A cost-effective video system for a rapid appraisal of deep-sea benthic habitats: The Azor drift-cam

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Funding Information
Governo dos Açores, Grant/Award Number: Açores-01-0145-FEDER-000056 (MapGES), Açores-01-0145-FEDER-000124 (DeepWalls) and M3.1.a/F/062/2016; Horizon 2020 Framework Programme, Grant/Award Number: 678760, 689518 and 818123; Oceano Azul Foundation, Grant/Award Number: Blue Azores Project; Fundação para a Ciência e Tecnologia, Grant/Award Number: UID/05634/2020, IF/01194/2013 and IF/01194/2013/CP1199/CT0002

Handling Editor: Phil Bouchet

Abstract
1. Deep-sea exploration relies on cutting-edge technology, which generally requires expensive instruments, highly specialized technicians and ship time. The increasing need to gather large-scale data on the distribution and conservation status of deep-sea benthic species and habitats could benefit from the availability of low-cost imaging tools to facilitate the access to the deep sea world-wide.

2. Here we describe the Azor drift-cam, a cost-effective video platform designed to conduct rapid appraisals of deep-sea benthic habitats. Built with off-the-shelf components, the Azor drift-cam should be regarded as an effective, affordable, simple-to-assemble, easy-to-operate, resilient, operational and reliable tool to visually explore the deep sea to 1,000 m depth.

3. Its performance was assessed during the MapGES_2019 cruise, where 135 successful dives between 100 and 800 m depth were carried out in 22 working days, providing over 100 hr of images for almost 80 km of seabed, mostly in areas that had never been explored before.

4. The system does not aim to become a substitute for more sophisticated underwater video and photography platforms, such as ROVs, AUVs or manned subsimmers. Rather, it aims to provide the means to perform quick assessments of deep-sea benthic habitats in a simple and affordable manner.

5. This drift-cam system has the potential to make deep-sea exploration more accessible, playing an important role in the Deep-Ocean Observing Strategy and measuring some of the Essential Ocean Variables for deep-sea monitoring and conservation strategies.

KEYWORDS
benthic habitats, deep-sea exploration, low cost, technological development, underwater imaging

1 INTRODUCTION

The deep sea, defined as those waters below 200 m depth (Levin et al., 2019), is the largest biome on Earth, covering 66% of the planet’s surface. Its scientific exploration started in the 19th century, when Beebe and Barton descended down the deep for the first time in a submersible (Beebe, 1934). During that time, the expeditions of Charles Wyville-Thomson, Prince Albert I of Monaco and
Carlos I King of Portugal opened a window to the rich and diverse habitats of the world’s deep sea (Ballard & Hively, 2017; Deacon et al., 2001). Although large efforts have historically been placed in better understanding this realm, the ocean’s deepest layers still remain largely unexplored due to its extension and its difficult accessibility (Ramírez-Llodra et al., 2010).

Advances in marine technology have provided the possibility of obtaining high-quality images of the seafloor, mainly through Human-Occupied Vehicles (HOVs), Remotely Operated Vehicles (ROVs), Autonomous Underwater Vehicles (AUVs) and towed camera systems (Bowden & Jones, 2016; Humphris & Soule, 2019; Huvenne et al., 2017; Kelley et al., 2016). These platforms, especially ROVs, currently represent the most common approach to the study of deep-sea benthic communities (Durden et al., 2016), replacing classical and more intrusive techniques, such as epibenthic sledges, beam trawls and grabs (Clark et al., 2016). Deep-sea research using cutting-edge technology requires a very expensive set up, with complex equipment, large oceanographic vessels and specialized crews, which ultimately represents elevated economic costs (Teague et al., 2018; Thorsnes et al., 2020).

The current commitments to protect marine biodiversity (e.g. UN 2030 Agenda for Sustainable Development and EU 2030 Biodiversity strategy) have highlighted the national and international responsibilities to collect large-scale scientific data on the distribution and conservation status of deep-sea benthic species and habitats. Thus, the information obtained by video tools is of paramount importance to identify priority areas for management and conservation, essential to achieve national and/or international conservation targets (e.g. Convention on Biological Diversity Aichi Biodiversity Target 11 or UN Sustainable Development Goal 14).

Given the expensive nature of deep-sea exploration, only a limited number of countries currently have the technical and financial means to pursue such goals. Therefore, there is a need for sampling tools that can generate new deep-sea scientific data at a reasonable cost, making deep-sea exploration easier, simpler, cheaper and accessible to many. In recent years, a number of low-cost deep-sea camera systems (Giddens et al., 2021; Phillips et al., 2019), sensors (Jiang et al., 2020) and video landers (Hannah & Blume, 2012) have been prototyped. However, we are not aware of any technological development that allows deep-sea exploration using relatively cheap off-the-shelf products. Here we describe the Azor drift-cam, a cost-effective and easy-to-operate video platform that can be used for a rapid appraisal of the deep seabed to 1,000 m depth. The main purpose driving this technological development is to democratize deep-sea exploration by sharing a simple yet versatile tool that can be used to survey shelf and deep-sea habitats on board of small local vessels.

2 | GUIDING PRINCIPLES

The overarching goal behind the development of the Azor drift-cam was to develop a cost-effective tool to explore and monitor shelf and deep-sea habitats from small vessels. Hence, its development was guided by a set of guiding principles (GP) that determined the characteristics of the tool and the choices adopted, namely:

1. Effectiveness—that is, suitable for a rapid appraisal of deep-sea benthic habitats.
2. Affordability—that is, total price to be kept low (10–15k €), including the necessary spare parts.
3. Simplicity—that is, components should be off-the-shelf, light and easy to assemble.
4. User-friendly—that is, its maintenance and operation should not require highly specialized staff.
5. Resiliency—that is, must be operational in most deep-sea areas, including complex topographies and heavily fished grounds.
6. Operability—that is, deployable from small platforms (including local fishing vessels) to keep its operation costs low.
7. Portability—that is, easily moved between sampling areas or countries.

3 | DRIFTING-CAMERA SYSTEM

The video platform proposed here does not require its own propulsion (like ROVs) nor being towed from a vessel at constant slow speeds (like towed cameras). Such tools are usually associated to high costs regarding human resources, technology and supporting vessels, typically large ships with dynamic positioning. Instead, we designed a device that simply drifts with the support vessel, taking advantage of water currents and surface winds. The system has been named Azor drift-cam to acknowledge the seminal role of the Azores in the early days of deep-sea exploration (Deacon et al., 2001).

3.1 | Structure and components

The Azor drift-cam is composed of three parts: the main body, the umbilical and the on-vessel components. The main body is made up of a stainless-steel frame with a 15–20 kg weight attached to its base. All electronic components are attached to the central bar: two action cameras, LED lights, external batteries and a video converter/transmitter (all housed in pressure-resistant containers), together with parallel lasers and a depth/temperature sensor (Figure 1). The two action cameras are placed in slightly different angles: live-view camera tilted higher up for navigation purposes and 4k camera pointing towards the seabed to better identify benthic species. To keep the system on an upright and forward-facing position, the structure uses a methacrylate stabilizing wing, as well as several deep-sea floats placed on the umbilical above the main body. The umbilical, made of polypropylene rope and electrical cable, connects to a video receiver placed on board of the vessel, followed by an analogue-to-digital adapter, which allows the images captured by the live-view camera to be displayed on a TV screen.
To comply with GP Simplicity, all electronic devices are battery operated, so no power is fed through the umbilical. To comply with GP Resiliency, the metallic frame generates an oval shape to protect its components, reducing the likelihood of entanglement in lost fishing gears or complex terrains. To comply with GPs Operability and Portability, and to allow operations from small vessels, the system is relatively small and light (easily lifted by two people). To comply with GPs Affordability and Simplicity, the umbilical is an off-the-shelf electrical cable.

A detailed guide illustrating the components that make up the Azor drift-cam, together with approximate retail prices and indications on how to ensemble them, is provided in Supporting Information 1.

### 3.2 | Operating procedure

#### 3.2.1 | Deployment and drifting navigation

Due to its low overall size and weight, the Azor drift-cam can be deployed by hand from the side of a small vessel without the need of a crane, although its use is recommended (Figure 2a). Once released, it freely descends through the water column at speeds of 1.4–1.5 m/s, reaching 500 m depth in 5–6 min. Once at the seabed, the system is simply left to cruise following the vessel’s drift, with the distance kept between the system and the seafloor controlled with a hydraulic winch, giving or recovering umbilical as required (Figure 2b). Indications to winch operators based on the live feed provided by the navigation camera are given by an observer (Figure 2c). The live feed, although in black and white and with less sharpness than the original feed produced by the action camera, is of sufficient quality for a safe underwater navigation. A GPS device is used to record the vessel’s position at short time intervals (1–2 s), and data collected by the temperature/depth sensor can be later used to adjust its position over the seabed.

#### 3.2.2 | Recovery and data produced

At the end of the dive, the system is recovered using the hydraulic winch, letting the umbilical accumulate inside a large bucket (Figure 2c). Recovery time depends on winch capacity, but a limit of 0.7–0.8 m/s is recommended to avoid damaging the electrical cable. At this pace, the system can reach surface from 500 m depth in about 12 min. Once on deck, the time required to prepare the equipment for the following deployment is short, since only SD cards and batteries for lights/cameras must be changed. It is recommended to have at least one set of spare batteries for each electronic device,
and recharged every 3–4 deployments. Each dive will produce video imagery from two action cameras, depth and temperature data and a GPS track with the ship’s position.

Due to the quality of the images recorded with the 4k action camera and its position with respect to the seabed (approx. 1–2 m over the seafloor), the analysis of the video footage allows for the identification of megabenthic species (i.e. larger than a few centimetres) with a good degree of taxonomic accuracy (see examples of selected video frames in Figure 3). Furthermore, the presence of parallel lasers on-screen allows for species counts to be transformed into density measures. This can be easily achieved by generating an estimate of the swept surface using the computed average field of view and the distance travelled over the seabed provided by the GPS track.

**4 | PERFORMANCE ASSESSMENT**

The performance of the Azor drift-cam was assessed during MapGES_2019 cruise on board a 25-m-long research vessel from the Government of the Azores (Morato et al., 2020). Additionally, the system was deployed from three different local fishing vessels (7, 12 and 13 m) and its performance on the 12-m-long vessel is provided in Supporting Information 2.

In general, smoother bottoms were easier to survey than rough terrains, especially if found on positive slopes. The type of substrate did not seem to exert a strong influence on the quality of the images obtained, with sandy bottoms (Figure 3a) similarly surveyed to mixed substrates with rocks and boulders (Figure 3b–e) or areas dominated by large rocky outcrops (Figure 3f,g). Very steep slopes and large vertical walls (Figure 3h) were the exception, since the Azor drift-cam had to be lifted at maximum speeds to avoid entanglement, limiting the quality of the video footage.

A sample clip with images recorded during MapGES_2019 cruise with the 4K action camera mounted on the Azor drift-cam covering different seabed types can be visualized in the following link: https://youtu.be/GJ-zh-a4Flw.

### 4.1 | Effectiveness

In all, 15 seamount-like structures along the Mid-Atlantic Ridge and a set of smaller seamounts located west of Faial and southeast of Pico islands (Azores) were explored during MapGES_2019 cruise, with 135 successful dives performed in 22 days (Figure 4; metadata for each dive provided in Supporting information Table S2). Dives were unevenly distributed, with sampling effort based on seamount size and ecological relevance. With 10–11 hr of daily work (no night shifts), an average of 6.1 ± 1.7 dives per day was accomplished. The time travelled over the seabed averaged 45 ± 21 min per dive, totalling 4.8 ± 1.9 hr of bottom time per day. This represented an average distance of 593 ± 128 m per dive, adding up to 3.7 ± 1.6 km per day. Overall, more than 78 km of seafloor between 100 and 800 m depth were surveyed, totalling 100 hr of bottom time (Table 1). These values are comparable to those obtained with standard ROVs capable of reaching 1,000 m. For example, the NOAA Deep Discoverer ROV, operated from the NOAA Ship Okeanos Explorer, performed 47 dives in 2019 (one per day), averaging 5.5 hr of bottom time and about 620 m of seafloor per day (https://repository.library.noaa.gov). Similarly, during the 2018 Blue Azores expedition on board NRP Gago Coutinho, the Luso ROV performed 14 dives (one per day), averaging 4.15 hr of bottom time and 450 m of seafloor per day (Morato et al., 2019). The images recorded during MapGES_2019 cruise were evaluated to determine their usefulness for the characterization of the megabenthic communities observed. In this preliminary...
assessment, more than 150 benthic invertebrate morphospecies (i.e. potential taxa) were identified, with differences across areas likely related to environmental characteristics and sampling effort (Table 1). Results derived from a more detailed evaluation of the video images, assisted by taxonomist, will likely reveal an even higher species richness than that reported here.
FIGURE 4  Areas explored with the Azor drift-cam during the MapGES_2019 cruise (above) and detailed maps of each area (below), displaying the 135 successful deployments achieved in 22 days. The path performed over the seabed by the Azor drift-cam during each deployment is represented with a white line. Metadata for each dive is provided in Supporting Information Table S2.
4.2 | Affordability

The present-day cost of the Azor drift-cam falls within the pre-defined 10–15k € range (itemized prices provided in Supporting information Table S1). This value is two orders of magnitude lower than a standard working-class ROV capable of reaching 1,000 m (600 k to 3.5 million €; Teague et al., 2018), but falls within the price range of low-cost shallow-water ROVs (e.g. Lund-Hansen et al., 2018) and towed video systems (e.g. Sheehan et al., 2016), and also other low-cost deep remote baited camera systems (e.g. Giddens et al., 2021). Keeping the Azor drift-cam affordable implied that some useful additions were left out (e.g. fibre optic cable, USBL positioning system, CTD profiler and extra lighting), always without compromising its general capabilities and goals.

4.3 | Simplicity

The Azor drift-cam resulted in a modular, simple, light and easy-to-assemble video platform made up with off-the-shelf components. Since all pieces are not inter-related but function independently, this provides a series of advantages:

1. The system is adjustable and easy to reconfigure. More components, new versions or equipment improvements can be easily added without changing the original configuration.

2. The malfunctioning of a component does not affect the functioning of the remaining parts. This allows for a quick identification of the potential problem.

3. The replacement of any damaged component is very straightforward, further reducing the time needed for repair.

4. Most types of malfunctioning can be repaired on board without the need of specific tools and complex testing (see Supporting Information 1). During MapGES_2019 cruise, a series of incidents occurred (e.g. cable damage and connections not working), which were always fixed while at sea.

4.4 | User-friendly

During MapGES_2019 cruise, the Azor drift-cam was operated by scientists and vessel crew members without the assistance of highly qualified technicians. This further reduces the costs of deep-sea exploration in a context where oceanographic vessels and highly specialized technical crews come at a cost.

4.5 | Resiliency

The main risk when operating deep-sea video platforms is entanglement on rocks, vertical walls or lost fishing gears, with the potential loss of the device or some of its components. During the
MapGES_2019 cruise, the Azor drift-cam was able to overcome all large rocks, steep slopes and vertical walls encountered except one, with visual navigation and the recovery speed of the winch proving sufficient. In that one case, the system got temporarily entangled on a vertical wall, but manoeuvring the vessel was enough to set it free with no structural damage. Lost fishing gears were observed in approximately 60% of the dives, with longlines lying flat over the seabed easily avoided by pulling the structure upwards. However, longlines that appeared suspended several meters over the ground were not detectable in the video feed, and the system got caught on seven abandoned fishing lines. The oval design of the device and the work done by the winch and vessel crew allowed for a successful release in all occasions, with no loss of equipment nor harm to the structure reported. It should be noted, however, that one complete system was lost in summer 2020 after becoming entangled in multiple suspended longlines on a vertical wall.

4.6 | Operability

The Azor drift-cam has now been successfully operated from a 25-m-long research vessel and from 7, 9 and 12-m-long local fishing vessels. Its simple use represents one of its advantages with respect to commercial ROVs or towed systems. The Azor drift-cam can be released manually from the side of the vessel and requires only a hydraulic winch to be operated. It can be used in weather conditions similar or worse to those required for ROV operations, incrementing the number of potential working days. Its fast deployment and recovery increase the number of dives that can be performed per day, generating a broader spatial coverage at a lower cost.

4.7 | Portability

Most parts of the Azor drift-cam are easily transportable. The frame, action cameras, lights, lasers and sensors can be shipped to any part of the world by land, air or sea. The International Air Transport Association (IATA) Dangerous Goods Regulations, however, restricts the shipment of lithium cells and batteries, which may have to be shipped in advance by sea or land. The umbilical, composed of polypropylene rope and electric cable, weights over 100 kg, making shipment by air expensive. These materials are found everywhere and therefore a new umbilical can be built upon arrival. In summer 2020, the whole system was moved using a regular passenger ferry from the island of Faial to Graciosa, where it was successfully operated from a local fishing vessel (Supporting Information 2).

5 | SURVEYING LIMITATIONS

Although the Azor drift-cam offers a series of advantages with respect to other deep-sea video platforms, there are still some drawbacks not to be overlooked. One major limitation relates to the impossibility of collecting samples or produce targeted filming during the dive, useful for taxonomic identification. Additionally, the maximum operation depth is constrained to 1,000 m due to the low-cost standard electrical cable used as umbilical, which produces a loss of video signal that increases with cable length. The use of more than 1,000 m of electrical cable implies that the image received at surface has lost colour and some of its sharpness, although it has proven sufficient for navigation purposes. In terms of operability, since the system follows the vessel’s drift, targeting specific areas or following a predefined path over the seabed is difficult unless weather conditions allow. This can be partially overcome by evaluating the vessel’s drift and the bathymetric chart prior to the dive. Cross-side currents over the seafloor can also influence performance, since they can turn the drift-cam system sideways, leaving the camera at an angle form the path followed. This not only limits image quality but also constrains video-based navigation by increasing entanglement risk. Downslope areas are also hard to survey since light is absorbed in the water column, thus limiting video quality for annotation and the possibility of detecting hazards.

6 | CONCLUSIONS

There is a large offer of state-of-the art underwater technology for different deep-sea applications. However, simple yet affordable systems that take advantage of the power of small commercial action cameras remain unavailable. The Azor drift-cam, built with off-the-shelf equipment, has proven cost-effective, easy to operate and reliable to explore deep-sea habitats to 1,000 m depth. This system aims to provide a simple yet versatile tool to facilitate the access to deep-sea exploration, not intending to become a substitute for other, more sophisticated, video and photography platforms (ROVs, AUVs or manned submersibles). In fact, both systems could complement each other, with the Azor drift-cam providing rapid assessments of the seabed over large areas, allowing relevant locations to be identified and subsequently targeted for a more detailed examination. This could further optimize and reduce the costs of ROV operations. Hence, the Azor drift-cam could play an important role in the Deep-Ocean Observing Strategy (Levin et al., 2019) and the measurement of Essential Ocean Variables for deep-sea monitoring and conservation strategies (Danovaro et al., 2020). We believe that by sharing this technological development, we can contribute to generate a paradigm shift in deep-sea exploration, opening the doors to many researchers/countries currently excluded from this research arena due to monetary and technological constraints.

ACKNOWLEDGEMENTS

This work contributes to the PO2020 MapGES Project (Acores-01-0145-FEDER-000056), and to the European Union’s Horizon 2020 research and innovation programme under grant agreements No 678760 (ATLAS), No 689518 (MERCES) and No 818123 (iAtlantic). We also acknowledge funds and support from the Fundação para a Ciência e a Tecnologia (FCT) through the strategic project (UID/05634/2020) granted to OKEANOS and the Fundação Oceano
Azul (FOA) through the Blue Azores Project. C.D.-C. was supported by the PO2020 Projects MapGES (Acores-01-0145-FEDER-000056) and DeepWalls (ACORES-01-0145-FEDER-000124), and the H2020 Project ATLAS (No 678760). T.M. was supported by Program Investigador FCT (IF/01194/2013), IFCT Exploratory Project (IF/01194/2013/CP11199/CT0002) from the Fundação para a Ciência e Tecnologia (POPH and QREN). J.F. was supported by the research grant M3.1.a/F/062/2016 funded by Fundo Regional de Ciência e Tecnologia from Governo dos Açores. We would like to especially acknowledge all those involved in the development of the Azor drift-cam, both in terms of technical assistance to develop the prototypes and help during the first trials at sea and the subsequent deep-sea surveys (MapGES_2018, 2019 and 2020 surveys), namely Sérgio Gomes, Gerald H. Taranto, Víctor Rosa, Gonçalo Graça, Marco Dutra, Jordi Blasco-Ferre, Manuela Ramos, Laurence Fauconnet, Cristina Gutiérrez-Zárate, Luís Rodrigues and Marina Carreiro-Siva. We are also grateful for the help provided by the crews of the research vessel ‘N/I Arquipélago’ and the fishing vessels ‘Tatiana’, ‘Garantia’ and ‘Galinha’. Finally, we would like to thank Group B Distribution Inc. for their technical assistance whenever needed.

AUTHORS’ CONTRIBUTIONS

T.M. and J.F. conceived the idea of a low-cost video system for the study of deep-sea benthic communities; C.D.-C. and T.M. led the design and technical development of the different prototypes conceived for the Azor drift-cam until reaching the current version; C.D.-C. and T.M. led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

DATA AVAILABILITY STATEMENT

No data were used for this manuscript.

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SUPPORTING INFORMATION
Additional supporting information may be found online in the Supporting Information section.

How to cite this article: Dominguez-Carrió C, Fontes J, Morato T. A cost-effective video system for a rapid appraisal of deep-sea benthic habitats: The Azor drift-cam. Methods Ecol Evol. 2021;00:1–10. https://doi.org/10.1111/2041-210X.13617