizens reached through the fan page, 6% by observations conducted by authors and 20% by WEK (Figure 2A). Records collected during swimming/snorkeling activities (46%) at a depth of 1–5 m come mainly from the central and the southern part of the studied area, while those reported by scuba divers (54%) are from the northern part (Figure 2B). Records of the worm presence are mainly distributed in the central-southern regions, while the northernmost records are Mali Lošinj (Island of Lošinj) and Stara Novalja (Island of Pag) (Figure 2C). Most records were recently collected (2015–2019, Figure 2D).

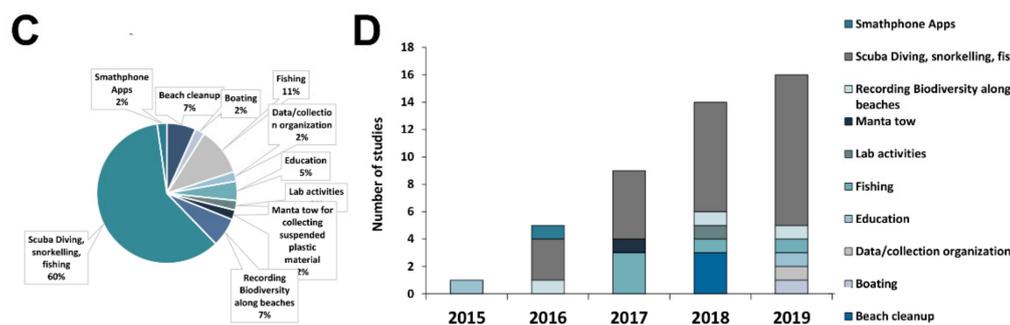
During scuba diving activities performed by the authors, *Hermodice carunculata* was observed in the southern Croatian localities such as Vis, Lastovo, Šipán, Dubrovnik (records of 2017–2019), while it was absent in the north (Lošinj, Ist, Molat, Susak, Preko; 2002–2010).

In WEK analyses, the polychaete was not observed in the examined videos from the northern Croatia except in the one taken in Dugi Otok in 2017, where the worm was preying on a yellow gorgonian (*Eunicella cavolini*).

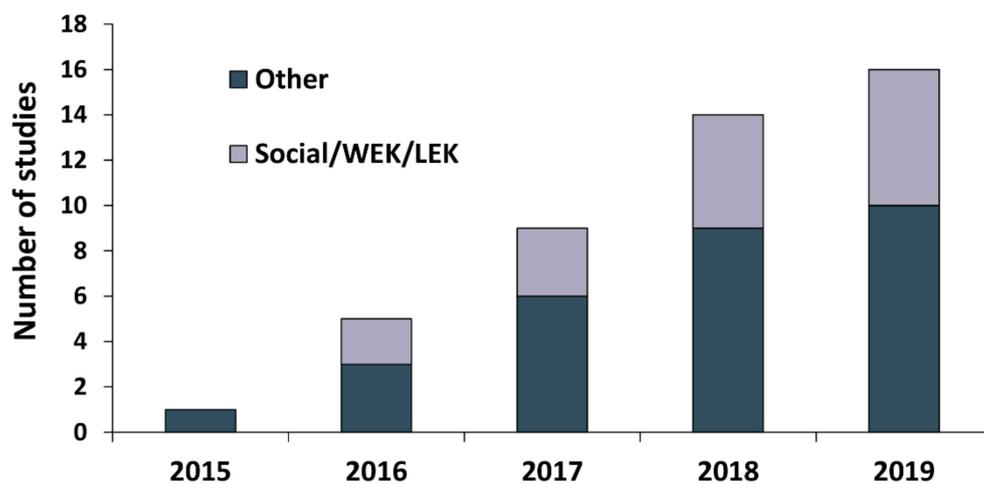
### Research topics



### Research tools



### E Research-based Citizen Science in the Mediterranean Sea



**Figure 4.** Analysis of citizen science-based studies in the Mediterranean Sea in 2015–2019. (A) Percentages and (B) trend of research topics; (C) percentages and (D) trend of research tools; (E) use of social platforms, web ecological knowledge (WEK) and local ecological knowledge (LEK) in marine citizen science.

### 3.3. Engagement of Dive Centers/Citizens through Facebook

The distribution of active DCs was the following: 43 (45%) in the north, 31 (33%) in the center and 22 (23%) in the south. Almost 30% of the active DCs answered to messages (28 on a total of 95 active DC); time of reply generally varied from few seconds to a week. Location analyses of the 28 DCs responding to messages showed that 9 (32%) were located in the north, 11 (39%) in the center and 8 (29%) in the south (Figure 2B, inset). The ratio of contacted/respondent DCs was about 1/5 in the north and 1/3 in the center and in the south.

Concerning records from citizens (77), people responded to our call for action both through social platforms (Facebook, 53%) and e-mail (47%). In total 55% of these records included at least one photo as well as comments about the worm. Records obtained from citizens (Figure 2B) were distributed 1% in the north, 55% in the center and 44% in the south of the studied area.

About 74% of the records from citizens were collected from swimmers/snorkelers in shallow waters (0–4 m), 24% during scuba diving (5–20 m) and 1% from fishermen (0–20 m) (Figure 2B).

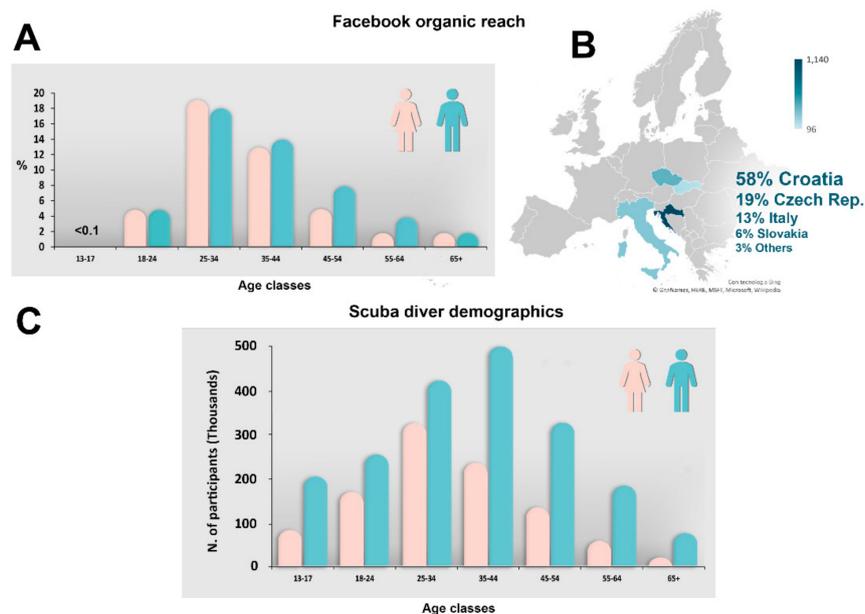
Almost all those that contacted us were from Croatia; in total 2.6% did not know that the target species was a stinging animal and 2.6% reported that the polychaete doubled or triple in about ten years.

In the considered temporal window of 28 days, fan page insights showed about 1000 views (from 2 to 333 views per day) and about 2000 reaches (i.e., the number of people who had one of these posts on their screens).

In total, there were 585 engagements (i.e., likes, comments, shares, etc.), with a peak (110) in the second part of August, after the fan page was linked to some online portals and newspapers.

Video posts generally received more attention than other posts (i.e., status, links, photos), with 144 views; however, the post with the highest engagement was our informative article about fireworms after being shared by another Croatian fan page named 'Morski.hr' [56], which has more than 8000 followers.

In terms of demographics, AmbienteMarino *insights* (Figure 5A) showed that most people reached by posts were 25–34 years old, with almost the same number of males (51%) and females (48%). However, the contribution of the age group 35–44 is also significant (about 14%). Teen-agers represent less than 1%. Teenagers represent less than 1%.



**Figure 5.** Comparison of demographics of (A,B) Facebook fans and (C) scuba divers. (A,B) Facebook organic reach for (A) age, sex and (B) place of origin; (C) demographics of participants to recreational scuba divers, from the divers alert network (DAN) Report (2015).

Considering nationality, 58% of the audience was from Croatia (above all from the southern county Dubrovnik–Neretva), 19% from Czech Republic and 13% from Italy (Figure 5B).

AmbienteMarino fans were online mostly from 8:00 a.m. to 12:00 a.m. (UTC+2), with a strong decrease from 15:00 to 21:00, suggesting that best time for posting is in the morning.

### 3.4. Search Volume of Terms Related to *Hermodice carunculata*

Search volume of 'vatreni crv', always relatively low (range: 0 to 9) from 2014 to July 2019, sharply increased in August 2019 with a peak around 25–31 August (range: 100) and then it came back to low range (4) in September 2019.

### 3.5. Questionnaire

Questionnaire results are shown in Figure 6. In total, there were 208 replies, 137 from Italy and 71 from Croatia. Most participants are used to exploring the sea (Figure 6A) by swimming/snorkeling (63% in Italy and 50% in Croatia); while, as expected, a minor part of them go diving or boating. A considerable part (27% vs. 48%) of the surveyed people used an underwater video/photo camera (Figure 6B). Considering the question 3, 'Do you think it is useful to supply your records to marine biologists?' (Figure 6C), most of them think that it is useful; in particular, 32% vs. 50% would participate in exciting discoveries, about 32% would take part in scientific research and about 17% would supply data just for fun. Over 8% of the Italians answered, 'I do not know why marine biologists are collecting data'.

More than 67% have never heard about 'Citizen Science' (Figure 6D), while, among those that knew about it (Figure 6E), more than 60% acquired this information through the Internet and less than 15% through magazines or television; while most people answering 'other', were marine biologists.

More than 57% vs. 32% declared that they got stung or injured by at least one marine animal (Figure 6F). In both Italy and Croatia, most injuries were inflicted by jellyfish, sea urchins and fish (above all weeverfish); nobody referred to fireworms.

Analyzing age groups (Figure 6G), the Croatian group was younger than Italian group. Considering education (Figure 6H), the majority had high school or college degree.

### 3.6. Behavior of *Hermodice carunculata*

Photos sent by DCs and citizens, together with those collected by authors, show a polychaete identified as *Hermodice carunculata*. The photographed worm was preying on different species (Figure 7A–H) such as cnidarians (*Parazoanthus axinellae*, *Paramuricea clavata*, *Eunicella cavolini*), gastropods (*Phorcus turbinatus*), echinoderms (*Ophidiaster ophidianus*, *Hacelia attenuata*, *Paracentrotus lividus*), dead or dying fish. The polychaete was also observed on living specimens of *Octopus vulgaris* that were probably injured by spearfishing.

Starfish photographed in waters of Vis and Lastovo islands (Figure 7F) showed maimed arms or scars along their bodies. Arm regrowth and scar recovery was often noticed (recent scars are white while recovering ones are yellowish); furthermore, colors of several starfish were not uniform probably due to repeated worm predation.

None of the participants photographed a predator of *H. carunculata*, although one of them reported that some old divers mentioned that the grey triggerfish (*Balistes caprisicus*) fed on fireworms.

The polychaete collected by the authors in waters of Vis Island while it was preying on *Paramuricea clavata*, produced dark red dejections about three hours after collection. Microscopy reveals presence of numerous sclerites of the gorgonian, confirming that the worm found on the gorgonian was eating the cnidarian tissue.

In waters of Vis Island, *H. carunculata* was very abundant from the surface to 70 meters. In this area, up to 4 specimens were observed on gorgonians (*Eunicella cavolini* and *Paramuricea clavata*) where the polychaete preferred central-apical portions of the gorgonian colonies. The predated gorgonian

branches can present small bared portions of the scleraxis; however, no signs of necrotic tissue were detected in the observed colonies.

## Survey



**Figure 6.** Survey questionnaire. Titles of histograms from (A–H) correspond to the questions of the survey; while, on the x-axis are indicated the possible choices, and on the y-axis there are the response percentages. Results of the survey from the participants from Italy are shown in blue; while, those relative to participants from Croatia are in red.



**Figure 7.** Feeding behavior of *Hermodice carunculata* from Croatian waters, underwater photos. (A–C). Fireworms feeding on (A) the zoanthid *Parazoanthus axinellae* and (B) the gorgonians *Eunicella cavolini* and (C) *Paramuricea clavata*; (D) starfish (*Hacelia attenuata*) attacked by fireworms. Note longitudinal white scars along the starfish arms due to bites of the fireworms; (E) detail of a worm biting an arm of *H. attenuata*; (F) several specimens of *Ophidiaster ophidianus* (first two pics) and *Hacelia attenuata* probably injured by fireworms. Note maimed arms, discolored areas, scars; Mass attack of fireworms on (G) the sea urchin *Paracentrotus lividus* and on a (H) young specimen of *Octopus vulgaris*.

## 4. Discussion

### 4.1. Background on Marine Citizen Science in the Mediterranean Sea

The analysis of the published articles highlights a growing participation of scuba divers in marine citizen science and an increase in use of nondestructive methods for collection of occurrence data. Several authors stressed the importance of applying alternative tools to assess aquatic diversity such as underwater videos/observations [57] or photogrammetry [58,59], since trawling or dredging are costly, cause bycatch, lead to habitat deterioration [60] and may favor settling/propagation of allochthone species [61].

Main target of marine citizen science is NIS/IAS due to possible negative effects of invasive organisms on the ecosystem [62] and due to interest in controlling/preventing their spreading [63].

Growing interest in endangered species is likely due to need in collecting data on distribution of *Pinna nobilis*, a bivalve species protected by the Habitat Directive [64] after recent mass mortality events of this bivalve [65].

On the contrary, few articles were published about coralligenous and habitat-forming corals, notwithstanding they could be observed—within scuba diving limits—by both recreational and technical scuba divers [66,67].

Ref. [17] recommend integrating marine citizen science and scuba diving industry to exploit their joint potential in data collection and environmental education [68].

Results in this study show a rapid increase in use of emerging technologies [39], web ecological knowledge and local ecological knowledge which could be exploited together with citizen science and scuba diving to develop cross-program synergies to foster marine conservation goals and to enhance public awareness.

### 4.2. Overview on Social Platforms

Following observations about social platforms are based on several websites [69,70]. In January 2019, the social networks YouTube and Facebook were the leading platforms all over the world, followed by Instagram. However, in order to exploit social platforms with aim to involve people in CS projects, social demographics should be analyzed also by nationality. Indeed, in Italy, the number of users of the social messenger WhatsApp is comparable to that of Facebook or Instagram, while in Croatia the social messenger Viber is the preferred one; in France and the UK the use of Snapchat is increasing. To do an example with Instagram, if we look for pictures of the fireworm using the hashtags #vermocane and #vatrenicrv, about 135 results were obtained with the Italian name and only seven with Croatian one, likely mirroring the number of users in the considered countries (Italy: 19 million (over 30% of the total population) [69]; Croatia: 1.1 million (25% of the total population) [71]).

Considering the age of users, most of the Facebook community is 25–34 years old, that is the same demographic target of most of the brands selling online [70]; Instagram community is composed above all by age group 18–29, while that of Snapchat is 12–17.

Even the audience gender should be considered by nationality; for example, in Italy Facebook and Instagram are used by a comparable number of males and females, while Twitter is preferred by males (68%) and Snapchat by females (73%). Moreover, females are more active social users since they share, like and post twice as much as males. Considering the post typology, video posts usually obtain the highest engagement (videos about 6%, photos about 4%, link about 3%, status about 2%); within the results in this study, video posts generated high attention.

These data suggest that Facebook is not a useful tool to engage neither people older than 55—they probably should be contacted by face-to-face interaction [23]—nor younger than 25. It is likely that the involvement of age group 18–29 could be increased by using Instagram while the younger group could be sensitized through citizen science projects trough educational system [72,73].

#### 4.3. Can Social Networks Provide a Scientifically Sound Dataset on Marine Species?

This research highlights that social platforms can be successfully used in order to engage dive centers and citizens to contribute to marine science. The first advantage in using social tools is possibility to check posts on a Diving Center's fan page in order to state if they are active or not; the second one is that the 'calls for action' sent to the DCs could be shared on their fan page with a cascade effect on other people. Ref. [31] reported that only 20% of the DCs contacted by e-mail answered. Percentage of replies obtained through Facebook was higher in comparison to those obtained by e-mail since social platforms allow reaching people instantly. Moreover, DCs as well as many other enterprises are abandoning communication through websites and e-mails in favor of that through fan pages, in order to increase the opportunity to connect with their own community [74] ([www.ondeck.com](http://www.ondeck.com)). Another relevant consideration is that people spend much of their free time on social networks and for this reason it is easier to reach them through Facebook [74].

In this research, many records were gathered mainly from non-scuba-diving citizens due to the fact the target species is very common even in shallow waters. Indeed, most volunteers contributing to marine science supply data from easily accessible nearshore, coastal and intertidal habitats [6,54].

Ref. [27] highlighted that information supplied by citizens through social platforms is less detailed than information obtained from biodiversity recording platforms. In this study, only one citizen supplied coordinates; however, most of finding places were indicated quite precisely. In any case, there is a substantial portion of citizens that would never register to a biodiversity recording platforms, but they could more readily send records by a faster and more interactive method [40] such as social networks.

A bias in sampling effort was observed, due to a different spatial distribution of the obtained data [75]. Data obtained in this research are few to perform a model distribution [76], however, it was clear that more data were obtained from DCs located in the central and in the northern part of the studied area, probably reflecting the distribution of DCs and tourist facilities (the latter is higher in the north, [77]. According to [77], even the number of tourists is higher in the north (52%), while, in the south and in the center is lower, 28% and 21%, respectively. On the contrary, records from citizens are mainly from the center and the south. Considering the fact that citizens contacted the authors only in order to communicate the presence of the worm, it could be hypothesized that the number of records from citizens mirrored the worm distribution.

Moreover, it is evident that in this study the contribution of tourists from the other countries was limited. To limit the highlighted bias, the participation of foreign tourists in marine citizen science projects could be promoted involving local tourist services, such as tourist offices and marinas and tour operators from foreign countries (at least the Czech one).

A considerable boost to our data collection was given when the fan page AmbienteMarino was linked to online national newspapers and when one of the authors was interviewed by a local television (Nova TV), suggesting that involvement of mass media could be crucial in citizen science projects [78].

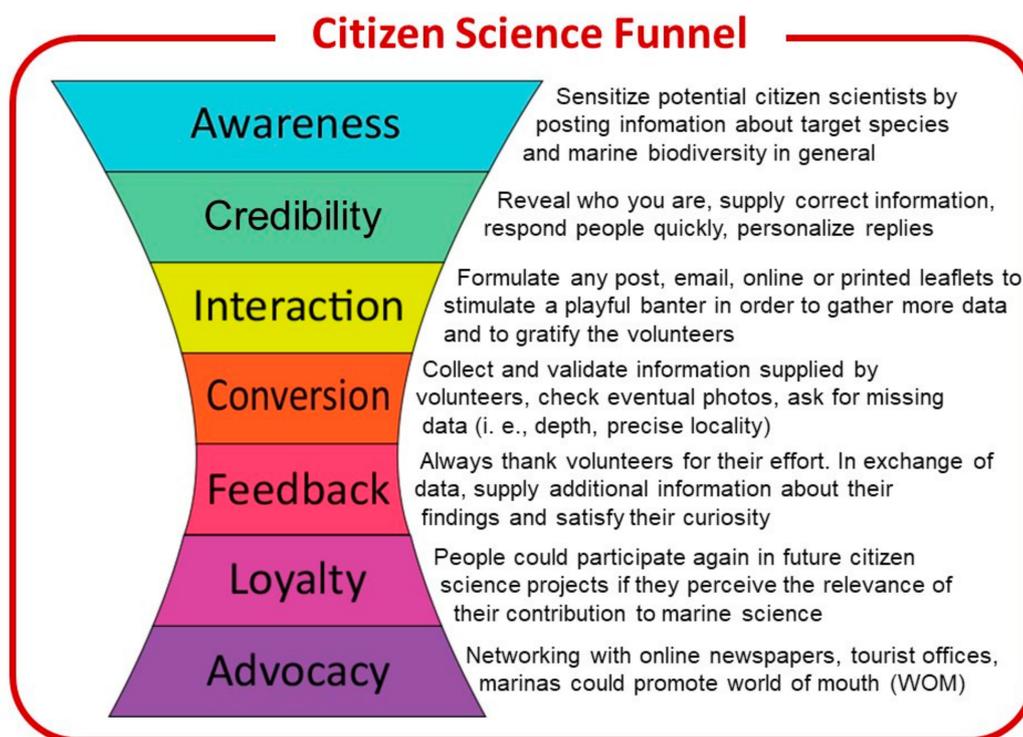
#### 4.4. Which Are the Effects That This Project Has on Volunteer Contributors?

First benefits of this study were an increased knowledge about the main topic (the polychaete) and an enhanced interest towards the marine environment in general. People's enthusiastic participation was due to the fact that it was the first time that public was informed about the polychaete in the considered area. Indeed, as an effect of this study, the search volume of the words 'vatreni crv'—that in Croatia was almost null in the last five years—sharply increased in the period June–August 2019 (Google trend).

Enhancing knowledge and curiosity indirectly boosts the motivation. Motivating people to participate in data collection is one of the trickiest components of citizen science [19]. Our task was surely simplified by the fact that the fireworm is a beautiful and potentially dangerous species (Online newspapers reported the story of a stung woman; however, only three persons referred that they got stung by the worm and nobody among participants of the survey).

Maintaining high interest on the fan page required a considerable time; however, the continuous interaction with public was indispensable in order to engage volunteers. People involved in this research were curious, passionate about environment or scared and disgusted by the worm; in any case, they shared their findings with us because they wanted to be informed about fireworm invasion, its reproduction, injuries caused by fireworm and treatments of injuries. Paying attention to citizens asking for information could have enforced authors’ credibility and probably would favor additional engagements in future projects. Indeed, in July 2020 people started to send new records to the fan page even without launching a new citizen science campaign (data not showed).

The authors answered to everyone that contacted them by Facebook or by e-mail. In any case, a preset reply was never given, but there was always used a customized feedback in order to promote an exchange of opinions. Indeed, people generally sent successive posts and e-mails supplying further details about their findings or reporting records from acquaintances. In digital marketing strategies, with aim to increase people conversions it is necessary to keep close relationships between companies and customers (Inbound marketing, [79], promoting high quality marketing contents [80] and shaping customer experiences [81]). A similar approach should also be followed in citizen science programs, winning the trust of people by preparing exhaustive contents and offering a citizen scientist experience. In the funnel diagram in Figure 8 proposed steps for public engagement are summarized. The final objective of this funnel is advocacy, i.e., incentivizing people to talk positively about their citizen science experience.



**Figure 8.** Citizen science funnel illustrating phases leading to conversion (i.e., engagement of citizen scientists).

#### 4.5. How Can the Profiling of Volunteers Support the Development of Conservation Projects Based on Citizen Science?

As for marketing strategies [80], targeting potential citizen scientists could be crucial to optimize contents and to have conversions, i.e., enrolling new participants to future projects.

For example, by targeting the audience through Facebook *insights*, it is shown that most followers of AmbienteMarino were about 25–34 years old (reflecting the age of most Facebook users); while, most scuba divers are 25–44 years old, with a higher number of males (Figure 5C, [82]), probably because fans of the fan page included more swimmers and snorkelers than scuba divers, as highlighted by

the analysis of obtained records (Figure 2B). It was also stated that tourists were scarcely engaged, that males and females are equally interested in contributing to marine science and that tourists from Czech Republic could be potential citizen scientists when frequenting the Croatian coast.

Concerning the information obtained by the survey, the collected data highlight that many people would contribute to marine science, but the same sample does not know what ‘citizen science’ was, as already documented in previous studies [20]. More strikingly, a consistent portion of citizens were unaware of importance of scientific data collecting, underlining the communication gap between marine science and citizens, at least in the involved countries. Channels of communication such as magazines and television still have a minor role in talking about citizen science, notwithstanding TV as a powerful interface between public and science [83]. The results of this survey will be useful to point out the gaps related to the engagement of marine citizen scientists, to help set a future well-structured questionnaire and to help plan eventual Facebook advertising campaigns to reach more people.

#### 4.6. Is WEK Confirmed as Effective Tool to Build Datasets on Species Distribution and Abundance?

Citizen scientists and people that publish photos/videos on the WWW, respectively are people who intentionally and unintentionally contribute to marine science [31]. This study confirms that WEK, still scarcely exploited, represents a consistent source of scientific information that is accessible and continuously updated. Indeed, the examined videos from the northern part of the studied area are a benchmark for tracing future records of occurrence of the fireworm and for better understanding whether it is expanding its distribution range. It is also underlined that most videos did not show information about depth and coordinates, as highlighted in Figure 1B, therefore it is important to stress the necessity to sensitize scuba divers about the importance of supplying these data in their videos.

#### 4.7. Ecological Traits of *Hermodice carunculata*

According to data gathered through this research, *Hermodice carunculata* is spreading in the central and southern Croatian counties. The work provides the northernmost occurrence record of the polychaete in the Mediterranean Sea and supplies further information on a potential biologic invasion sensu [84] in this basin. Due to the water temperature increase and changing in thermohaline circulation of the Adriatic Sea [85], extension of northern limit of distribution of warm-affinity species is expected [86]. The eastern Mediterranean is particularly prone to invasion of thermophilic species [87] and data on species distribution from this area could be used to set further field surveys and to forecast the worm spreading northward.

Predation on starfish was already documented in southern Brazil [88] while this is the first documented report of this trophic relationship for the Mediterranean Sea. The ability of Asteroidea to regenerate tissues is a slow process [89]; therefore, the continuous predation by fireworms could influence the stress response [90] in the predated starfish.

One of the predated species—*Ophidiaster ophidianus*—is listed in the Appendix II (Strictly protected fauna species) of the Bern Convention [91] due to harvesting for ornament industry or aquarium trade [92]; moreover, since the renewal rate of adults of *O. ophidianus* could be low [93], populations of *Ophidiaster* as well as of other starfish in the Mediterranean Sea should urgently be monitored.

Predated gorgonians were healthy, and the bared portions left by the worm feeding activity were small, suggesting that the corals could quickly recover after predation. [94] noticed that the octocoral *Ellisella paraplexauroides* from Chafarinas Islands (western Mediterranean) regrows quickly after being predated by *Hermodice*. At the moment, in the studied area damages caused to starfish seem to be more worrying than those inflicted to gorgonians and further research should be performed in order to understand the frequency and the intensity of the polychaete predation on benthic species.

In the studied area there are no signs of disease in common azooxanthellate corals predated by *Hermodice* such as *Madracis pharensis*, *Leptopsammia pruvoti* and *Polycyathus muelleriae* while, there is not information about the zooxanthellate coral *Cladocora cespitosa*.

It has been hypothesized that *H. carunculata* is a reservoir and a vector for pathogens (*Vibrio shiloi*) involved in bleaching of the scleractinian *Oculina patagonica* in the eastern Mediterranean when sea temperature rises above 25–30 °C [95,96]. However, it was demonstrated that *O. patagonica* becomes resistant to *Vibrio* when associated with beneficial bacteria [97].

Bacteria from hard-bodied coral *Madracis decactis* and *Hermodice carunculata* from Brazil were characterized [98]; the authors found *Vibrio shiloi* in *H. carunculata*, but not in the coral and hypothesized a possible role of other facultative anaerobic bacteria and/or anthropogenic impacts in triggering coral bleaching.

The only predator of *H. carunculata* seen in the Croatian waters seems to be a balistid fish that is plausible since gray triggerfish became more abundant in the Adriatic Sea probably due to climatic and hydrographic changes [99]. Recent evidence of predation on *Hermodice* is a sequence of photos from the Strait of Messina (South of Italy, 2018) posted on Facebook by Mr. Pasquale Caristo showing *Pleurobranchia meckeli* (Gastropoda: Heterobranchia) engulfing an entire worm.

Several photos sent to authors showed aggregation of mating polychaetes, suggesting that the reproduction strategy of this species is crucial in determining its invasiveness. According to a recent study about early developmental stages of *H. carunculata* [49], the amphinomid likely is iteroparous and presents prolonged planktonic stages. For these reasons, it would be fundamental and urgent to study the reproductive biology of this polychaete [44].

## 5. Conclusions

A key point of this work is to underline the importance of shaping ‘citizen science experiences’, i.e., interacting with people, supplying them with knowledge about marine life and giving a feedback about the project’s results. In this context, social platforms could be considered as virtual forum where this interaction may occur and where scientists can monitor the participation of citizens. *Pro* and *cons* for scientists and benefits for people involved through social platforms are summarized in Table 1.

**Table 1.** Pro and cons of citizen science through social platforms.

Benefits for People	Benefits for Science (in Comparison to a Traditional Citizen Science Project)	Limits for Science
Gratified curiosity, enhanced knowledge on marine diversity by living a ‘citizen science experience’	Involvement of wider public in comparison to a traditional project, with the possibility of making more people aware of marine environment and retrieving more data	Creating new contents and customized feedback for people interacting with the fan page is time-consuming
Increased pleasure of discovery	Faster interaction, file sharing and data validation	Eventual advertising campaign could be costly
Increased fun	Continuous monitoring of the insights is essential for choosing strategies that correspond to them	social aspects should be analyzed together with experts in social science
Gaining a more correct behavior in the marine environment (more respect for marine species/habitats and higher safety level for bathers/divers)	Establishing a solid, trustful relationship with citizen scientists which may collaborate to future projects	The proposed strategy works with species easy to identify
The involvement takes little time	Posts shared through social networks may generate a virtual word of mouth useful to enroll further citizen scientists.	
Increased sense of belonging to a common conservation project		
Enhanced sense of responsibility towards the marine environment		

Problems encountered during the implementation of this research and their possible solutions are summarized in Table 2. In particular, it was noticed that people are more inclined to supply presence than absence data, leading to biased data [100] (i.e., not homogeneous data distribution in the studied area). Some authors suggest overcoming this problem by supplying species lists [101]; however, this solution is in conflict with the strategy based on a fast method. In this study, the issue was fixed by vetting the web ecological knowledge.

**Table 2.** Limits in the use of social platforms for marine citizen science projects and how to fix them.

Limits	Solutions
A fan page on <i>Facebook</i> is not useful to involve people over 55	Face-to-face interviews
Obtained data do not have a homogeneous distribution in the studied area since people are more prone to record presence than absence of a target species	Informative campaigns about the target species should be implemented (online and offline) to raise people awareness to underline the importance of absence data. Local TV and online newspapers could be also involved, especially in case of stinging or highly endangered species.†Data from WEK (web ecological knowledge) and in particular from YouTube can be exploited to fill this gap
Inadequate involvement of tourists	Involvement of tourist offices, marinas, tourist operators that could share online bills and other printed informative material
People are ignorant about citizen science	Informative campaigns should explain what citizen science is
Participation of dive centers is still limited	At moment, dive centers' owners participate as any other citizen to marine science. The role of dive centers should be enhanced by involving them as partners/stakeholders in founded citizen science projects
Participation of nonprofessional scuba divers is still scant	Involved dive centers will inform and train scuba divers to promote the data collection
It is difficult to spread a survey for targeting citizen scientists	WhatsApp could be tested to promote chain messages among personal contacts
People are reluctant to supply coordinates	Ask people for supplying at least a screenshot of a Google Earth map

Since the warm glow for protecting the environment [20] is relevant in citizen science projects, the promotion of the informative campaigns about the target species (online and offline) are necessary, in order to raise people awareness and to underline the importance of absence data. Moreover, it is important to highlight the crucial role of diving centers in communicating with scuba divers and in engaging them in research (Table 2).

Future research on *Hermodice carunculata* should consider reproduction behavior in the studied area, including citizens records collected through social platforms that may contribute to highlighting mating periods, number of aggregating fireworms and role of artificial substrates and enclosed areas in promoting aggregation.

**Supplementary Materials:** The following are available online at <http://www.mdpi.com/1424-2818/12/8/311/s1>, Table S1: Research-based citizen science conducted in the Mediterranean Sea; Table S2: Records of *Hermodice carunculata* in the study area.

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