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Development and catch efficiency of an attracting device to collect and monitor the invasive fireworm *Hermodice carunculata* in the Mediterranean Sea

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Abstract

The fireworm *Hermodice carunculata* (Annelida) is emerging as a native invader and a neonative species in the Central Mediterranean basins. Its ongoing areal expansion has probably been triggered and pursued by the climate alterations which are affecting the Mediterranean environments and biota. However, increased *H. carunculata* abundance and distribution may be miscalculated and underestimated due to the lack of effective tools for collection and monitoring. Indeed, fireworms spend most of the daytime in crevices and holes, making it impossible to obtain reliable data in underwater surveys.

In this study, traps were developed to provide suitable shelter and food to fireworms, and their effectiveness and specificity were assessed by testing different immersion times, environmental conditions and types of bait. Pierced plastic baskets adapted for fireworm capture proved to be extremely easy to set up, reproducible, cheap, and highly specific. The devices were used at 11 sites located along the Ionian Apulian coast (Italy). They proved to be suitable and effective: more than 90% of the traps baited with raw fish succeeded in capturing *H. carunculata* specimens, with an average of 8-9 fireworms captured *per* trap. The traps were deployed at a depth range of 1.5-9 m with immersion times of up to 4 h, and even large sized fireworms (> 32 cm in length) were caught.

These attracting devices could be successful in different forthcoming challenges, allowing the collection of a great number of fireworms to investigate their impact on rocky bottom communities, distribution, and potential for bioprospecting. Besides, the cheapness and ease of use of the traps also make them suitable for Citizen Science studies and sampling campaigns aiming at characterizing the expanding populations. Future applications will be critical to improve deployment success and test user friendliness.

Keywords: Invasive species; Trap; Amphinomida; Mediterranean Sea; Monitoring.

Introduction

Ongoing climate alterations have led to critical changes in environmental conditions, affecting marine biota, ecosystems, and the valuable ecosystem services associated with them (Sunday *et al.,* 2012; Marzloff *et al.,* 2016; Pecl *et al.,* 2017; Lovejoy & Wilson, 2019; Sampaio and Rosa, 2020). As a consequence of global warming, warm-water species are changing their distribution range, abundance and behavior, shifting their presence towards higher latitudes and greater depths (Poloczanska *et al.,* 2016). Thermophilic mobile species are further favored since they can benefit from temperature increase and move to new suitable areas in a colonization attempt (Azzurro *et al.,* 2018). In the Mediterranean, seawater warming is prompting the expansion of subtropical species, which often interact with native fauna in the neo-colonized areas (Lejeusne *et al.,* 2010; Marbà *et al.,* 2015; Bianchi *et al.,* 2018). Research studies have mainly been focused on the invasive alien species, but also the thermophilic “native invaders”, which become invasive in their own native range, can seriously impact local trophic chains and community structure (Carey *et al.,* 2012; Cunningham *et al.,* 2016).

During the last decade, “the bearded fireworm” *Hermodice carunculata* (Pallas, 1766) has emerged as a native invader in the Central Mediterranean Sea (Righi *et al.,* 2020). This amphinomid polychaete is widespread in the Western Atlantic Ocean, Caribbean, and Gulf of Mexico, and in the Red and Mediterranean Seas (Schulze *et al.,* 2017). In the Mediterranean, it has been reported since the 19th century along the Southern Sicilian and Southern Adriatic Croatian coasts (Simonini *et al.,* 2019; Righi *et al.,* 2020).

The reconstruction of *H. carunculata* distribution along the Italian Peninsula and its changes during the last

50 years has confirmed a trend of expansion consistent with the northward displacement of the 14° C isotherm of February (Righi *et al.,* 2020). Fireworms are moving farther and farther northward than in the past, and have reached the coasts of Sardinia, the Tuscan Archipelago (Tyrrhenian Sea, Western Mediterranean Sea) and the northernmost Croatian islands (Adriatic Sea) (Kržel*j et al.,* 2020; Righi *et al.,* 2020). Also, although this species had not previously been reported in the list of marine annelids from continental Spain (Parapar *et al.,* 2012), populations have been recently observed along the coasts of Andalusia and Murcia (Coma *et al.,* 2011; Righi *et al.,* 2020) and towards the south-western Iberian Peninsula (Encarnação *et al.,* 2019).

To date, no species able to consistently feed on *H. carunculata* in the Mediterranean Sea has been reported (Righi, 2021). In contrast, fireworms can efficiently prey on a wide range of invertebrate taxa, including organisms endued with physical and/or chemical defences (Simonini *et al.,* 2018). In the Caribbean, *H. carunculata* is a well-known opportunistic scavenger and generalist predator which feeds on carrion, injured organisms and living corals (Ott & Lewis, 1972; Wolf & Nugues, 2013; Wolf *et al.,* 2014; Schulze *et al.,* 2017). In the Mediterranean, its feeding activity may extend over a wide range of prey, including cnidarians, nudibranchs, chitons, ascidians, and echinoderms (Simonini *et al.,* 2017, 2018). *H. carunculata* predatory abilities are related to brittle stinging chaetae, whose deterrent capacities are due to a combination of needle-like shape, calcareous composition and vehiculated chemicals (Righi 2021; Simonini *et al.,* 2021).

An uncontrolled increase in *H. carunculata* density has been claimed along the coasts of Apulia, Sicily, and Calabria: this occurrence can represent a potential risk for both benthic ecosystems and "*sea users*" such as fishermen, scuba divers and beach goers (Kržel*j et al.,* 2020; Righi *et al.,* 2020). Along the Southern coasts of Italy, *H. carunculata* even colonizes the shallow depths popular with tourists, who can encounter the fireworms while in the water (Righi *et al.,* 2020). Flared tufts of dorsal chaetae cause an immediate painful burning sensation, erythema, and paresthesia on contact (Smith, 2002). The effect of the stings depends on personal sensitivity to the chemicals stored in the chaetae. Particularly exposed to contact, fishermen can be stung while cleaning nets, since chaetae remain stuck in the mesh (EastMed, 2010).

H. carunculata populations can also damage fisheries: fireworms are known to take bait and are commonly found attached to dead fish (Glasby & Bailey-Brock, 2001; Simonini *et al.,* 2018). Fish trapped in nets may attract fireworms, whose feeding action makes the catch unsuitable for commercialization (Celona & Comparetto, 2010). *H. carunculata* density can also significantly increase in seabeds affected by anthropogenic organic matter input, such as those impacted by aquaculture farms and the discharge of fishery waste (Rodrigo *et al.,* 2014).

The study of the massive proliferation and rapid expansion of *H. carunculata* needs tools for population monitoring and specimen collection, in order to shed light on its toxins, map the range-shift and investigate the serious ecological impact it may cause in the colonized areas (Righi *et al.,* 2020; Toso *et al.,* 2020; Righi, 2021).

H. carunculata specimens can be collected for scientific purposes by scuba divers through hand-picking, possibly with tweezers (Righi *et al.,* 2020). However, this approach is time-consuming, expensive, not suitable for standardization and may even be dangerous, as it implies underwater contact with the worm chaetae. Natural abundance and distribution data for *H. carunculata* are very hard to obtain in underwater surveys (Wolf *et al.,* 2014), because the three-dimensionality of rocky environments characterized by crevices and holes makes it difficult to find and collect specimens (Ott & Lewis, 1972; Lewis & Crooks, 1996).

To the best of our knowledge, the only field experiments aimed at providing a nondestructive proxy for *H. carunculata* abundance were performed in the Caribbean, using micropredator- attracting devices (MADs). The MADs were made of small nylon mesh nets, which were large enough to allow the entrance of the fireworms, and filled with green algae (*Halimeda opuntia*), fragments of decaying corals and raw fish (Wolf *et al.,* 2014; Wolf & Nugues, 2013).

The main purpose of the present study was to develop an effective, easy-to use and cheap device for attracting fireworms, with potential usefulness in the collection and monitoring of this species through the study of its biology, population dynamics, increased abundance, and areal expansion. In the Mediterranean, *H. carunculata* specimens often colonize vertical rocky substrates lacking erect algae, and where true coral reefs are absent. Thus, instead of relying on the MADs, we modified commercial pierced plastic baskets to create baited traps. The best bait and immersion time were assessed, then we evaluated 1) the traps' ability to reveal fireworm presence in colonized areas; 2) the effect of local anthropic pressure on the number of catches and the size of the animals collected; 3) the existence of relationships between the number of catches and depth. We also assessed their specificity and efficacy in attracting *H. carunculata* specimens by providing suitable shelter and food. Given *H. carunculata* opportunistic feeding habits (Celona & Comparetto, 2010; Rodrigo *et al.,* 2014), we expected that the number of specimens collected would have been higher in areas with a greater anthropic pressure.

Materials and Methods

Fireworm trap development

The traps were set up based on our knowledge of Mediterranean *H. carunculata* behaviour (Simonini *et al.,* 2017, 2018; Righi *et al.,* 2019; Simonini *et al.,* 2021). Tens of specimens tend to form large groups close to dead animals in the field (Celona & Comparetto, 2010; Rodrigo *et al.,* 2014; Schulze *et al.,* 2017), or find refuge in artificial structures like drilled bricks, creating aggregations in aquaria (Authors' personal observation). Thanks to the ability to modify and elongate the body shape typical of annelids (e.g., Rouse & Pleijel, 2011), fireworms can enter tight holes and penetrate narrow openings.

In this study, 12 fireworm traps were developed based on the design of recycling bins for organic waste collection (distributed by Hera Spa, Italy). They consisted of a pierced polypropylene basket (about 20 cm length x 24 cm wide x 30 cm height, volume 10 L) with a handle and cover (Fig. 1A-C). The cover was pierced and kept closed using plastic-coated iron wire to ensure both secure closure and easy opening. The holes on the walls and bottom were about 1 cm wide like those in the MADs (Wolf *et al.,* 2014; Wolf & Nugues 2013; Fig. 1A-C). The basket was weighed down with a 1 kg dive weight fixed with cable ties to the bottom, to prevent trap movement on the target substrate due to marine currents. A 10 m nylon rope (with cable ties as metric references for every 0.5 m) tied to the handle enabled the trap to be lowered, retrieved, and tied to rocks (Fig. 1A).

Field experiments

We conducted experiments in September 2020 close to 11 sites located along the Ionian Apulian coast, Italy (A1-A11; Fig. 2; Table S1). The rocky coast is characterized by several headlands, islets and cliffs (Supplementary video), and the presence of *H. carunculata* has been reported since 1970 (Righi *et al.,* 2020). We distinguished sites characterized by "high" or "low-absent" anthropic pressure (Fig. 2).

During several on-site observations of *H. carunculata* specimens, their opportunistic feeding habits towards a variety of food sources was extremely clear (Authors' personal observation). In addition, preliminary lab tests with thawed fish, poultry meat and boiled eggs confirmed that all these items were consumed equally by fireworms (Simonini *et al.,* 2018; Authors' personal observation). Thus, the choice of what bait to place within the traps fell to those that were easy to handle and prepare. Boiled eggs leave no unpleasant odour and are cheaper, easier to prepare and less perishable than fish, although they leave a stronger odor plume. Approximately 100-150 g of boiled white eggs, or alternatively raw fish (e.g., *Engraulis encrasicolus* and *Sardina pilchardus*) together with thawed fish (*Scomber scombrus*) were placed inside a nylon mesh net (1 cm mesh) (hereinafter "fish"). The bait was prepared shortly before the fieldwork and transported to the sampling sites in thermal containers.

The traps were deployed between 2:00 pm and 7:00 pm, using the afternoon hours of daylight to work safely while the fireworms are most active (Wolf *et al.,* 2014; Schulze *et al.,* 2017).

Before trap deployment and retrieval, the surface water temperature was recorded.

The baited traps were deployed by hand from the cliff and lowered slowly and vertically within a depth range of 2-10 m, keeping the rope taut. Once the trap reached the bottom, the depth was measured using metric references on the rope. Then, the rope was tied to rocks and the trap was left from half an hour to four hours depending on the immersion time tested. Then, the trap was retrieved quickly, paying attention to not impact with rocks, to prevent the fireworms from falling out. On the ground, it was opened inside a container with seawater in it (Fig. 1C), and all the *H. carunculata* specimens with at least part of their body within the trap were considered captured and

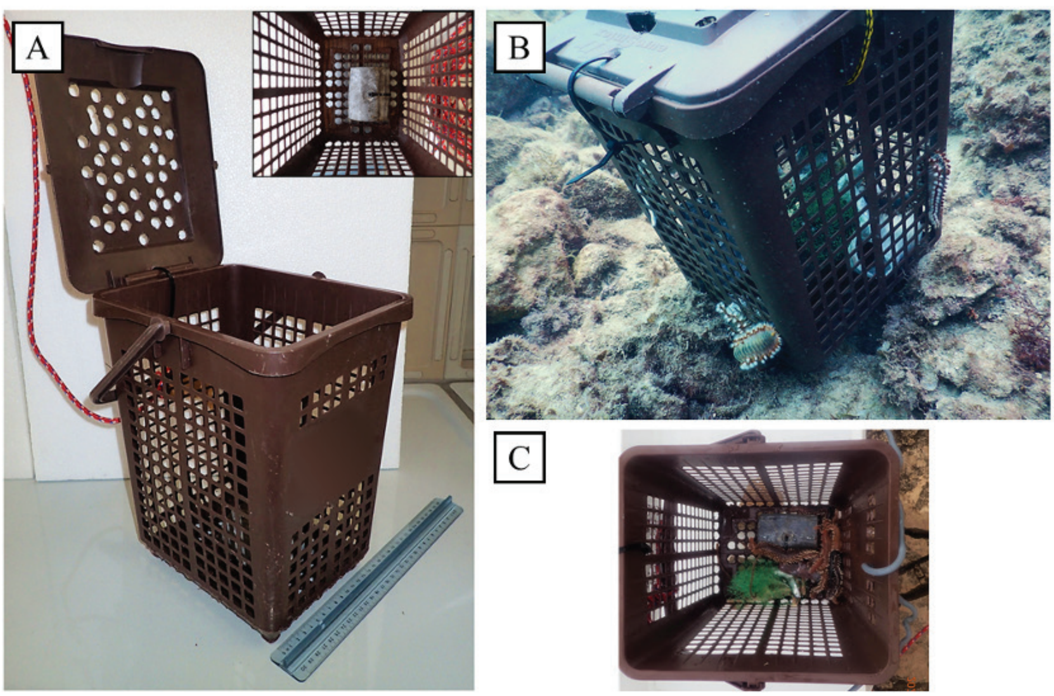

Fig. 1: (A-C). Attracting device to collect *H. caruncul ata*. (A) Polypropylene basket developed in the lab characterized by a handle, cover, 1 cm wide holes on walls and bottom, red nylon rope, and weighed down with a 1 kg (inlet). (B) Fireworm trap filled with bait (raw fish) and deployed on the target substrate with fireworms entering the holes (see Supplementary video for details). (C) Trap retrieved and opened, containing the fireworms captured and the remains of the baits.

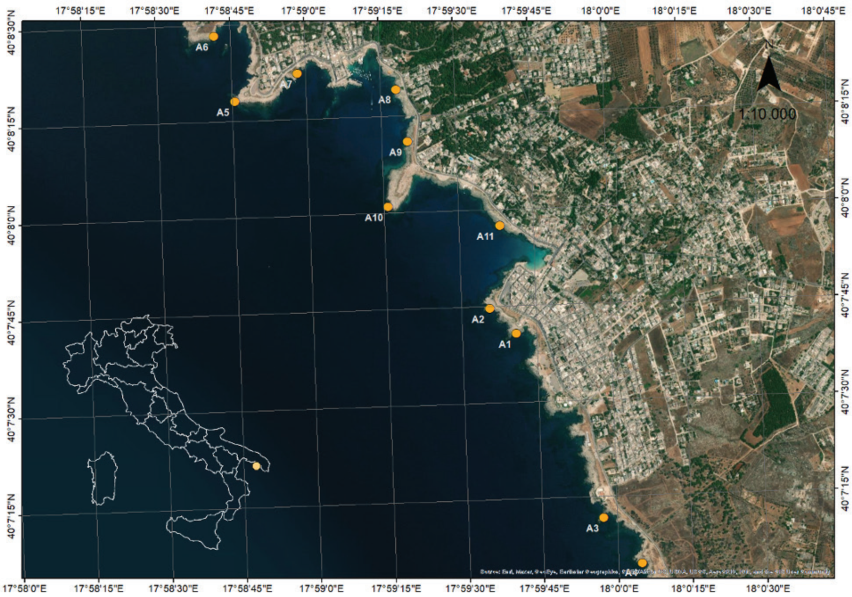

Fig. 2: Study area along the Ionian Apulian coast showing the eleven sampling sites (A1 – A11) to test fireworm traps. The sites A1, A2 and A3 are characterized by high anthropic pressure.

therefore counted. The bait remains were also examined looking for the presence of small fireworm specimens potentially hidden within the nylon mesh net.

The fireworms collected from each site were placed into 10 L containers with seawater for transportation to the lab. There, the seawater was immediately changed and oxygenated with aerators. The next morning, 10 fireworms *per* container were picked up randomly, anesthetized in $MgCl_2$ 7% and photographed to derive the body length and number of chaetigers (Righi *et al.,* 2019). The bottoms of the containers were checked to collect potential food items ingested by the fireworms before collection and expelled during the night together with fecal pellets.

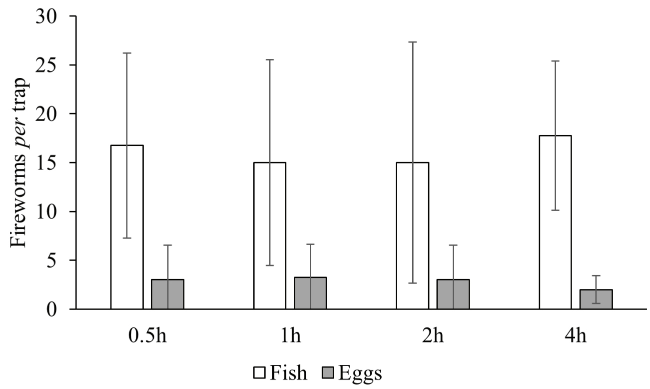

Fig. 3: Number of *H. carunculata* (mean ± standard deviation) collected with traps baited with fish or eggs, and deployed for 0.5, 1, 2 or 4 hours (n = 4 traps for each Bait x Time combination). The data were log transformed before running the 2-way ANOVA test (Levene´s test for homogeneity of variance $p > 0.28$).

Catch efficiency of fireworm traps

Two main experiments were performed. Firstly, a “setting up experiment” was developed to evaluate the best bait and immersion time by deploying 32 traps along a stretch of coast affected by high anthropic pressure (between A1 and A2 sites; Fig. 2; Table S1). Two fixed factors were considered: “Bait” (B), with two levels (boiled white eggs and fish) and “Immersion time” (T), with four levels (0.5 h, 1 h, 2 h and 4 h). T levels were defined considering that trap set-up, deployment, retrieval and fireworm counting require about 30’ - 1 h, and that excessive immersion time would have led to *H. carunculata* escaping from the trap after consuming the bait. The interactions of bait/immersion time (BxT, 4 replicates) and the effect of B and T were studied using a two-way ANOVA. Prior to all the analyses, the data were assessed for normality and homogeneity of variance using the Jarque-Bera and Levene’s tests, respectively, and logarithmic [ln (x + 1)] transformation of the data was performed if necessary (see the caption of Fig. 3 for further details).

Once the optimum type of bait and immersion time to ensure catch efficiency had been defined, a second “monitoring experiment” to estimate catch efficiency was performed (Table S1). A total of 22 traps were deployed at sites with high (sites A1-A3) and low-absent (sites A4-A11) anthropic pressure (Fig. 2). Two traps *per* site were submerged for 1 h (Table S1).

The number of the captured specimens and their allometric traits (i.e., length and number of chaetigers) were tested for normality (Shapiro-Wilk’s test) and homogeneity of variance (test F) and compared between sites with high and low-absent anthropic pressure by the t-test. Logarithmic [ln(x+1)] transformation of data was applied if necessary (see the caption of Fig. 4 for further details).

The relation between the depth reached by the trap and the number of captured fireworms were tested using Spearman’s correlation. The data analyses were performed using the statistic software PAST (Hammer *et al.,* 2008) and α was set at 0.05 for all the tests.

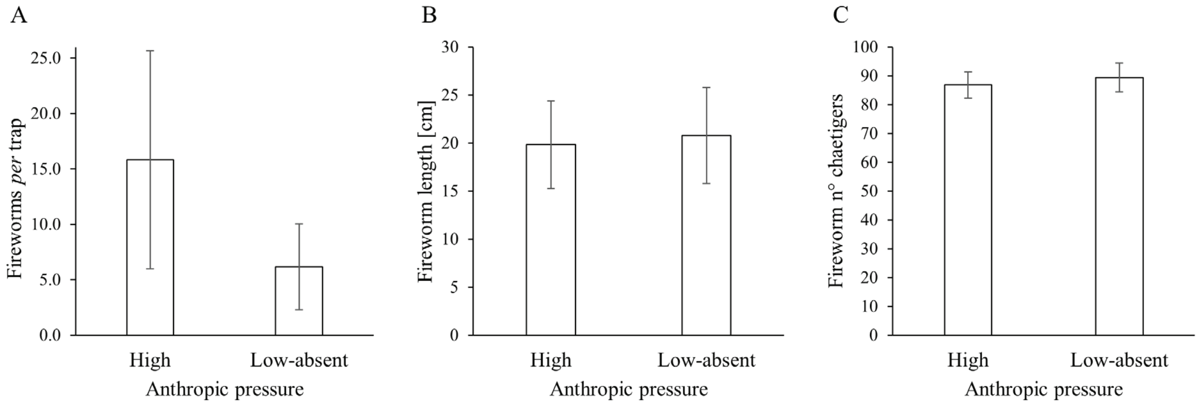

Fig. 4: (A-C). *H. carunculata* specimens collected in traps baited with fish and deployed for 1 h. Mean ± standard deviation values are reported. (A) Number of fireworms captured with traps deployed at sites with high (n = 6) and low-absent (n = 16) anthropic pressure. The data were log transformed before running the t-test (F-tests for equal variances on log transformed data F = 1.34, $p >$ 0.79); length (B) and number of chaetigers (C) of the fireworms (n = 37) collected (F-tests for equal variances on the original data: F = 1.20, $p > 0.59$; F = 1.6842, $p > 0.12$ for length and chaetigers, respectively). The data were log transformed before running the t-test on the number of chaetigers.

Results

During the setting up experiment, a total of 303 fireworms were captured across 32 deployments (Fig. 3).

The number of fireworms collected was affected by the type of bait (B: $F_{1,24} = 34.84$; $p = 4.33 \cdot 10^{-6}$), while it did not differ significantly among immersion times (T: $F_{3,24} = 0.11$; $p > 0.95$ n.s.; TxB: $F_{3,24} = 0.18$; $p > 0.91$ n.s.). Indeed, the mean number of *H. carunculata* specimens caught in traps baited with fish was six times higher than those collected using boiled eggs (11.6 ± 8.7 *vs* 2.8 ± 2.8, respectively, mean ± standard deviation; Fig. 3). Noteworthy, 3 traps baited with boiled white eggs were retrieved empty, while 2 traps with fish contained 30 specimens each.

Based on the above findings, the immersion time of 1 h was considered the most eligible for the monitoring experiment, since it enabled both sampling preparation (i.e. trap set-up and deployment) and the subsequent phases of trap retrieval and fireworm counting to be carried out carefully at a minimum of two sites, including the time for moving from one site to the next. Overall, the monitoring experiment allowed the capture of 194 *H. carunculata* specimens across 22 deployments (an average of 8-9 fireworms *per* trap), only one trap being found empty, with a capture percentage of 95%. In particular, the number of fireworms collected close to sources of anthropic pressure (n = 16 ± 10) was significantly greater than at sites where the enrichment was low-absent (n = 6 ± 4; t = 3.0, $p = 0.013$, Fig. 4A). Chiton plates and sea urchin spines were always found among the food remains expelled by the fireworms during the night and retrieved from the bottom of the seawater container. Surprisingly, *H. carunculata* captured from bottoms subjected to anthropic pressure also rejected crab fragments, several waxworm fragments and entire waxworms, the caterpillar larvae of wax moths (Pyralidae).

The body size of the animals did not differ between sites with high or low-absent anthropic pressure. Indeed, they were similar both in length (19.8 ± 4.6 cm and 20.8 ± 5.0 cm, for the sites with high and low-absent anthropic pressure, respectively; t = 0.87, $p = 0.388$, Fig. 4B), and in the number of chaetigers (86.9 ± 4.6 and 89.4 ± 5.0, for the sites with high and low-absent anthropic pressure, respectively; t = 0.95, $p = 0.348$, Fig. 4C). Considering the fireworms collected at all the sites, the length varied between 11.6 and 32 cm, and the number of chaetigers between 58 and 116.

The fireworm abundance was not related ($r_s = 0.51$, $p = 0.1500$) to the depth reached by the trap, which ranged from 1.5 to 9 m (4.8 ± 2.0 m). The depth reached by the traps did not differ (t = 1.87, $p > 0.06$, untrasformed data) between sites with high (5.8 ± 1.7 m) and low-absent (4.7 ± 2.3 m) anthropic pressure.

Discussion

Traps made of pierced polypropylene baskets proved to be highly effective: more than 90% of them succeeded in collecting *H. carunculata* specimens without the intervention of scuba divers. Besides, they were even found to be highly specific, making it harder for other predators with an enlarged body shape to enter the trap: indeed, gastropods with bulky shells were occasionally found attached to the outside of the trap. Underwater inspections showed that even fish and crabs were attracted by the fish bait used, but *H. carunculata* specimens quickly came out from surrounding rocks and, even when large-sized (with a maximum length of 32 cm), they could easily enter the 1 cm holes on the sides of the trap by elongating their bodies (Supplementary video).

Quantitative studies on the motile benthos in rocky communities are challenging, as this fauna escapes the usual sampling methods (Cattaneo-Vietti & Mojetta, 2021). Good results were obtained by scraping rocky surfaces of 100-400 cm^2 (Giangrande *et al.,* 2004), using small nets or sucking pumps operated directly underwater (Giangrande *et al.,* 1986). Samples of hard substrate small-sized fauna assemblages were also obtained following the NaGISA protocol (Keklikoglou *et al.,* 2019). However, sampling methods mainly based on scraping and suction devices often did not account for large-sized crawling polychaetes like *H. carunculata* (Righi *et al.,* 2020). Moreover, even if accurate, they are often too limited and point-like, and can damage the animals, particularly if large-sized (Górska *et al.,* 2019; Cattaneo-Vietti & Mojetta, 2021). Diver-based observational methods, such as underwater visual census, are the most commonly used approach to surveying shallow coastal water megafauna (Caldwell, 2016), but are inherently limited by depth and time (i.e., scuba diving constraints; Cattaneo-Vietti & Mojetta, 2021). To the best of our knowledge, no alternative strategies have been developed for fireworm monitoring and collection, apart from catching amphinomids on baited hooks while fishing (Glasby & Bailey-Brock, 2001), scuba diving (Righi *et al.,* 2020) or using attracting devices made of mesh bags (i.e., MADs; Wolf & Nugues, 2013; Wolf *et al.,* 2014).

MADs were used by scuba divers in the Curacao reefs (Caribbean Sea) and consist of small nylon mesh nets (1 cm mesh) filled with clumps of the alga *Halimeda opuntia*, each covering an area of 200 cm^2 on the coral reef substrate. These mesh bags proved to be specific for *H. carunculata*: all the fireworms captured belonged to this species, and the corallivorous snail *C. abbreviata* was found in only 5 out of the 146 *H. opuntia* clumps collected (3,4%), compared to the 71 clumps containing *H. carunculata* (49%) (Wolf & Nugues, 2013).

In accordance with Wolf *et al.* (2014), the MADs were retrieved by scuba divers after 6-96 h of deployment. In the present study, the immersion time of the traps was much shorter (0.5-4 h), but also successful. Given that the number of fireworms collected was not significantly different among the immersion times tested, a period of 1 h was chosen. This finding together with underwater observations suggests that traps are efficient in attracting fireworms next to them (within a range of about 10 m). If the traps are left for 1 h, a representative number of fireworms will enter the trap, consuming the bait and remaining inside the basket. Otherwise, if the traps are left longer, the specimens which fed on the bait first will leave the trap and other fireworms could arrive. Thus 1 h can be considered the best time for trap use, combining both a significant number of captures and a manageable activity for users.

The traps proved to be simple and functional, thus multiple deployment and retrieval during an afternoon was possible for even a single operator, although working in pairs increases safety. Besides, excessively long, or short immersion times could lead to a reduction in the number of traps deployed during the sampling period (an afternoon) or to an overlapping of the sampling phases among more traps deployed in sequence, respectively.

Among the different baits tested with MADs, raw fish and decayed coral fragments were the most attractive: in particular, the median number of fireworms observed in the MADs filled with raw fish was 3 (interquartile range 2-4) (Wolf *et al.,* 2014). Accordingly, we observed that boiled white eggs were useful for transportation and handling, but fish proved to be extremely attractive: the median number of fireworms observed in pierced polypropylene baskets baited with raw fish was 9.5 (interquartile range 4.5–14.5). Besides, at least one fireworm was collected in 21 out of the 22 traps baited with fish at different sites, in accordance with local divers, who reported *H. carunculata* presence in the whole study area. The organic remains of bait can easily be washed off with seawater and tap water, ensuring low odor once the trap is dried.

H. carunculata is notorious as a generalist predator and scavenger, which colonizes coastal zones impacted by anthropic pressure (Celona & Comparetto, 2010; Rodrigo *et al.,* 2014; Schulze *et al.,* 2017), frequented by beach goers, fishermen or close to restaurants, thus with a great organic matter load due to the dispersal of fish baits and food remains.

The number of fireworms captured at sites with high anthropic pressure was three times higher than those obtained from other sites. The direct connection between human presence and the density of *H. carunculata* was confirmed by the remains of crabs, sea urchins and waxworms expelled by fireworms after housing. The gonads of sea urchins (e.g., *Paracentrotus lividus*) are highly appreciated by beach goers in Apulia (Volpe *et al.,* 2018), and urchins are often collected and eaten raw on the beach, while empty shells are discarded into the sea, attracting fireworms. Pieces of crab and waxworm are among the most popular baits used by local anglers, and large quantities are commonly released into the water to attract fish to the hooks. Even in this case, the excess of organic matter becomes extremely appealing to fireworms. The retrieval of chiton plates confirmed the existence of a predator-prey interaction between fireworms and chitons, as previously reported in lab observations (Simonini *et al.,* 2018).

The majority of fireworm reports along the Italian coasts derives from bottoms between the low tide level and a depth of 20 m (Righi *et al.,* 2020). In this study, traps were deployed from 1.5 to 9 m depth and no effects of the depth on the number of captures were highlighted. This result confirms the findings obtained when the MADs were deployed in different reef zones along a gradient ranging from 1 to 10 m (Wolf *et al.,* 2014).

Based on our experience in Ionian Apulia, an expert scientific diver familiar with fireworms takes at least 4 h to collect approximately 50 specimens during an *ad hoc* dive in environments characterized by anthropic pressure, where *H. carunculata* abundance is high. In addition to the time required for routine diving procedures (including pre-dive preparation, in-water procedures, and after-dive maintenance of equipment), once underwater an initial settling-in time is essential in order to start recognizing fireworms, which at first are hard to distinguish from the surrounding environment. In the same habitat and time, the deployment of 6 traps (a mean of 16 fireworms *per* trap) can allow the capture of about 90-100 specimens. Our traps also ensure safer sampling since they prevent contact with fireworm stinging chaetae underwater. These considerations strongly support pierced polypropylene basket effectiveness and employment potential. Besides, the traps also proved extremely cheap, since all the source materials are readily available in any hardware store or on the Web. The approximate cost for the materials *per* trap was about € 12.50, including the ropes, cable ties, plastic wires, and weights, which could be replaced by common stones or bricks. This cost is in line with those of other plastic traps weighed down with dive weights, like the "crab condo", used to sample the Chinese mitten crab *Eriocheir sinensis*, that is, about € 18.12 including weights, floats, and ropes (Hewitt & McDonald, 2013). Likewise, even the Gee's Minnow trap and subsequent metal and/or plastic varieties have an approximate cost *per* trap of about € 15.00-25.00 (Kronshage & Glandt, 2014). These expenditures are significantly lower than collection made by SCUBA divers, since only the rent of a SCUBA tank is approximately € 10.00, and the time required to capture the same number of fireworms as the traps is much higher.

The traps developed and the protocol set up were easy and quick to employ for the selective and quantitative monitoring of *H. carunculata*. These tools could be successful in different forthcoming challenges to investigate fireworm impact on shallow rocky bottom communities, and their distribution and potential for bioprospecting (Simonini *et al.,* 2017; Righi *et al.,* 2020; Toso *et al.,* 2020; Righi, 2021). Indeed, they could be crucial for the collection of a large number of *H. carunculata* specimens necessary for research focused on blue biotechnologies and marine biodiscovery. The availability of great initial quantities of biological samples is critical for the isolation of pigments, bioactive compounds, and the characterization and structure elucidation of the toxins that trigger the fireworm's stinging effect (Righi, 2021).

The cheapness and ease of the trap developed also make it suitable for citizen science studies aimed at reconstructing *H. carunculata* distribution and the temporal variations that are occurring in its abundance on large spatial and time scales (Righi *et al.,* 2020).

In the Mediterranean, *H. carunculata* has already become the target of citizen science initiatives, such as the occurrence records collected along the Croatian Archipelago between 2006 and 2019 by dive centers/citizens using social platforms (Krželj *et al.,* 2020). Informed citizens could be extremely instrumental in helping scientists to track fireworm presence and expansion and in warning about underwater environments that seem to have been critically damaged by *H. carunculata* specimens. Sampling campaigns would allow the characterization of the morphometry and genetics of expanding populations, clarifying the inter-population variability of Mediterranean fireworms (Righi *et al.,* 2019).

Predation on a wide range of benthic taxa may lead to a reduction in biodiversity and habitat degradation in both localized and broader-scale areas. Fireworms' opportunistic and voracious feeding habits can compromise the attractiveness of popular dive destinations, affecting the main fauna of valuable submersed environments, with potential long-term effects (Righi, 2021). To that end, validation of the monitoring tool would strongly support the study of mitigation measures for this marker species of the ongoing "tropicalization" of the Mediterranean Sea (Bianchi *et al.,* 2018; Toso *et al.,* 2020).

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Supplementary data

The following supplementary information is available online for the article:

Video: Geomorphology of the coastal study site for testing the catch efficiency of fireworm traps. The baited traps were deployed by hand from the cliff trying to reach an area with a minimum depth of 1.5 m, then they were lowered slowly and vertically once in water. When the baited trap reached the seafloor, the raw fish odor strongly attracted fireworms, that started whipping heads back and forth and quickly moved towards the trap. Even if also larger fish came closer, they could not enter the holes in the plastic basket.