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What do marine zoologists need from an underwater vehicle?

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***Abstract* – Future perspectives in underwater vehicles potential uses and needed features are here presented and discussed through different study cases embracing research, monitoring and exploration, from shallow-water to deep-sea habitats and communities. Essential features asked to the next generation of underwater vehicles include the possibilities to explore deeper depths, observe in detail targeted specimens, use further spectra besides the visible, sample soft-body benthic organisms, move within demanding situations (e.g. obstacles on the seabed), as well as the ability to stably stop on the seabed and collect images in a relative long (e.g. few hours) time spam.**

I. INTRODUCTION

The last decades represented a turning point in the marine exploration worldwide, thanks to the development of underwater vehicles, such as Remotely Operated Vehicles (ROVs) and submersibles for the observation of the seabed, as well as, more recently, Autonomous Underwater Vehicles (AUVs) and underwater gliders [1]. The marine exploration has gone further also in the Mediterranean Sea, traditionally considered as one of the most intensively investigated areas of the world [2], but still unexplored in many parts. In this basin, only recently visual technologies allowed the observation of many species and communities, some of them thought to be extinct or never observed before [3,4]. However, much remains to be done also in this basin, particularly in the mesophotic (ca. 50–200 m depth) and aphotic zones (> 200 m depth), where many unknown species are likely to be present.

The present and the near-future underwater vehicles will be asked to be more and more effective in targeted studies, to understand features and processes characterizing these scantly-known areas, as well as to deepen in the study of marine habitats and species from shallow to deep-sea waters. We report four main issues to address in the future, with relative study cases, as examples of what do zoologists and marine biologists need from an underwater vehicle, to push the boundaries of the current state of knowledge in marine research and stimulate the improving of exploration vehicles in this sense.

II. ISSUES AND STUDY CASES

A. Depth

Underwater vehicles are asked to work in increasingly deeper areas, for the study of deep-sea communities such as those structured by the so-called cold-water corals (CWCs), that represent Vulnerable Marine Ecosystems (VMEs) [5] deserving urgent protection measures. These communities are mainly structured by framework-forming stony corals such as *Madrepora oculata* Linnaeus, 1758, *Desmophyllum pertusum* (Linnaeus, 1758) and *D. dianthus* (Esper, 1794), forest-forming black corals such as *Antipathes dichotoma* Pallas, 1766, *Leiopathes glaberrima* (Esper, 1788) and *Parantipathes larix* (Esper, 1788), alcyonaceans such as *Callogorgia verticillata* (Pallas, 1766), *Viminella flagellum* (Johnson, 1863) and *Isidella elongata* (Esper, 1788), as well as field-forming pennatulaceans such as *Funiculina quadrangularis* (Pallas, 1766) and *Kophobelemnon stelliferum* (Müller, 1776) [4,6]. The exploration of areas deeper than those surveyed so far could contribute in filling knowledge gaps about the distribution of important CWC communities and other VMEs, with fundamental implications for their understanding and protection.

Together with very deep areas, next-generation underwater vehicles are needed to work in shallow-water habitats. In fact, peculiar biogenic structures can be also present in very shallow waters, such as the bioconstructions structured by the polychaetes of the genus *Sabellaria* [7]. These animals can build extensive three-dimensional structures in the low mesolittoral and the upper infralittoral zones (*sensu* [8]), from the surface to 8–10 m depth. The study of this very shallow water habitat is currently carried out only by scuba diving [7], because the shallow depth and the presence of tree-dimensional biogenic structures (>2 m high) still makes operations with underwater vehicles difficult.

B. Observations

Together with the discovery of peculiar communities inhabiting and structuring the deep seabed, detailed studies are needed to deepen in the observation of the specimens, to see where do they live and how do they behave. The remote observation of benthic communities is generally carried out with vehicles, such as ROVs, or fixed observation platforms, such as landers [9]. Although ROVs allow to explore a relatively wide area of the seabed, their stationing in the same place for a certain period is difficult. On the contrary, landers allow the stable observation of the same target for few hours or more, but their deployment in deep areas do not allow to precisely chose the target and to frame it accordingly. For this reason, the behavioral study of many deep-sea species is still challenging, and most of the interactions occurring within the communities are yet unknown. Some examples of unexpected behaviors observed in mesophotic and deep-sea species from different phyla are here reported.

The red sea pen *Pennatula rubra* (Ellis, 1761) is a Mediterranean-endemic species, representing one of the most important field-forming sea pens of the continental shelf [10,11] and reported as vulnerable in the Red List of the International Union for the Conservation of Nature (IUCN) [12]. Some colonies of this species were observed and monitored to document their behavior and their reactions to disturbance [13].

The spider crab *Anamathia rissoana* (Roux, 1828) is characterized by long, thin and pointed legs, not particularly efficient to walk on the muddy bottoms where this species live. The stationary observation of this species in its environment allowed to understand the biological motivation behind the development of such legs structure [14].

The robust cusk-eel *Benthocometes robustus* (Goode & Bean, 1886) is characterized by a particular shape with a slender tail and a robust head that induced the development of several theories to justify such unusual morphology. In fact, the slender tail excluded a high mobility in this species, typical of swimming, nektonic fishes. Moreover, the robust head with frontal mouth does not fit with the typical features of benthic species, usually feeding on the sea bottom (with the mouth downwards) or feeding on species moving in proximity of the bottom (sit-and-wait feeding strategy, with the mouth upwards). *In vivo* observations of *B. robustus* in its environment recently allowed to explain such peculiar body shape [14].

Further observation techniques associated to underwater vehicles and aiming to study the structure and composition of specific habitats can benefit of particular hyperspectral images of the seafloor acquired within the continuous spectrum of light in the visible band (390-700 nm) [15]. This approach has been used to study and describe biogenic habitats such as coralligenous outcrops and CWC frameworks. These are important, valuable and sensitive habitats representing some of the main marine bioconstructions of the Mediterranean Sea [16]. In particular, coralligenous is a peculiar Mediterranean habitat built up by organisms accumulating calcium carbonate in their bodies (mostly calcareous algae, corals, bryozoans, molluscs and serpulids), growing one on the other, generation after generation, creating a three-dimensional habitat of great ecological and aesthetic importance [17,18].

C. Sampling

The taxonomic identification of many species can be made or confirmed only analyzing a sample. The collection of samples from the deep-sea is often challenging, particularly for those soft-bodied species that cannot be collected with the typical ROV arm. This is the case, for example, of the Mediterranean-endemic deep-sea holothuroid *Penilpidia ludwigi* (von Marenzeller, 1893), only occasionally captured in sediment traps [19] but never collected on purpose from deep-sea exploration vehicles because of its small size (often less than 2 cm) and its gelatinous consistency [20]. Another study case is represented by the macrophagous deep-sea ascidian *Dicopia antirrhinum* Monniot, 1972, only occasionally observed and very difficult to sample because of its soft body and its contraction ability [21,22].

D. Movement

The seabed topography, as well as the occurrence of both natural and anthropogenic obstacles can complicate or even make impossible the use of underwater vehicles for exploration and monitoring purposes. In highly impacted basins, such as the Mar Piccolo of Taranto (Ionian Sea, Italy) [23], scuba divers still represent the only possibility to work for remediation purposes, as well as for the study and conservation of protected species [24]. In fact, the occurrence of many anthropic obstacles makes impossible the deployment of vehicles connected to the boat with a cable, while the use of AUVs is too risky.

III. RESULTS

A. Depth

More than 60 CWC sites have been found in the deep Mediterranean Sea in the last two decades, with several areas characterized by a large coral growth and colony density known as CWC provinces [4]. CWC sites known to date are mainly present from 150 to 1000 depth. Some CWC species are likely to be present deeper than 1000 m depth, but explorative efforts at higher depth are currently lacking. Moreover, considering that trawling is forbidden at depth >1000 m, these deep communities should be more protected from destructive fishing practices. Underwater vehicles for the deep-sea exploration are now facing with the possibility to reach higher depth with relatively low costs, as alternative of the expensive workclass ROVs.

On the contrary, vehicles for shallow operations, such as those related to the study of *Sabellaria* spp.

bioconstructions, should be structured as "walking robots" able to move from few meters depth to the tide limit (mesolittoral zone) thanks to a legged structure that could allow to avoid obstacles.

B. Observations

ROV surveys in particularly favorable conditions (low currents, low wind, calm sea) allowed the observation of peculiar animal behaviors thanks to the possibility to stay for long on the seabed with the same framing. This revealed new insights about the studied species and highlighted the promising results that could be obtained with the opportunity of built an underwater vehicle which, when needed, can stop at the bottom like a fixed observation platform.

These ROV surveys allowed the first observation of an unknown behavior in *P. rubra*. This species was observed performing a slow (from 3 to 6 minutes) withdrawal behavior after a mechanic disturbance. Thanks to the expulsion of a large amount of water, the colony is able to significantly reduce its size and withdraw into its own hole on the soft seabed. Despite this species was first described at the end of the 17th century, such behavior was never mentioned, differently from the rapid (i.e. a few seconds) withdrawal ability of certain pennatulacean species. Moreover, some colonies of *P. rubra* were observed out of the sediment, inflating themselves with seawater and getting carried by currents as a sort of dispersal behavior [13].

In deeper areas, *A. rissoana* was observed climbing on the colonies of the bamboo coral *I. elongata* and on antipatharians to catch its small preys [14]. Such behavior as coral-climber could justify the particular shape of its legs.

In the same area, the unusual morphology of *B. robustus* resulted as an adaptation for a particular lifestyle. In fact, all the specimens observed were swimming vertically behind coral branches as a camouflaging strategy, in association with alcyonaceans and antipatharians [14].

The observation of the seabed using hyperspectral imagers on ROVs enabled the collection of high-resolution spectral images for the classification and monitoring of habitats and species [25]. This well-established technology for the study of subaerial environments was applied in the marine environment to map and monitor benthic habitats in shallow and deep-water environments [25]. This technique could allow the easy finding of peculiar benthic species such as those of conservation importance (e.g. seagrass, corals, sponges) based on their spectrum.

C. Sampling

The uncommon species *P. ludwigi* and *D. antirrhinum* have been recently recorded in certain areas of the Mediterranean [20,21], revealing that these species are probably not so rare. However, in these cases sampling was not possible, thus the confirmation of the taxonomic identification based on samples features was not done. For these purposes, the vehicle used should be equipped with *ad hoc* baskets or traps to collect these soft-body species from the seabed without damaging the samples. In fact, samples currently available are mainly based on more or less accidental samplings [19,21].

D. Movement

Moving in difficult environments and demanding situations is one of the goals to achieve in the near future. For instance, the large efforts recently done for the monitoring of protected species in the polluted area of Taranto [24] resulted impossible to be done with underwater vehicles and drones, due to the large amount of anthropic obstacles including lost nets, wrecks (vessels, but also illegal car dumping), as well as mussels and fish farms. ROVs using a cable connected with a floating Wi-Fi-buoy on the surface, as well as an autonomous *ad hoc* underwater vehicle with cameras could help in future operations carried out in focal areas like the Mar Piccolo of Taranto [23].

IV. DISCUSSIONS

The relentless technological advancement could allow the next-generation underwater vehicles to address the problems that are now challenging the marine zoologists. For example, exploring the current CWC sites boundaries and the deeper environs would allow to find new important coral sites and to assess the presence of continuous CWC belts, as the one located along the Apulian margin from Bari Canyon to Santa Maria di Leuca CWC provinces [4,26]. AUVs can represent useful instruments to investigate the biological and physical composition of the seabed utilizing a suite of image capture and high-resolution geophysical tools. They have been used to survey several marine habitats and organisms worldwide, including kelp-dominated rocky reefs to deep mid-she and deep reefs that are otherwise difficult to access [27], urchin barrens [28] and CWC mounds [29]. However, although they display a high accuracy attitude and navigation system [30], their use is often limited to places that are not totally unexplored. In fact, unexplored areas can have challenging obstacles such as rough topographies or anthropogenic impacts (e.g. lost nets, wrecks, poles) that can affect the use of AUVs, while ROVs are often more feasible, although they allow to explore a smaller area.

The possibility to develop a vehicle able to sit and wait on specific targets would allow the observation of unknown behaviors, leading the understanding of species roles and interactions in remote environments, as the deep sea. For small or soft-body species, specific sampler arms could resolve the lack of samples, to support both morphologic and genetic studies of many marine species.

Finally, a large effort is still needed in the development of vehicles able to move and work in complex environments, as those characterized by a large number of obstacles both on the seabed and on the surface. To address all these future challenges, the multidisciplinary cooperation of scientists and engineers is essential, with a desirable involvement of the formers in the ideation and development processes, and of the seconds in the fieldwork operations.

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