Complementary Underwater Imaging Methods for Collecting Biological and Environmental Data
Volume 1: Sampling Devices

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Complementary Underwater Imaging Methods for Collecting Biological and Environmental Data
Volume 1: Sampling Devices

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ABSTRACT

Scallon-Chouinard, P.-M., Lévesque, D. and Roux, M.-J. 2022. Complementary Underwater Imaging Methods for Collecting Biological and Environmental Data. Volume 1: Sampling Devices. Can. Tech. Rep. Fish. Aquat. Sci. 3264: ix + 52 p.

This report describes two complementary and non-invasive sampling methods for photo and video sampling and biological and environmental data acquisition. This includes a baited stereoscopic underwater video system (BRUV) for fish and invertebrates sampling in coastal environments (up to 100 m depth) and offshore environments (up to 1750 m depth) and a deposited photo camera system (DPC) for the characterization of benthic habitats and organisms and coastal aquatic vegetation (up to 60 m depth). The information required for assembling, using and optimizing these systems in cold waters, including a description of their various components and sampling parameters, is provided in the document. Results from performance tests of selected cameras and lighting systems under a range of conditions are also presented. The BRUV and DPC are versatile and well adapted to the challenges of taking samples from various types of vessels, uneven bottoms, very cold water, and strong tidal currents. They can be assembled at a low cost and optimize the collection of ecological and environmental data in support of the implementation of ecosystem-based management. Image sampling systems contribute to the development of non invasive and non extractive sampling techniques, allowing to minimize the impact of scientific data collection on the marine environment and organisms.

RÉSUMÉ

Scallon-Chouinard, P.-M., Lévesque, D. and Roux, M.-J. 2022. Complementary Underwater Imaging Methods for Collecting Biological and Environmental Data. Volume 1: Sampling Devices. Can. Tech. Rep. Fish. Aquat. Sci. 3264: ix + 52 p.

Ce rapport décrit deux dispositifs complémentaires d’échantillonnage visuel non extractif utilisant des systèmes d’acquisition d’échantillons photo et vidéo pour la collecte de données biologiques et environnementales. Il s’agit d’un système de caméras vidéo stéréoscopiques appâté (CVSA) pour l’échantillonnage des poissons et invertébrés en milieux côtiers (jusqu’à 100 m de profondeur) et hauturiers (jusqu’à 1750 m de profondeur); et d’un système de caméras photo déposé (CPD) pour l’échantillonnage des habitats et organismes benthiques et la végétation aquatique submergée en milieux côtiers (jusqu’à 60 m de profondeur). Les informations nécessaires à l’assemblage, l’utilisation et l’optimisation de ces systèmes pour l’échantillonnage en eaux froides, incluant une description des différentes composantes et paramètres d’utilisation, sont consignées dans ce document. Les résultats de tests de performance des systèmes de caméras et d’éclairage sélectionnés selon différentes conditions, sont également présentés. Ces dispositifs d’imagerie sont polyvalents et adaptés aux défis de l’échantillonnage sur différents types d’embarcations et sur des fonds marins accidentés, en eaux froides, et en présence de forts courants de marée. Ils peuvent être assemblés à faibles coûts et permettre d’optimiser la collecte de données écologiques et environnementales en support à la mise en œuvre d’une gestion écosystémique. La mise au point de ces systèmes contribue au développement de techniques d’échantillonnage non invasives et non extractives permettant de minimiser l’impact de la collecte des données scientifiques sur les organismes et les habitats marins.

1. INTRODUCTION

Data collection in support of ecosystem-based management of fisheries resources represents a significant logistical challenge due to its complexity, particularly in dynamic, sensitive environments, such as coastal areas and marine protected areas. Conventional sampling methods such as trawling cannot be used in marine protected areas (Côté et al. 2021) or bottoms characterized by uneven terrain, large rocks and/or steep slopes (Cappo et al. 2004). For these reasons, the development of alternative methods for accessing habitats that have been sampled very little or not at all, and minimizing the impact of scientific data collection on the marine environment, is desirable and even necessary (Wallace et al. 2015; Trenkel et al. 2019). The development and operationalization of versatile non-extractive systems to optimize sampling by facilitating the simultaneous acquisition of different types of ecosystem data should also be prioritized. These needs can be met by underwater imaging systems (Mallet and Pelletier 2014).

Underwater imaging methods have existed since the late 19th century (Boutan 1893), but their use has continued to grow for some thirty years (Syvitski et al. 1983; Bicknell et al. 2016). They allow for the acquisition of data on various components of aquatic ecosystems, particularly submerged vegetation in terms of occurrence, coverage and biomass (Short et al. 2001; York et al. 2015); occurrence, species diversity, abundance, size and behaviour of fish (Harvey et al. 2010; Bennett et al. 2016; Boldt et al. 2018) and invertebrates (Cuvelier et al. 2012; Mallet and Pelletier 2014; Bicknell et al. 2016); and substrate type (Valentine et al. 2005; Mallet and Pelletier 2014). The constant evolution of technology allows for the easy and affordable procurement of cameras with high image resolution, several hours of battery life and enough storage capacity to record videos (Letessier et al. 2015; Bicknell et al. 2016).

Underwater imaging systems are indispensable for collecting scientific information in sensitive environments, such as marine protected areas (Mallet and Pelletier 2014; Côté et al. 2021), nurseries and other habitats that are essential to commercially important fish and invertebrates in coastal environments (Dalley et al. 2017; Laurel et al. 2016; Stoner et al. 2008). Furthermore, the versatility of these imaging methods facilitates the integration of an ecosystem aspect into sampling protocols, since they can easily be multi-instrumented and combined with various sampling activities (e.g. oceanographic and commercial stock biomass surveys). Sample images can be archived and referenced for later consultation or validation. Photo and video analysis can be iterative or sequential, depending on the information sought (Cappo et al. 2009). However, underwater imaging requires more analysis time in post-processing to extract biological and ecological data; this can present a significant challenge (Mallet and Pelletier 2014), which can be lessened with the refinement of machine learning. Another challenge associated with these methods is the need to standardize deployment and image analysis protocols to facilitate data sharing and comparability of results (Whitmarsh et al. 2017).

Photo and video sampling methods include fixed or deposited systems and mobile systems. Fixed or stationary systems are deposited onto the bottom, may or may not be connected to a vessel, and are used for sporadic or continuous sampling (e.g. deposited cameras and remote baited underwater video). Mobile systems include cameras operated by a diver, towed cameras, and autonomous underwater imaging performed using a drone and/or other type of remote vehicle (Mallet and Pelletier 2014; Bicknell et al. 2016). The main advantages of fixed systems are as follows: 1) they limit the impact of visual sample collection on the marine environment compared to camera systems that are towed over the bottom; 2) they facilitate access to certain types of uneven bottoms with rocky substrates; 3) their versatility and ease of use allow them to be combined with other sampling methods and minimize personnel and time required for sample collection; and 4) their versatility allows them to be easily equipped to collect a significant volume of ecosystem data (Mallet and Pelletier 2014; Bicknell et al. 2016; Langlois et al. 2012).

Several initiatives by the Department of Fisheries and Oceans Canada (DFO), including the integration of an ecosystem-based approach into commercial fishery stock assessments (Pepin et al. 2020), achievement of international targets for marine area protection (Government of Canada 2011, 2018; Benoît et al. 2020), and increased research and monitoring activities for coastal areas (Government of Canada 2020), are in line with the development of non-extractive underwater imaging methods. This report presents two stationary photo and video sampling systems: a baited stereoscopic underwater video system (BRUV) and a deposited photo camera system (DPC). The information required for the assembly, deployment and optimal use of the BRUV and DPC systems in order to acquire image samples in a marine environment is included. The components of both systems and their operating parameters are detailed, as well as the results of basic performance tests conducted on the light and camera models selected.

BRUV and DPC sampling can be integrated simply and opportunistically into various at-sea surveys, helping increase data and knowledge on organisms and their habitats. It can maximize ecosystem sampling opportunities while limiting the impact of scientific information collection on the marine environment.

2. BAITED STEREOSCOPIC UNDERWATER VIDEO SYSTEM

2.1 General description

The BRUV system is a set composed of a frame with a lighting system, two video cameras allowing for stereoscopic vision, and a bait arm attached (Figure 1). Following calibration, the stereoscopic configuration of the cameras allows the user to make precise measurements on the images collected (e.g. size and other morphometric measurements on the organisms). The BRUV system is deployed for a set amount of time to count, observe and measure marine organisms near the deployment site, as well as the characteristics of the habitat and the dominant environmental conditions at the time of the sampling. The use of bait maximizes the probability of detection and the time that organisms remain in the cameras' field of vision. The bait alters the natural environment by attracting species that are present near the deployment site. Accordingly, the type and quantity of bait selected influences the organisms observed and the data collected (Coghlan et al. 2017).

Two configurations of the BRUV system were designed based on the original system, developed by the Australian company SeaGIS (www.SeaGIS.com.au): a coastal configuration for sampling in shallow water (less than 100 m deep), and an offshore configuration for sampling in deep water (up to 1700 m). These systems were adapted and optimized by the personnel at the Maurice Lamontagne Institute (MLI) for sampling in cold water, with strong currents and moving ice in winter, and to cover a wide range of depths, on bottoms that can be uneven.

The modifications made to the original system include the following additions: 1) a lighting system (mounts and lights), 2) movable protection in the form of aluminum rods at the top of the frame to protect the lighting system, 3) a bait cage, and 4) an adapted camera housing to contain a high-capacity external battery to increase operation time in cold water. A rope and buoy set to facilitate the safe and efficient deployment and recovery of the system at depths ranging from 5 to 500 m was also designed. A current meter and CTD multi-sensor, as well as their respective mounts, were integrated into the assembly to sample environmental conditions in situ. The components of the two configurations of the BRUV system are described in the following sections, and a summary of their specific characteristics is set out in Appendix 1.

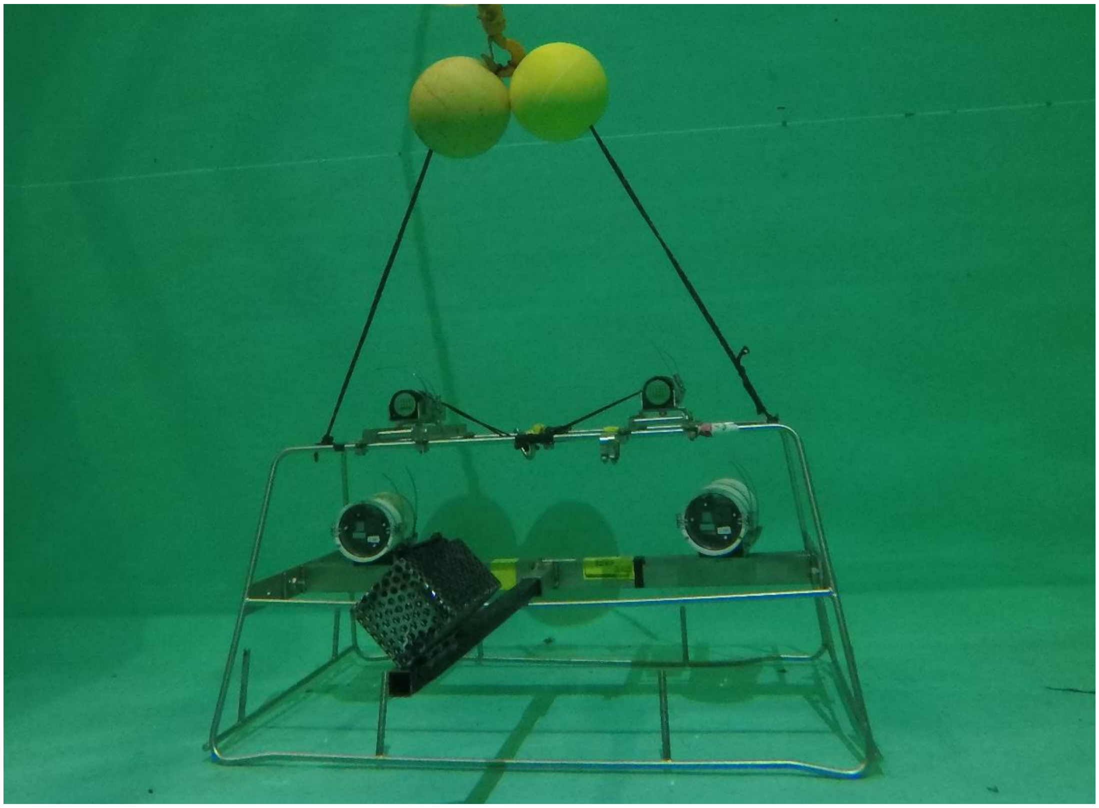

Figure 1. Baited stereoscopic underwater video system for sampling in coastal environments (0-100 m at chart datum).

2.2 Description of components

2.2.1 Main frame

The BRUV system (Figure 2) is made up of a trapezoid-shaped main frame (1), to which the various components are attached. The trapezoid shape provides stability to the frame when it is lowered, and ensures that it is positioned stably on the bottom. The camera bar (2) is attached to the frame at a height of 30 cm from the base. The camera bar contains two symmetrical mounts (3), on which are positioned the two housings containing the video cameras and their power supply (4). A six-degree angle and a 60-cm distance between the two camera mounts optimizes the stereoscopic field of vision (Harvey and Shortis 1995; Langlois et al. 2012). On the top of the frame are two mounts (5) for lighting systems (6). An 85-cm movable bait bar (7), which allows for the attachment of a bait cage (8), is inserted in line with the camera bar. Finally, mounts for the sinker (9), located on the bottom four bars of the frame, complete the BRUV assembly.

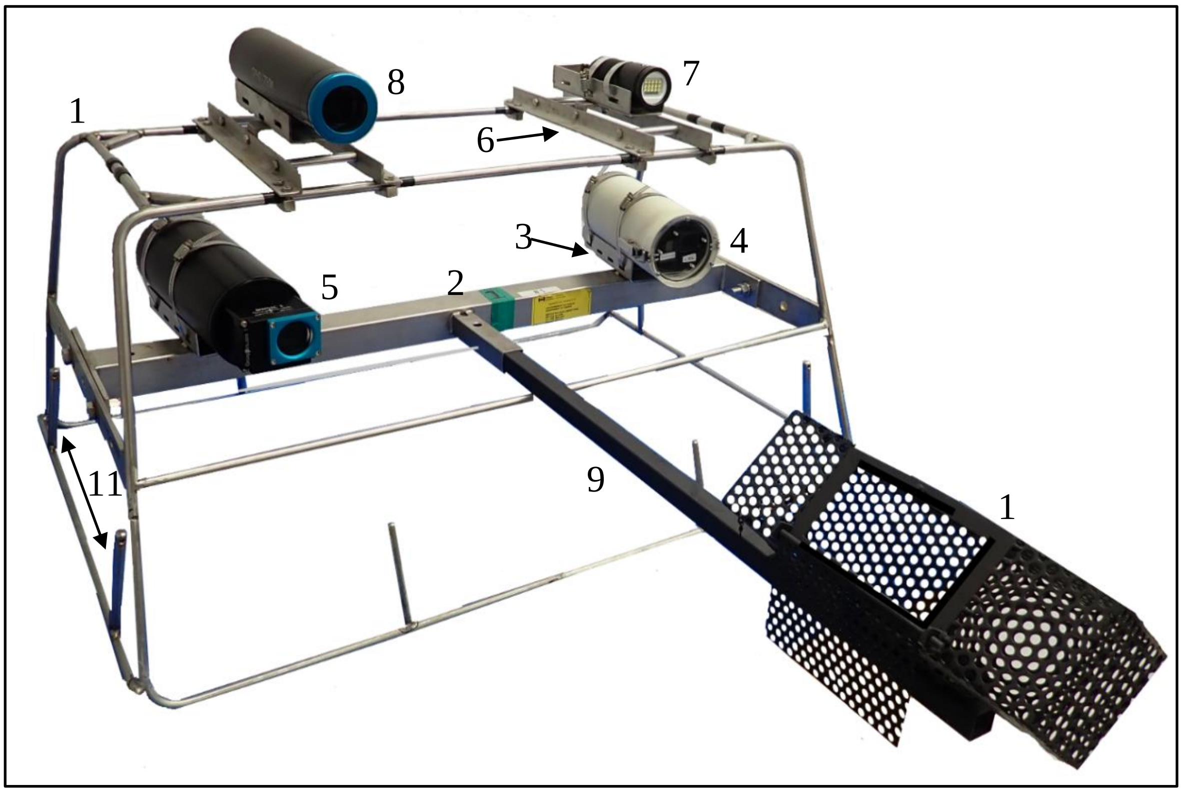

Figure 2. BRUV system and its components. 1= Main frame, 2= Camera bar, 3= Camera housing mounts, 4= Coastal housing, 5= Deep water housing, 6= Light mounts, 7= Dive light (coastal lighting), 8= Light housing (deep water lighting), 9= Bait arm, 10= Bait cage, 11= Sinker mount (not visible). Note: both configurations of the BRUV system include two coastal camera housings and two dive lights (coastal configuration), and two deep water housings and light housings (offshore configuration).

2.2.2 Camera system

The current camera system is composed of two GoPro cameras, HERO5 Black model (www.GoPro.com), and video is recorded on Micro SD memory cards. Each camera is connected to an external battery with a capacity of 6,000 to 20,000 mAh, depending on the autonomy required (see section: Camera power supply). The external battery is connected to the GoPro camera by a Universal Serial Bus (USB) cable. The cable has a USB-C connector at a 90° angle on the camera end, and a USB-A connector on the other end (Figure 3A, B). The side door of the camera has been removed to allow for the continuous connection of the external power source. The 90° angle of the USB cable is essential to allow for the camera to be connected to the external power source inside the housing. The internal battery has been removed from the GoPro camera, and only the external battery is used to prevent the power source from switching during sampling, which would cause the video recording to stop. The power source is inserted into a Styrofoam support to stabilize it inside the housing (Figure 3A-3, 3B-3).

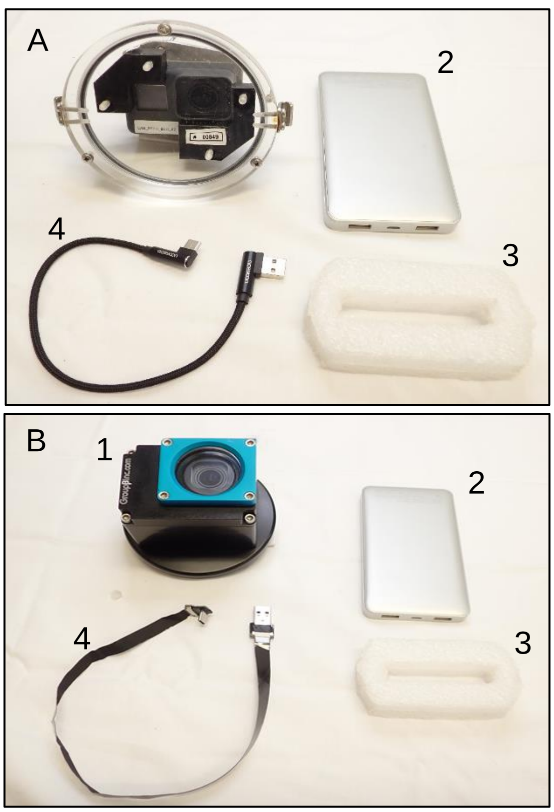

Figure 3. Camera system components (A), SeaGIS coastal housing (B) and GroupBinc Benthic 3 deep water housing. 1 = GoPro camera and viewport, 2 = external power source, 3 = support to stabilize the external battery, 4 = cable with USB-C connector at a 90° angle on the camera end (not visible) and USB-A connector on the power source end.

2.2.3 Housing

Two types of watertight camera housings are used, depending on the sampling depth (Figure 4). SeaGIS coastal housings are used for sampling at depths of up to 150 m, while GroupBinc Benthic3 and GPH10 housings are used for sampling at depths of up to 1750 m.

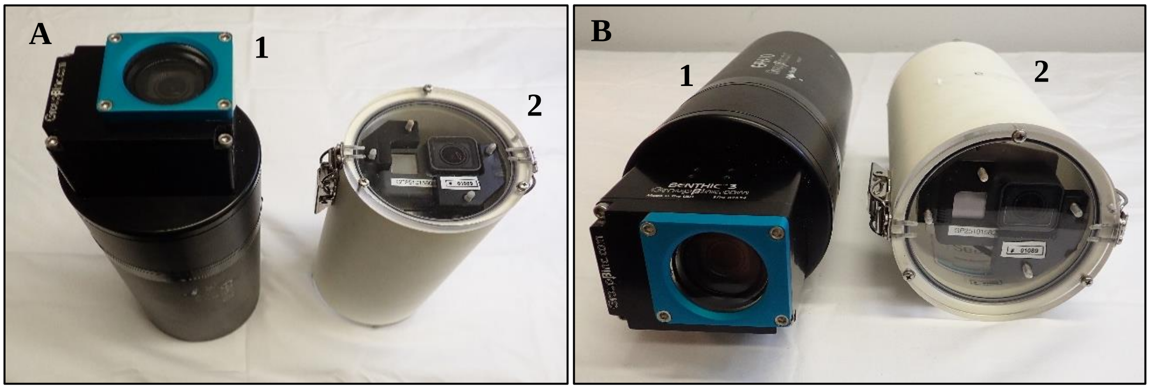

Figure 4. Benthic 3 (camera) and GPH10 (battery) housings used in deep water (< 1750 m) (A1 and B1), and SeaGIS housings used for coastal environments (< 150 m) (A2 and B2). The side view (A) illustrates the camera compartments, and the front view (B) illustrates the viewports and camera positioning.

Coastal housings

For sampling in coastal environments, cameras are positioned in the SeaGIS housing viewport (Figure 5). This method ensures that cameras remain in a fixed position when the housings are opened post-calibration, letting the user keep the housings in place when removing the cameras. This makes it easier to check video recording parameters during missions, or to perform tasks necessary for the use of the cameras, such as turning them on and off, changing batteries, and retrieving data from the memory cards between deployments. The cameras must absolutely maintain their initial configuration and position in the housings to take stereoscopic measurements (Harvey et al. 2010). This positioning ensures that calibration parameters are maintained, and helps guarantee the accuracy and precision of 2D and 3D measurements taken during analyses (Shortis et al. 2008). Housings must also maintain a fixed position on the camera bar once calibration has been completed, and must always be associated with the same system in the same order. To that end, camera housings are numbered and marked with a line along their longitudinal axis to ensure that their initial positioning is maintained throughout the sampling process and between deployments. These indications serve as a reference in the event that housings are moved during a mission. Potential causes for such an event include replacement of a damaged camera, warping of the camera bar as a result of an impact, or breakage or loss of housings, leading to their replacement.

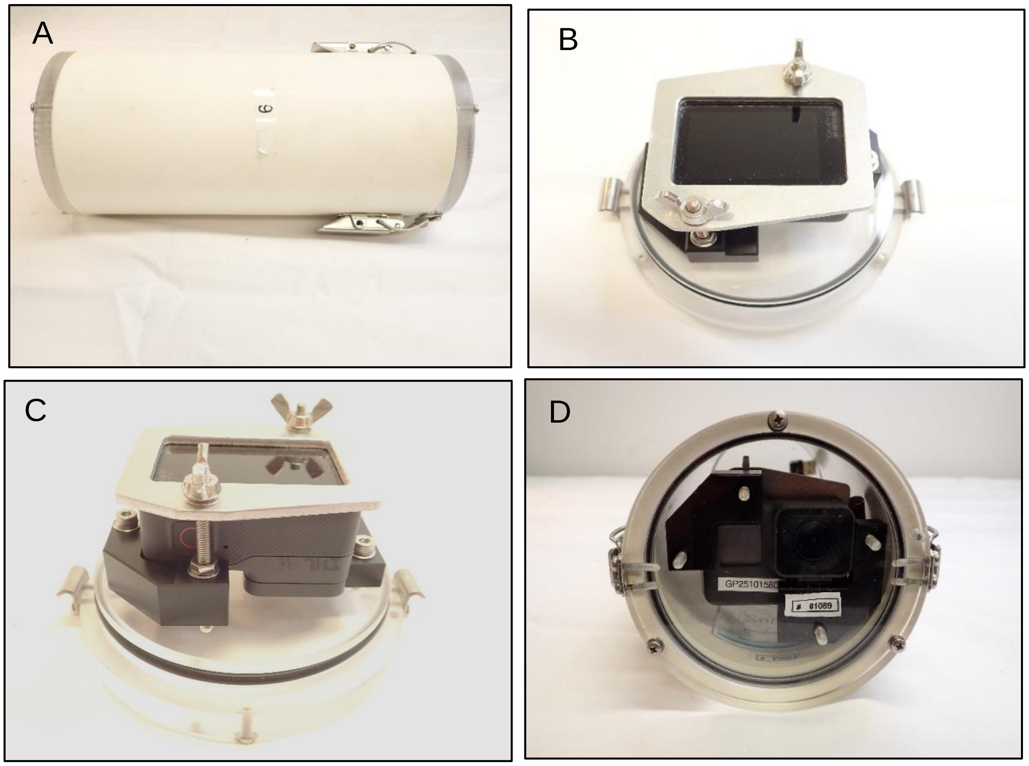

Figure 5. GoPro camera attachment and positioning mechanisms in SeaGIS coastal housings. Side view (A) with the positioning line to ensure the fixed position of the housing on its mount, interior view (B) (inside of the viewport) illustrating the camera attachment mechanism, side view (C) and front view (D) of the viewport.

Deep water housings

For deep water sampling in offshore environments, the cameras are positioned in Benthic3 watertight housings and kept in place by a foam support (Figure 6A and 6B). In this type of housing, and unlike coastal housings, the cameras are not completely immobilized inside the housing. When the housings are opened, to replace the battery or retrieve data, the positioning of the cameras may change slightly, lowering the accuracy of the stereoscopic measurements conducted on the images. The Benthic3 housing is attached to an adaptor that allows the camera compartment to be connected to the GPH10 watertight housing containing the external battery (Figure 6C and 6D). Like the coastal housings, these housings must maintain their position on the camera bar once calibration has been completed, and must always be associated with the same system, in the same configuration. To that end, housings are numbered and marked with a line to ensure fixed positioning on their respective mounts on the camera bar.

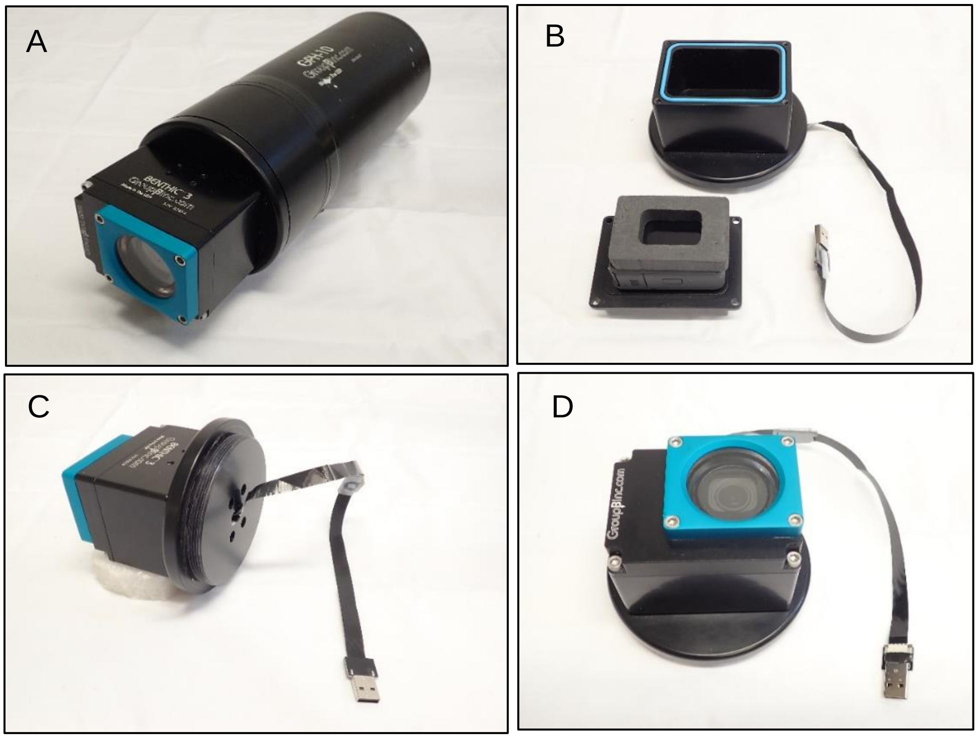

Figure 6. GoPro camera attachment and positioning mechanisms in GroupBinc deep water housings. Side view (A) of the Benthic 3 camera housing and GPH 10 housing, showing the lateral positioning line that aligns with the housing mount, rear view (B) of the Benthic 3 camera housing, illustrating the camera attachment mechanism, side view (C) illustrating the path of the camera power cable and the adaptor that allows the Benthic 3 housing to be attached to the GPH10 housing, and front view (D) illustrating the positioning of the camera in the Benthic 3 housing.

2.2.4 Lighting system

Lights

The lighting system is composed of two Bigblue dive lights, model VTL7200 (Figure 7A) (www.bigblue.com). These lights produce two types of white light, warm and cool, 5,500 and 6,500K respectively. They have three levels of light output (900, 1,800 and 3,600 Lm for warm white and 1,800, 3,600 and 7,200 Lm for cool white), as well as a red light setting (500 Lm). For the coastal configuration of the BRUV system, the lights are attached directly to adjustable mounts; for the deep water configuration, the lights are modified and placed permanently in GroupBinc watertight housings, model GHP 2. Two types of light housings are used: the 20-cm short model (Figure 7B) and the 45-cm long model Figure 7C). The use of light housings provides the lighting system with additional protection from pressure and impacts. The beam angle of the Bigblue lights, which is 120°, is reduced to 100° when the lights are modified and installed in the housings. The modifications to the lights, which are performed by Multi-Electronique (www.multi-electronique.com), consist of transferring the light-emitting diode (LED) lights, the reflector and the electronic control module inside the housings (Figure 7D). A mount designed using a 3D printer, which can hold one or two batteries depending on the housing model used, is included in the rear part of the housing. A magnetic switch is installed at the terminal end of the mount to minimize the number of times that the housings are opened when the lights are turned on.

The light output of the Bigblue dive lights decreases incrementally with immersion time. It is recommended that users work only with the first two levels of cool white light (7,200 and 3,600 Lm), which produce two to four hours of autonomy in cold water (2 to 6 °C). Based on observations of video samples taken in the field, only these levels allow for reliable, high-quality taxonomic identifications during image analysis. For the models modified to be used in housings, only the strongest two levels of white light output were retained. The Bigblue lights, as well as their modified version in GroupBinc housing, use the standard battery provided by the manufacturer: rechargeable lithium-ion batteries, model Batcell 18650 x 4. However, these batteries could be replaced to increase light autonomy for extended sampling and/or sampling in cold water.

Figure 7. BRUV lighting system including (A), from left to right, the modified lights in the GPH 2 (long) and GPH 1 (short) deep water housings and a Bigblue VTL7200 light used in coastal systems; (B) inside view of a modified light in the GPH 1 housing; (C) Bigblue battery used in all light models; and (D) inside view of a modified light (dual battery) in the GPH 2 housing.

Light mounts and racks

The light mounts are installed on top of the BRUV frame (Figure 8A and 8B). These adjustable mounts allow the lights to be tilted, and therefore their beam angles to be adjusted vertically and horizontally. The spacing between the mounts can also be adjusted to move the two light beams closer or farther away. These adjustments optimize the lighting according to research objectives and environmental conditions in order to obtain the best possible images. A safety knob, to prevent the light from falling off if the mount or rack fails, can be installed on unmodified lights. The knob connects the lights to the main frame with a carabiner (Figure 8B).

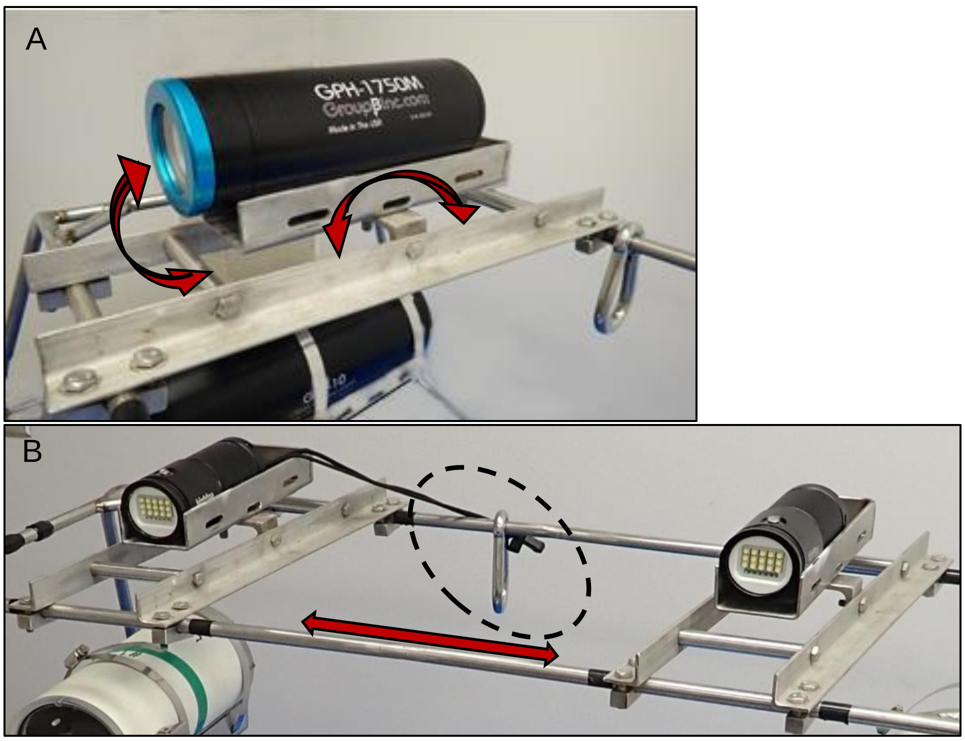

Figure 8. Positioning of lights and their mounts on the BRUV frame (A) for the deep water system and (B) for the coastal system. The arrows indicate possible adjustments. The dotted line in photo B indicates the safety knob.

2.2.5 Bait arm and cage

A removable 85 cm long bait arm is attached to the main frame at the same height as the camera bar, 30 cm above the base of the frame (Figure 2), and is secured with a locking pin or bolt with a nut. The end of the bait arm sticking out away from the frame is larger, so a bait cage or bag can be attached. The bait is held in different types of containers using various methods of attachment, in particular a traditional fishing bait bag, different models of cylindrical cages made of polyvinyl chloride (PVC) and metal, and a rectangular cage (Figure 9). Field-tested methods to attach the bait arm include elasticated ropes, plastic ties (Figure 9A and 9B), aluminum (Figure 9C, 9D and 9E) and a version that is welded directly on the bait arm (Figure 9F).

In terms of stability of bait placement on the arm, cage strength, ease of use and efficient diffusion of bait into the environment, the use of a rectangular metal cage welded to the bait arm produced the best results. This configuration is therefore the recommended method of attachment. The size of the rectangular cage (8 x 8 x 30 cm) has been optimized to contain one kilogram of bait, which offers the best compromise in terms of the flow and diffusion of bait into the environment. The size also minimizes the space occupied by the cage in the camera's field of view (Langlois et al. 2012). This configuration also makes bait handling a cleaner, more efficient process when the cage is being filled. The cage was painted black to negate the reflective nature metal cages, which can impact video quality.

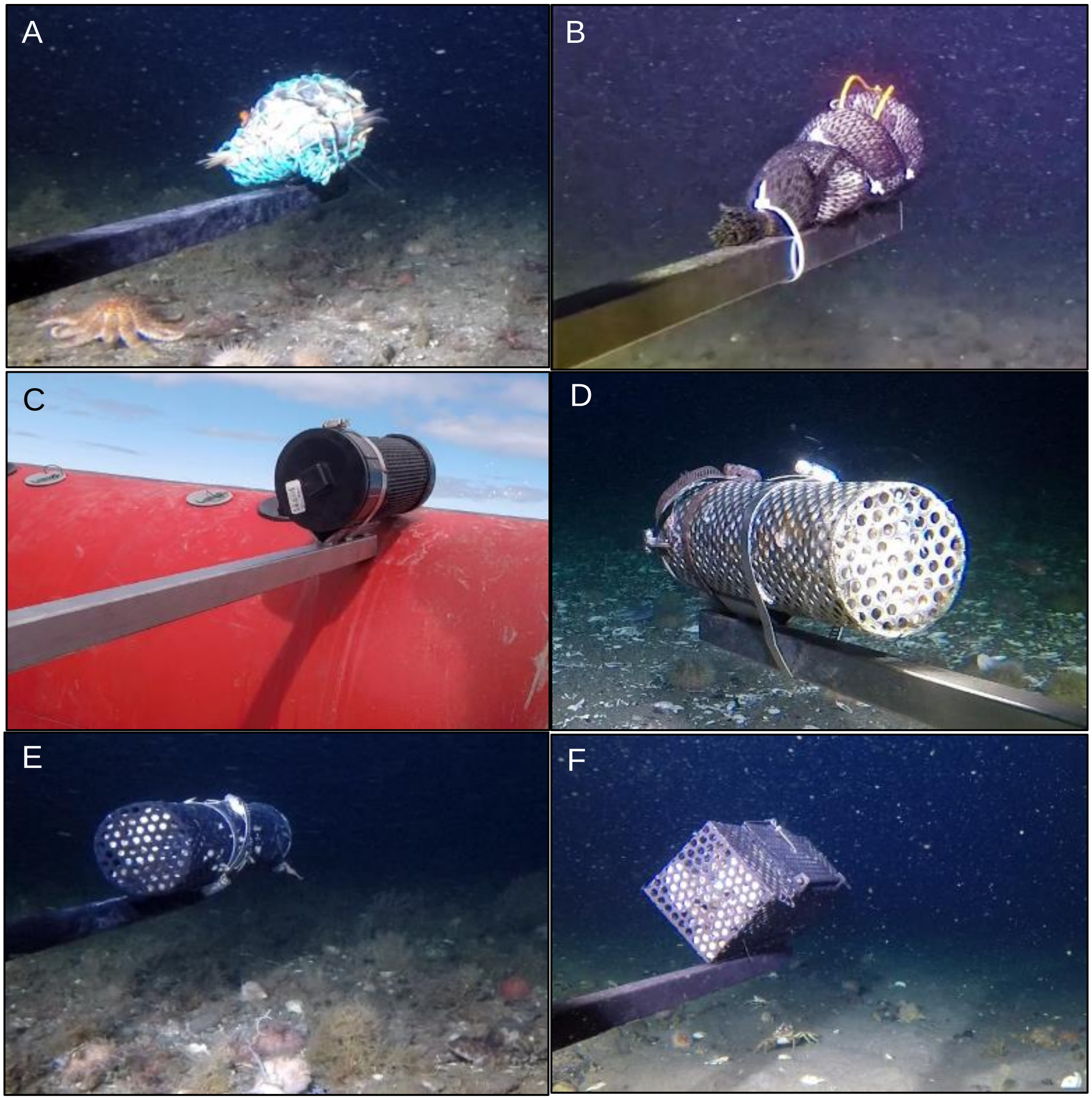

Figure 9. The different types of bait cages that were tested and that can be used are (A) large, mesh, soft bait bag cinched with plastic ties; (B) flexible bait bag with a protective lining (to protect from predators) closed with plastic ties; (C) PVC cylindrical cage attached with couplings; (D) the first aluminum cylindrical bait cage attached with couplings; (E) the same cylindrical bait cage with a matte black finish, to eliminate reflections, attached with couplings; and (F) rectangular-shaped bait cage with a matte black finish welded to the bait arm.

2.2.6 Bait

The type and quantity of bait used will depend on the objectives of the study (MacRae and Jackson 2006; Harvey et al. 2007). The use of a local species is generally recommended (Dorman et al. 2012) to help develop and exploit a reliable supply of the by-products produced from fisheries or scientific projects. In BRUV systems in the St. Lawrence estuary and gulf, 1-kg portions of Atlantic herring (*Clupea harengus*) are used. This bait was selected based on its availability (ease of supply) and its successful history of use in local commercial fishing. The flesh of the Atlantic herring is known to contain and release large amounts of oil and fat (Spitz et al. 2010), which maximizes the range of the bait used (Australian CSIRO Marine Laboratories 1987). Bait is used to attract and keep organisms in the camera's field of view.

2.2.7 Buoy line

The buoy line ensures that the BRUV system can be deployed and recovered. The buoy line has three complementary and independent sections of floating rope that measures 1.27 cm (½ inch) or 1.91 cm (¾ inch) in diameter: 1) floating connecting lines that are attached to the frame and supported by two fixed buoys, connecting the frame to the main line; 2) the main line (contains sub-sections of leadline), which makes up the central body and connects the frame to the surface buoys; and 3) surface buoys (floating lines) that make the BRUV system visible, easy to locate and recoverable at the water's surface (Figure 10). A stainless steel quick release shackle allows the frame connection lines and surface buoys to be easily detached from the main line. The length of the main line can easily be adjusted according to the depth of the sampling site. These adjustments can be made to accommodate up to 500 m of depth. Their effectiveness has been demonstrated up to 300 m. In order to facilitate operations, several interchangeable main lines of different lengths are prepared in advance to quickly adapt the set to the depth of the sampling site.

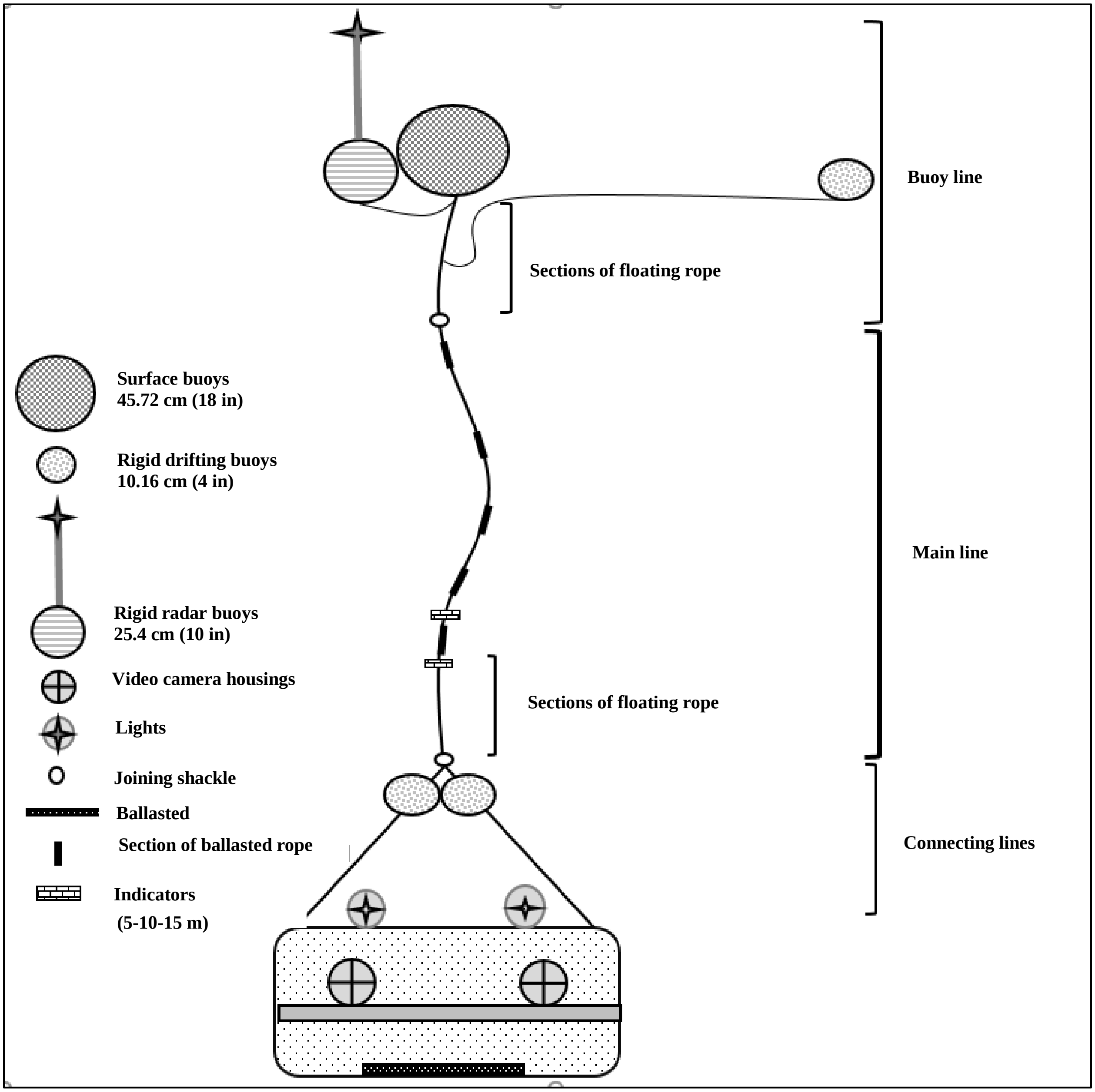

Figure 10. General diagram of the BRUV set systems

Connecting lines
Connecting lines are composed of 1.5 m sections of floating ropes connected to either side or to the four corners of the BRUV frame (Figure 10). The length of the ropes allows 1.5 m of clearance between the frame and the main line to be maintained as required for the various probes and instruments attached to the frame. The presence of two 10.16 cm (4 in) rigid buoys ensures that the ropes and shackles float. The ropes must float, so as not to obstruct the cameras' field of view or the light beams. The floating ropes also help keep the BRUV system in a fixed location on the bottom. The ropes are connected to each other and attached to the main line using a swivel shackle and a quick-release shackle to easily adjust the length of the main line according to the depth, without changing the connecting lines.

Main line
The main line has sections of floating rope and 45 cm sections of leadline (Figure 10). The first sections of leadline are located one metre from the joining shackle connecting the surface buoy line and five metres from the joining shackle attaching the frame's connecting lines. This set-up prevents the main line from falling in front of the cameras and obstructing the field of view. Additional sections of leadline are installed every two metres. This set-up ensures vertical positioning and keeps the line stable in the water column (up to 300 m deep), which helps keep the BRUV system in a fixed position on the bottom despite currents or tides. This set-up also facilitates the safe deployment and recovery of the system by preventing too much of the line from floating on the surface and posing a risk to navigation. Indicators marking the last fifteen, ten and five metres of line are in place to better control the rate of recovery and to safely retrieve the system at the water's surface. Another version of the main line was tested with promising results. This version behaves similarly in the water column and is easier to deploy, especially for depths over 100 m. This version has alternating sections of floating rope and ballasted rope throughout the main line. Sections of floating rope are installed at the ends of the system next to the surface buoys and the main frame. The entire length of the main line has alternating sections of floating and ballasted rope.

The length of the main line should be adjusted according to the depth of the site and environmental conditions such as tides, waves, currents, winds and ice conditions. Enough cable must be present to compensate for tidal zones and/or changes in wave height. Strong currents will reposition the rope in the water into a diagonal position, which increases the length of rope required. The need for longer rope is amplified by the depth: the deeper the sampling site, the longer the cable must be to ensure safe operation. If the cable is too short, it is more likely that the position of the BRUV system on the bottom will shift, which can compromise the quality of video samples and could even result in the loss of the system (if surface buoys are submerged due to environmental conditions). At coastal sites, the current is less likely to move the main line in a diagonal position, but the lines are at the mercy of the waves and tides. For example, recommendations include using a main line that is 1.5 times longer than the depth of the sampling site when the depth is 50 m or less, and using a main line that is 2–2.5 times longer than the depth for deeper sites (> 50 to 300 m). This recommendation must be adapted to local, seasonal and weather conditions such as performing sampling when tides or winds are high. Be vigilant during long-term (evening to morning) deployments where environmental conditions can change dramatically.

Surface buoys

The network of surface buoys (Figure 10) is made up of two or three buoys connected to each other by a floating rope, which is attached to the main line (Figure 11). The largest buoy has a diameter of 45.72 cm (18 in) and serves as a visual reference when recovering the system. The second, smaller buoy has a diameter of 10.16 cm (4 in). The buoy is rigid and is connected to the others by a cable measuring four metres in length (Figure 11). This buoy is mainly used to indicate the direction of the current in order to facilitate the approach of the craft when recovering the BRUV system. A third, rigid buoy with a diameter of 25.4 cm (10 in) is fitted with a radar reflector for identification purposes and a tri-coloured LED light (red, green, white) for increased visibility (Figure 11). This third buoy can be added as required depending on the sampling time and conditions and the vessel used for deployment and recovery of the set. A GPS tracking system can also be attached to surface buoys so they are easier to find if the BRUV system drifts (Figure 11).

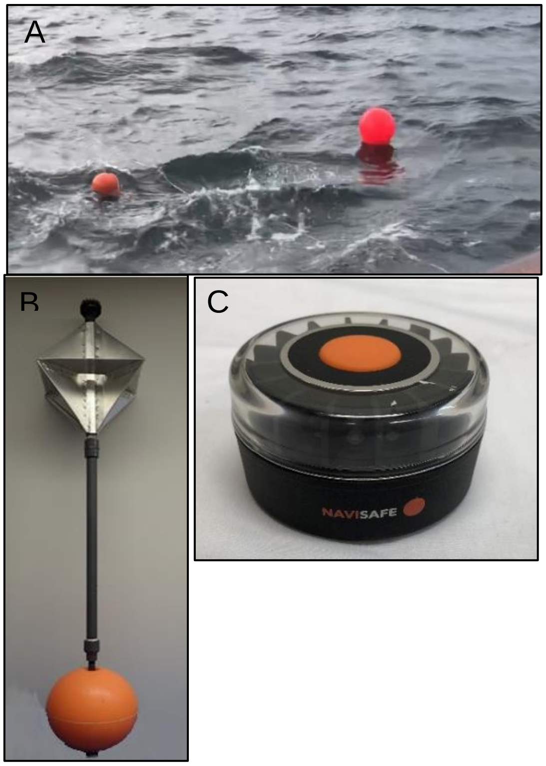

Figure 11. The components that make it easier to locate BRUV systems are (A) surface buoys, (B) optional radar buoy, and (C) the NAVISAFE light used on radar buoys.

2.2.8 Ballast

Ballast, in the form of 5.2 kg lead bars (Figure 12), is added to the ballast supports on the BRUV's main frame ((Figure 2). Four pairs of brackets are installed on either side of the main frame. Each bracket can accommodate two lead bars. Each BRUV system can therefore be ballasted to a maximum of 41.6 kg (the minimum recommended is 10.4 kg). Weights are used in pairs (always two weights facing each other), to maintain the balance of the main frame and ensure the system is properly positioned on the bottom. Ballast can be adjusted according to the weather and environmental conditions. The more severe the conditions (high wind, high current or wind shear, extreme depth), the heavier the ballast must be to maintain the most vertical descent possible and stop the BRUV system from moving or drifting during sampling.

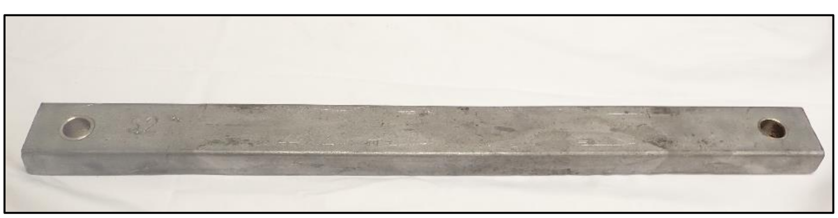

Figure 12. 5.2 kg of ballast can be added to the BRUV and DPC

2.2.9 Complementary equipment

The BRUV system can be equipped with additional components and materials that are not required for the proper operation of the system, but that make it easier to collect larger amounts of environmental and ecological data. In particular, additional guards, a multiparameter probe to measure conductivity, temperature and depth in situ (DST-CTD), a current meter and an emergency recovery system can be added as required. These devices are attached to the main frame with metal couplings and/or various mounts. The various components and connecting mechanisms outlined here (except for the emergency recovery system) have been tested. These components and mechanisms allow the various devices to operate smoothly without interfering with the video sampling process.

Additional guards

An additional detachable guard, made of aluminum rods that are attached to the four corners of the main BRUV frame, can be added to better protect the lighting system when sampling is being performed over rough seabeds (Figure 13). This guard also protects the lighting if the BRUV system flips when the system hits the seabed or, more frequently, when the system is brought back to the surface. When additional guards are added, the ring on top of the guards is used to secure the main line instead of using the connecting lines.

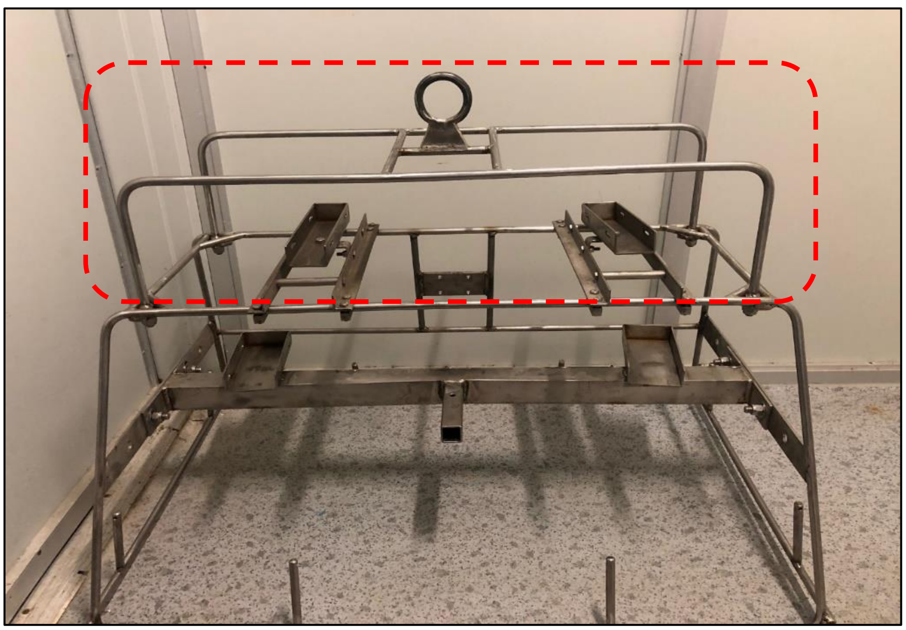

Figure 13. Removable guard (dotted box) for the lighting system attached to the main frame.

CTD multi-sensor

A Star-Oddi DST-CTD multi-sensor (star-oddi@star-oddi.com) measures depth, temperature and salinity. This sensor is attached to the top of the main frame and samples environmental conditions when the BRUV system is deployed (Figure 14).

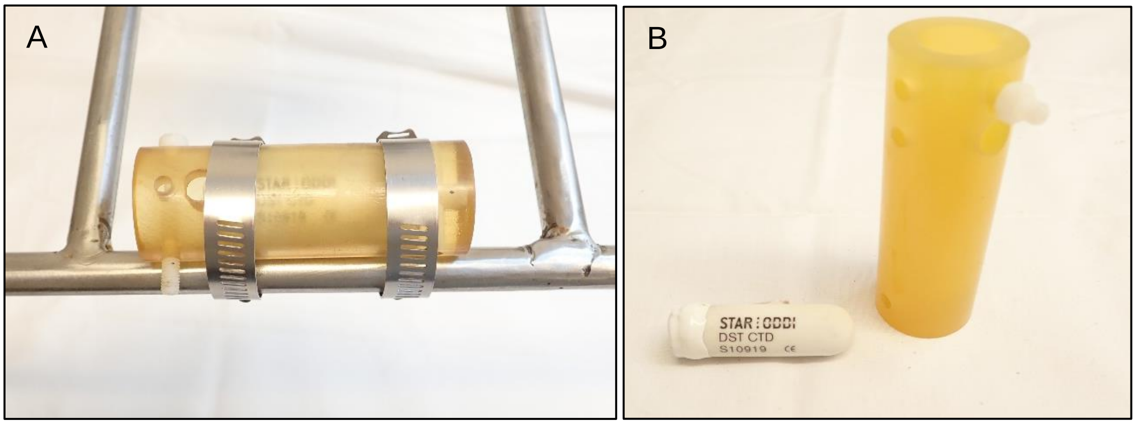

Figure 14. The Star-Oddi CTD sensor (A) installed on the BRUV system frame and (B) not attached to the mount.

Current meter

A Lowell Instrument (https://lowellinstruments.com/) TCM-1 current meter is attached to the top of the BRUV frame (Figure 15A). This piece of equipment is used to measure the direction and velocity of the current and to calculate the diffusion radius of the bait in the environment under study. This current meter contains an accelerometer and a magnetometer in a 76 cm PVC tube attached at the base of the main frame with a short rope. The current meter sways in the current and the degree of tilt is converted by the accelerometer to determine speed, while its orientation, measured by the magnetometer, corresponds to the direction of the current. A mount was designed to hold the current meter (Figure 15B and 15C) on the rear pole of the main frame and maintain its position. This mount provides the freedom of movement required for the current meter to operate properly. The BRUV system's connecting lines were designed to allow the current meter to move in a 76 cm radius. The lines do not inhibit the current meter's movement.

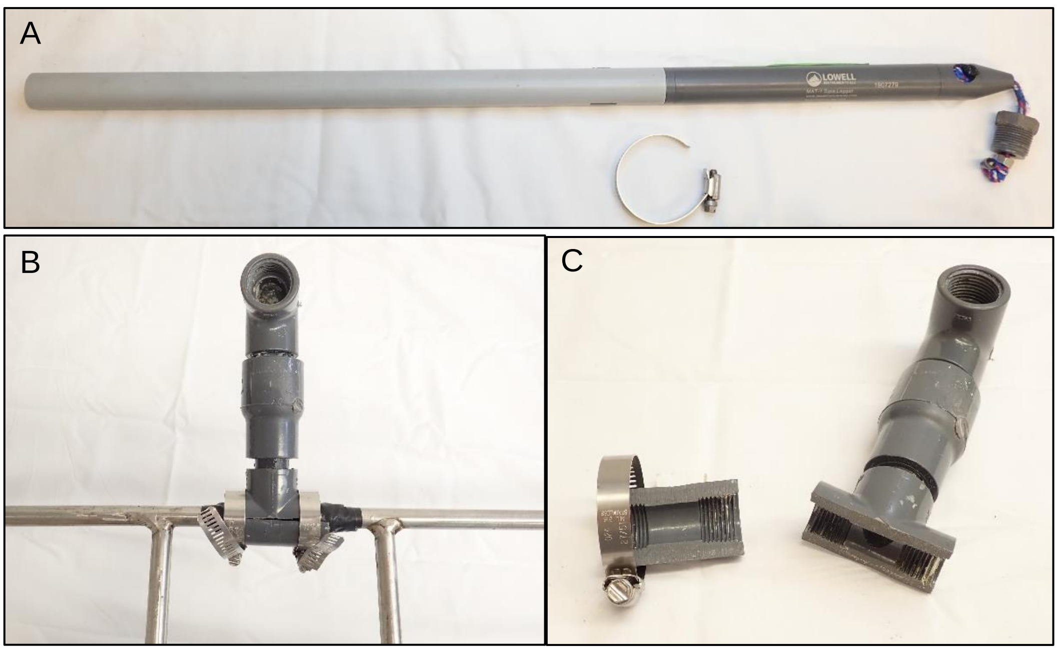

Figure 15. (A) Lowell TCM-1 current meter, (B) current meter installation mount on the BRUV frame, and (C) mount off the frame.

Remote operation

The advantage of GoPro cameras is that they can be operated remotely with a remote control (Figure 16). The GoPro *Smart Remote* (www.GoPro.com) makes it possible to turn the cameras on and off without needing to open the waterproof camera housing multiple times. This saves time and energy, maximizing battery life in the field. The remote also ensures that the cameras are synchronized, making it easier to collect subsamples of photos and videos. The GoPro remote control is simple to operate, and up to 50 cameras can be paired with a single remote control. Pairing can be established between the remote control and the cameras over WiFi.

Figure 16. GoPro Smart Remote

The remote control loses its connection to the cameras when they are immersed in water, but the cameras continue recording according to the settings established when the camera was turned on. The remote control will reconnect when the cameras are back on the water surface and communication is automatically restored. Automatic reconnection between the cameras and the remote control often fails. This problem can be avoided by turning on the cameras before they are placed in their housings and starting the recording shortly before they are deployed in the water. Recording can then be stopped between stations in order to save the batteries. However, the cameras are not turned off. It is recommended that a separate remote control be used for each BRUV system deployed and a single GoPro camera model be used in each system to minimize connection problems between the cameras and the remote control.

Emergency recovery system

An emergency recovery module system, consisting of a Teledyne Acoustic Release, Model R500 (http://www.teledynedalsa.com/en/home), is installed on a rigid buoy that measures 10.16 cm (4 in) in diameter and that is connected to a recovery rope that measures 500 m in length and 36 mm (5/32 in) in diameter. This rope can be connected to the BRUV system's main frame. This acoustic release is equipped with a geolocation system that tracks the position of the BRUV system under water if the system is lost. The position of the ballast must be adjusted if the recovery system is used to maintain system balance and ensure proper positioning on the bottom. Note that this system has not been tested.

2.3 BRUV sampling

The main advantage of the BRUV system over other conventional underwater imaging methods is its versatility. The system can be easily deployed for sampling from different types of vessels. The type and size of the vessel and its manoeuvrability affects the deployment and recovery procedures. These procedures and the equipment used will vary from vessel to vessel (Figure 17). For safety reasons, the BRUV system should be handled by two people at all times, regardless of the size of the vessel used.

2.3.1 Deployment

The system can be manually deployed from small (< 10 m) and medium-sized vessels (10–25 m), since rails on those vessels are generally less than one metre high. The system is allowed to sink to the bottom and the lowering speed is controlled manually. A slight slack in the main line indicates that the BRUV system has reached the bottom. The excess rope as well as the surface buoys are then released. On large vessels, such as research vessels (≥ 25 m) with higher rails (2–5 m), or for deployments at depths of 50 m and above, the use of a capstan or winch (hydraulic or electric) is required. This equipment makes it easier and safer to deploy the BRUV system by controlling the rate of descent and ensuring proper positioning of the BRUV system on the seabed. It is therefore recommended that they be adapted for use on all types of vessels.

2.3.2 Retrieval

To retrieve the set, first recover the surface buoys using a grapple or a gaffe. Lift them on board the craft. Because small vessels are very maneuverable, surface buoys can generally be approached directly from the side of the vessel, and the vessel can get very close to the set. On larger, less maneuverable boats, they can be approached with the side of the vessel when a crane or reaching arm is available, or by backing up the rear of the vessel toward the set if a hydraulic gantry is available. Buoy recovery can also be carried out using a secondary vessel such as an inflatable craft if weather, environmental conditions or the presence of obstacles make it difficult to approach the set. In this case, the secondary vessel recovers the buoys to bring them to the vessel that is responsible for recovering the set.

After the surface buoys have been brought on board, the main line can be pulled onto the vessel by hand, using pulleys or a simple secondary device (e.g., drill-powered capstan) or a motorized device, depending on the vessel (Figure 16). Some of the motorized devices tested for hauling the BRUV system include winches, capstans and pot hauler hydraulic winches. Once the system is close to the surface, the lift speed is reduced to bring the system back on board and avoid any impact with the vessel or lifting mechanisms.

Figure 17. Different methods can be used to deploy and recover the BRUV system depending on the type of boat, including (A) the crane on the side of the *CCGS M. Perley*; (B) the Y-arm support and the crane on the side of the *CCGS M. Perley*; (C) the deployable side-sweep arm that is fitted with an open-faced pulley and a capstan on the *CCGS Octopus;* (D) the side-sweep arm fitted with a pulley and a manual sailboat capstan powered by a chuck and an electric drill on the *CCGS Colvert*; (E) recovery from a portal on the side of the *CCGS Amundsen*; (F) recovery of the BRUV from a portal on the back of the *CCGS Leim;* (G) the pulley system and the portal on the back of the *CCGS Leim;* (H) the capstan used on the portal on the back of the *CCGS Leim;* and (I) the BRUV system being transported to a coastal area on an inflatable boat.

3. DEPOSITED CAMERA SYSTEM

3.1 General description

Deposited camera systems (DPC) can be used to characterize the density and biomass of submerged aquatic vegetation (Short et al. 2001; York et al. 2015), the density of epibenthic organisms (Sheehan et al. 2010; Mallet and Pelletier 2014) and the composition of the substrate in sensitive or uneven seabeds (Valentine et al. 2005; Larocque and Thorne 2012). The DPC system shown here has a frame with a quadrat integrated into the base (Figure 18). This quadrat is lit up by two diving lights and photographed by two cameras. The first camera captures a downward, centred view from above the quadrat and the second captures a wider, tilted view of the quadrat. The DPC system is designed for coastal areas (≤ 50 m depth) and can be deployed from a boat equipped with an electric, hydraulic or manual winch. It is also possible to manually deploy the system in shallow (≤ 10 m) areas.

3.2 Description of components

3.2.1 Frame

The DPC system's frame is a triangular-based prism that measures 50 cm in width, 100 cm in length and 76 cm in height to the ring at the top of the central crest (Figure 18A). Its base has a divider running through it creating a 50 x 50 cm quadrat that is used in the assessment of the density and coverage percentage (Short et al. 2001). Biomass per unit area can also be calculated by comparing the quantity of vegetation visible in a photo to the biomass harvested by divers using the method established by Short et al. (2001), and amended by York et al. (2015). The DPC system is equipped with two cameras and two 7200 or 8000 lm dive lights (Figure 18B). The first camera is installed on the highest horizontal bar in the centre of the quadrat. This camera faces downward and captures organisms in the quadrat from above. The second camera is attached to the small horizontal bar in the triangle adjacent to the quadrat (Figure 18A). This camera is positioned in portrait mode, allowing a tilted view (≈ 30˚ downward angle). The photos from the second camera in the tilted view make it easier to assess the relative size of the organisms captured in the quadrat. The two angles are complementary and make it easier to detect and accurately identify organisms.

3.2.2 Cameras

The DPC system currently uses two GoPro video cameras, including the HERO5, HERO6 or HERO7 models, which have internal memory cards and are powered by the original battery provided with the camera. These three models of cameras were chosen based on their compatibility with the GoPro Super Suit watertight housing, which makes it possible for cameras to be submerged to a depth of 60 m. We recommend using the same camera model in the vertical position throughout a sea mission to limit any possible discrepancies, although these models are very similar in regard to photography. These action cameras are often used in underwater video and photo systems (Letessier et al. 2015). They offer a balance of performance, cost, sturdiness, photo and video quality, and ease of deployment in the DPC system, i.e., minimize the size and number of components on the system. The cameras' watertight housings can be attached to the frame using the removable, custommade mount (Figure 18C and 18D). Any other model of dive camera could be used with the DPC system, but the vertical and tilted cameras must cover the entire quadrat to be captured under water.

3.2.3 Lighting system

The lighting system consists of two Bigblue lights, including models VTL7200 and VTL8000, which emit 7200 and 8000 lm at 6500K. Cool white light is recommended when collecting photographic samples. The lights have a beam angle of 120° and are waterproof to a depth of 100 m. The two lights are secured by U-bolts on either side of the vertical view camera to illuminate the quadrat evenly (Figure 19). These two lights provide adequate luminous intensity for both cameras.

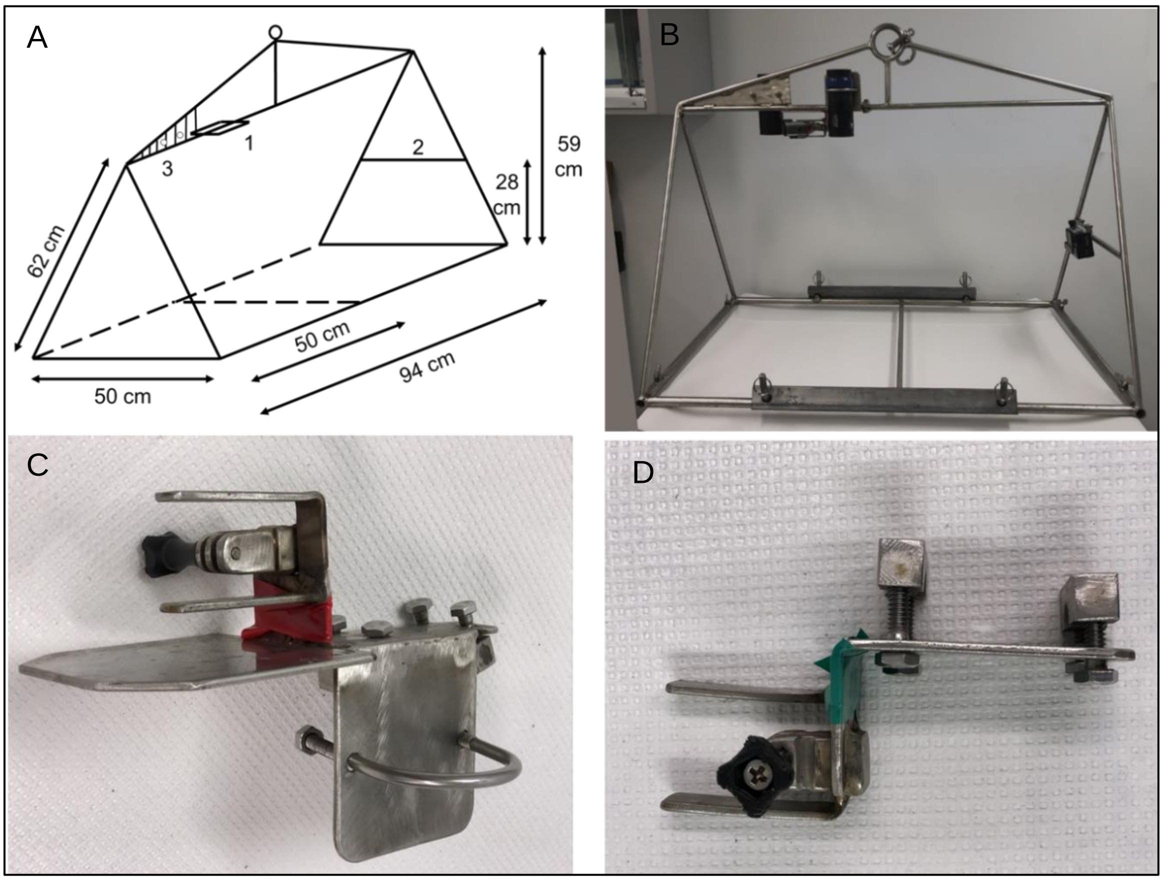

Figure 18. Deposited camera system (DPC) (A) diagram; (B) camera including removable camera mounts; (C) removable bracket for one of the two dive lights; and (D) mount for the tilted camera. In photo (A), 1 indicates the position of the vertical camera mount, 2 indicates the horizontal mounting bar for the tilted camera and 3 indicates the mounting bracket for the second dive light.

Figure 19. A lighting system with two dive lights installed on either side of the top camera to light up the quadrat.

3.3 DPC set up and deployment

The DPC system was designed for easy deployment from small or large boats. The DPC system sits on the bottom for a short time (< 2 min) while remaining attached to the boat. The system is then moved a short distance and sits there. Systems should be deployed consecutively to increase sample replication and to maximize area sampled to characterize the degree of site heterogeneity. When deployed from a small vessel to a depth of less than 10 m, the DPC system is light and maneuverable enough to be deployed without a winch. However, two people should deploy the system for safety reasons.

When the DPC system is deployed to a depth of more than 10 m, the use of an electric, hydraulic or manual winch is recommended. The addition of ballast ensures a vertical descent and increases the likelihood that the DPC is in the correct position to take photos. Lead discs weighing 5 kilograms each can be attached to each corner of the system with ropes. Two lead bars weighing 5.2 kg each can also be used (Figure 12) and attached to anchoring points (Figure 18B and 20A). The main consideration when choosing what ballast to use is to ensure it does not encroach in the quadrat where photographs will be taken.

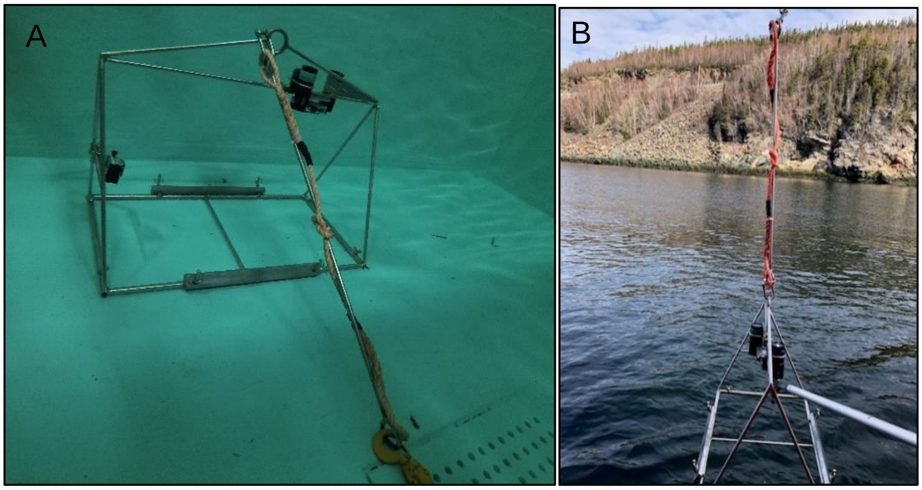

Figure 20. (A) A rigid, stainless steel rod measuring one metre in length runs along the rope, from the DPC system to the hook. It rests on the bottom in the water and (B) is shown in operation when attached to the hook of the boat, which prevents it from dropping into the quadrat or breaking the camera.

Winch cables on most vessels are fitted with a large hook or shackle, which could hit the cameras when the system is deposited on the bottom and could fall into the quadrat. To avoid these problems, a 1-m metal rod with a ring welded at either end is added between the DPC system and the boat hook. A safety rope is also installed between the boat hook and the DPC system in case the weld fails (Figure 20B).

When deploying the system in shallow water (< 10 m) from a small vessel, it is more efficient to anchor and allow the boat to drift with the current. Deploy several DPC systems while travelling upstream along the anchor rope until the anchor no longer holds the boat in place. Leave at least approximately four metres between each system placed on the bottom. The vessel must then be moved and anchored again. Repeat these steps until the number of deployments required is achieved. The number of deployments varies depending on the study's objectives and the environment. Generally, 5 sets are deployed for mostly homogeneous sites and 15 sets are deployed for heterogeneous sites. The DPC can be deployed without anchoring, by leaving the engine running to maintain the vessel's position. After the DPC system has settled on the bottom, enough slack must remain in the rope to avoid any tension that could cause it to tip over.

Systems must remain on the bottom for at least one minute, and are generally left for two minutes. Most resuspended particles settle quickly enough to obtain photos with the clarity required for biological and environmental analyses.

4. SAMPLING PARAMETERS

This section describes the sampling parameters that were tested and used for the GoPro cameras and the lighting systems for the BRUV and the DPC systems.

4.1 BRUV system video recording settings

The video recording settings used correspond to the GoPro HERO5 camera parameters recommended by SeaGIS and are a compromise between image quality and recording duration. The format is 1080p at 30 frames per second (fps) with a medium field of view used. An ISO sensitivity of 3200 enables sampling methods to be adapted to the frequent turbid conditions and the type of light used. The observations to date have led us to conclude that the video is of sufficient quality to identify organisms (Table 1).

Table 1. The sampling parameters for lighting and colour management used for the BRUV and DPC systems.

System	Colour	White balance	ISO sensitivity	Shutter	Exposure	Image sharpness	Audio
BRUV	Flat	Auto	3200	Auto	0	High	On
DPC	GoPro	Auto	400-800	NA	0	High	NA

Note: NA = not applicable.

The 4K video feature was tested but was only available in 30 fps with the GoPro HERO 5. This feature does not significantly increase video quality when the video is paused on an image for better taxonomic identification. Additionally, it considerably increases the memory space required to save videos. Under these conditions, it is preferable to reduce the resolution to 1080 p and maximize the frames per second. For GoPro models where frames per second can be increased to 60 or 80, recording in 4K video will improve the quality of results if the memory space needed to save the video is not an issue. A higher ISO compensates for the lack of light available in deep water by producing a sharper image without needing to increase the intensity of the lights. It is important to use an appropriate light intensity to ensure good visibility without overexposing suspended matter. Suspended matter can reflect light and/or become over-exposed in light, which decreases the quality and clarity of the images. The intensity of the lights used combined with a high ISO sensitivity serves as a good compromise to achieve highly accurate taxonomic identification. With adequate lighting, image quality can be improved when the video undergoes post-editing. A lower ISO sensitivity could be used in higher visibility environments, or to increase the quality of certain image details. A medium field of view can be used to eliminate spherical aberration around the edges of an image. This field of view complicates the performance of stereoscopic measurements by introducing a bias. If flat is selected in the GoPro’s colour settings, the resulting image will have lower contrast. Details in this image’s light and shadowed areas will still be preserved. This setting preserves the most details possible throughout the image’s tonal range. Details will be easier to sharpen in post-editing because colours can be amplified as necessary.

4.2 DPC photo recording system settings

The two DPC system cameras have the same recording settings: one photo every 10 seconds in the interval setting with a wide field of view (Table 1). Ideally, the recordings should be started simultaneously with the Smart Remote in order to capture synchronized photos, which will facilitate research during analyses. The camera's wide field of view captures the whole quadrat from a vertical angle. The wide field of view is also appropriate for the camera positioned in the tilted angle, since it captures the entire quadrat. The underwater photos captured are somewhat distorted by spherical aberrations. This distortion is acceptable because exact measurements of organisms is not required or expected.

4.3 Camera power supply

The GoPro has an internal battery with a capacity of 1200 mAh (standard AABAT-001-CA model provided with the cameras) and external batteries of various capacities including 6,000, 10,000, 15,000 mAh (Appendix 1), are used to power cameras in the DPC and BRUV systems. Laboratory and tank testing determined the maximum video recording time with the various types of batteries. Recording time was evaluated using the video recording parameters described in section 4.2. The tests were performed at ambient temperature (22 °C) in a laboratory and in a cold water tank (2 °C). The cold-water tests were performed by submerging the cameras, protected inside of SeaGIS housings, in a tank where water was constantly kept at a 2 °C by a heat pump system. Three models of GoPro camera, the HERO5, HERO6 and HERO8, are powered by an internal or external battery with different capacities. These were compared by using three memory cards with storage capacities of 64 GB, 128 GB and 256 GB respectively. The maximum video recording times are compiled in the Table 2.

The battery life was proven to be limited by the duration of the recording for only internal batteries. The maximum recording time with the internal battery is approximately 90 minutes, regardless of the temperature or the camera model used (Table 2). For the external batteries, recording time was not limited by the power supply, but by the storage space on the memory card. The maximum video recording time was similar for the same memory space with three external batteries regardless of the temperature (Table 2). The only difference observed was between the HERO5 model and the more recent HERO6 and HERO8 models. The more recent models were able to record for 36% less time on average than the HERO5 with external batteries. An external power source can increase the maximum recording time to 16 hours for the HERO5 when equipped with a 256 GB memory card. It is worth mentioning that these results, obtained both in a lab and a tank, likely overestimate the maximum recording time for use in a natural environment where movement and light are likely to vary.

The recharge time for the different batteries varies in terms of charge status and wear and tear as well as the type of charger used. The internal battery recharges in about one hour, while the different external batteries can take between two and eight hours to fully recharge based on their initial capacity. Larger batteries take longer to charge, but also have greater battery life.

Table 2. Maximum video recording time for the three GoPro cameras in an ambient laboratory (22 °C) (written in black) and in cold water (2 °C) (italicized and bold) in terms of the battery used (internal or external), power capacity in milliampere (mAh) and memory card capacity (in GB) for the standard video configuration selected for sampling with the BRUV system (format 1080 p to 30 fps, medium field of view and an ISO sensitivity of 3200).

GoPro model	**Battery capacity (mAh)**	**Battery type**	**Memory card size (GB)**		
			64	**128**	**256**
HERO5	1,220	Internal	1:34	1:33	1:33
			1:33	***1:33***	***1:34***
	6,000	External	4:05	8:08	16:21
			4:04	***8:11***	***16:18***
	10,000	External	4:04	8:12	16:18
			4:05	***8:10***	***16:19***
	15,000	External	4:04	8:11	16:24
			4:04	***8:09***	***16:23***
HERO6	1,220	Internal	1:33	1:33	1:33
			1:34	***1:33***	***1:33***
	6,000	External	2:36	5:15	10:34
			2:37	***5:16***	***10:32***
	10,000	External	2:35	5:16	10:34
			2:37	***5:15***	***10:33***
	15,000	External	2:37	5:16	10:32
			2:36	***5:16***	***10:33***
HERO8	1,220	Internal	1:33	1:33	1:33
			1:34	***1:34***	***1:34***
	6,000	External	2:38	5:15	10:34
			2:36	**5:16**	**10:34**
	10,000	External	2:38	5:16	10:34
			2:38	**5:16**	**10:31**
	15,000	External	2:36	5:15	10:32
			2:36	***5:17***	***10:33***

4.4 Stereoscopic video calibration of the BRUV system

Camera calibration is required when stereoscopic video samples are captured using baited stereo-video camera (BRUV) systems (Shortis and Harvey 1998; Shortis et al. 2008). This calibration should be performed in an aquatic environment (swimming pool, pond or natural environment) with water that is sufficiently clear. Calibration is performed by measuring rotating objects of known dimensions from different angles. A set of three-dimensional points are generated when the images are measured (Boutros et al. 2015). We use the photogrammetric network method (Clarke and Fryer 1998) as developed for the CAL software (SeaGIS). The calibration process involves placing the camera in a housing underwater and taking a set of measurements using a 3D calibration cube (Figure 21A) and a 2D calibration bar (Figure 21B) at various angles and distances. The parameters established during the calibration process (set of 3D points) are then applied to the measurements taken on the images analyzed.

It is strongly recommended that calibration be performed before and after each sampling mission to measure any deviations caused by the camera shifting or the camera housing shifting during the mission. These shifts can happen if a damaged camera is replaced or if the camera base bar gets warped after an impact. To limit shifting, it is strongly recommended that users do not move the camera base bar once it is installed on the frame and do not remove the housing from its base after the initial calibration. As compensation when using deep-water housings, a calibration curve can be produced that represents the BRUV system's normal use in order to determine the severity of the deviations in regards to the calibration parameters. However, the calibration curve method is much less precise.

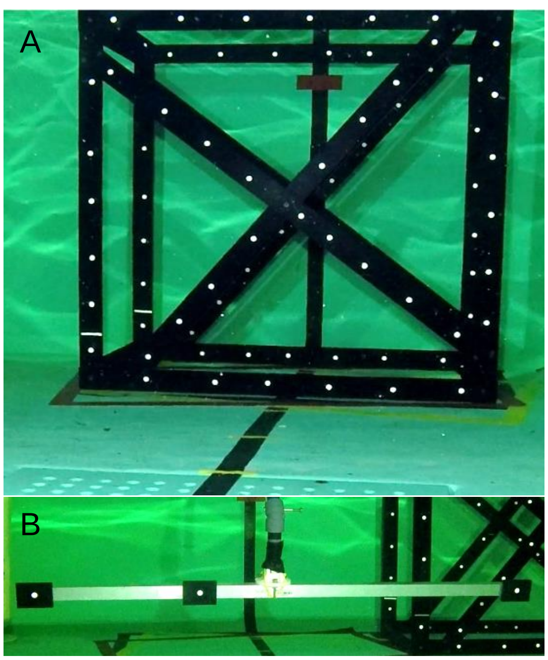

Figure 21. (A) Cube and (B) SeaGIS calibration bar.

4.5 Samples collected and image analyses

The BRUV and DPC systems collect photo and video samples to be processed by underwater imaging software, which extracts biological, ecological and environmental data. The wide range of environmental conditions during underwater sampling present challenges in regards to standardized image quality and the taxonomic identification level possible (Figure 22 and Figure 23, respectively). The organisms observed in the images are identified at the lowest taxonomic rank, which generally is the species for fish and megabenthic invertebrates. For some invertebrates, the lowest possible taxonomic level is family or order (e.g., *Caridea* for shrimp). Microscopy is needed to identify encrusting organisms, including bryozoans, algae and sponges (*Porifera sp.*). These organisms are therefore generally identified at the branch or class level in underwater imaging.

Video samples are analyzed using SeaGIS Eventasure, which allows videos to be annotated, species to be identified and stereoscopic measurement to be performed directly on images using the 2D and 3D parameters defined during calibration (Langlois et al. 2012). Photo samples are analyzed using ImageJ, a free image software. ImageJ can be used to perform quantitative analyses on the images, to enter annotations and to display captured images sequences (time series). Information regarding how the photos and videos collected during DPC and BRUV sampling were processed is available in the second volume of this series of reports. The third volume focuses on the taxonomic catalogue used to identify organisms.

Figure 22. Examples of images from video collected using the BSVC system.

Figure 23. Examples of photos captured of the same quadrat in tilted view with portrait layout (left) and in vertical view (right) with landscape layout by a DPC system camera.

5. CONCLUSION

This report describes two visual sampling methods that can be used to better collect biological and environmental data in different aquatic environments, and to reduce the impact of sampling on organisms and on the marine environment. The methods are the baited stereoscopic video camera system (BRUV) and the deposited photo camera system (DPC). The description of the components and set up required for these methods to function properly could be used to help develop or adapt similar systems in order to meet research needs. BRUV and DPC systems have been tested and have demonstrated their utility in a variety of habitats (intertidal, coastal and offshore zones) and sampling conditions (collection from small inflatable boats, icebreakers or commercial fishing vessels). Their main advantages are their ease of use and versatility. These systems can be deployed on virtually any type of boat and can be easily integrated into various sampling protocols at sea, which would increase the time and resources dedicated to meeting ecosystem and multidisciplinary objectives. BRUV and DPC methods make it easier to access marine habitats, especially marine protected areas and uneven seabeds, that are not readily accessible to conventional methods such as trawling. Another significant benefit is their low cost—DPC and BRUV systems can be developed and implemented at initial costs ranging from \$1,000–\$5,000 or from \$5,000–\$10,000, respectively.

The combined use of the DPC and BRUV systems maximizes the number of static, real-time observations (DPC) to better characterize the heterogeneity of an environment, and increases the likelihood of detecting mobile species such as fish and crabs through continuous, dynamic observations at the same site (BRUV). These complementary methods expand our ability to characterize the physical, biological and ecological aspects of habitats and communities. The addition of accessory sensors on DPC and BRUV systems allows environmental data to be collected without additional effort or procedures. In light of DFO's current priorities, including the implementation of an ecosystem-level approach in the formulation of scientific advice for fisheries management (Pepin et al. 2019), the increase in the area of marine protected areas (Government of Canada 2011 2018) and the increase in research and monitoring in coastal areas (Government of Canada 2020), the importance of photo and video protocols is expected to grow. Several DFO groups are already under development (Larocque and Thorne 2012; Wudrick et al. 2020). Underwater imaging is being used to monitor commercial invertebrates (Nozères and Roy 2021), to monitor marine protected areas (Beazley et al. 2019; Côté et al. 2021), to perform mapping at the sub-meter scale in nearshore benthic habitats (Vandermeulen 2014) and to enhance costal nurseries for commercial species (Dalley et al. 2017). The implementation and synergy between these initiatives and other initiatives under development will pave the way for scientific practices that are more protective of the environment and for marine resource and habitat management practices that are implemented at an ecosystem level.

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8. APPENDICES

Appendix 1. BRUV and DPC System Specifications and Components

Components	**Supplier**	**BSCV**	**DPC**	**Description**
Main frame	SeaGIS: *The dimensions were measured on the original model.* Local contractor: *Additional versions made with the permission of SeaGIS*	X		Trapezoid-shaped stainless steel main frame for securing the various equipment required for sampling. This includes the camera support bar for attaching and positioning camera housings. <u>Dimensions:</u> Base: 105 x 70 cm Top: 35 x 95 cm Height: 50 cm
Main frame	Local contractor		X	Stainless steel main frame in the shape of a triangular-based prism, to which you can attach the equipment required for sampling. Its base has a section measuring 50 x 50 cm. <u>Dimensions:</u> Length: 100 cm Width: 50 cm Height: 76 cm to the top ring
Calibration frame	SeaGIS	X		Frame for calibrating the BRUV system for taking stereo-video measurements. Dimensions: 1000 x 1000 x 500 mm
Coastal camera housings	SeaGIS	X		Protective PVC housings to secure and protect the GoPro cameras. Tested and certified waterproof to a depth of 150 m. They also ensure that the GoPro camera positions are maintained during handling and maintenance. Compatible with GoPro HERO5, HERO6 and HERO7 models. <u>Measurements</u> Length: 25 cm Diameter: 11 cm
Deep-water camera housings	GroupBinc	X		<u>Models</u>: Benthic 3 and GPH10 Protective aluminum housings to secure and protect the GoPro cameras. Tested and certified waterproof to a depth of 2,600 m for the Benthic 3 and 2,800 m for the GPH10. Compatible with GoPro HERO5, HERO6 and HERO7 models. These housings have two components, the first (Benthic 3) maintains the GoPro cameras' position during sampling. The Benthic 3 enclosure is attached to the second cylindrical component (GPH10) containing the external batteries. <u>Measurements</u> Benthic 3: 8.6 cm (length) x 7.6 cm (width) x 6.3 cm (height) GPH10: 11.5 cm (diameter) x 27.5 cm (length) Total: 11.5 cm (diameter) x 35 cm (length)
GoPro housing	GoPro		X	<u>Model</u>: Super Suit

Components	Supplier	BSCV	DPC	Description
				Housing waterproof up to 60 m, compatible with GoPro HERO5, HERO6 and HERO7 cameras.
Lights	Bigblue	X	X	Model: VTL7200, 7 200 lm Tri-Color Video Light Light source: 15 x XML LED + 6 XPE LED Colour temperature: Cool white: 6500K Warm white: 5500K Light intensity Cool white: 1,800 lm (level 1) 3,600 lm (level 2) 7,200 lm (level 3) Warm white: 900 lm (level 1) 1,800 lm (level 2) 3,600 lm (level 3) Beam angle: 120° Dimensions: 13 cm (length) x 5.5 cm (diameter) Power: Rechargeable Li-Ion BACCELL18650 battery x 4
Lights	Bigblue	X	X	Model: VTL8000, 7200 lm Tri-Color Video Light Light source: 15 x XML LED + 6 XPE LED Colour temperature: Cool white: 6500K Warm white: 5500K Light intensity: Cool white: 2000 lm (level 1) 4,000 lm (level 2) 8,000 lm (level 3) Warm white: 1,000 lm (level 1) 2,000 lm (level 2) 4,000 lm (level 3) Beam angle: 120° Dimensions: 13.0 cm (length) x 5.5 cm (diameter) Power: Rechargeable Li-Ion BACCELL18650 battery x 4
Deep-water light housings	GroupBinc	X		Model: GHP-2, with viewport Aluminum protective housings allows installation of a modified Bigblue VTL7200 light (see the BRUV lighting system section). Tested and certified waterproof to a depth of 1,750 m. Dimensions: 7.5 (diameter) x 19.0 cm (length) Beam angle in the housing: 100°
GoPro camera	GoPro	X	X	**BRUV:** The HERO5 Black is used on the BRUV system. Check compatibility with suppliers of different housing types when changing models. **DPC:** The HERO5, HERO6 and HERO7 models that are compatible with the Super Suit.
Camera battery	GoPro Belkin	X	X	GoPro internal battery: 1,220 mAh GoPro external battery: 6,000 mAh GoPro external battery: 10,000 mAh Belkin external battery: 10,000 mAh Belkin external battery: 15,000 mAh
CTD sensor	Star Oddi	X		Model: **DST CTD** Sensor that measures and records salinity, temperature and depth.

Components	Supplier	BSCV	DPC	Description
				Salinity range: 13–50 mS / cm Depth range: 5–500 m Dimensions: 50 mm x 15 mm
Current meter	Lowell Instruments LLC	X	X	Model: TCM-1 Tilt Current Meter Records the speed and direction of currents. Tested and certified waterproof to a depth of 300 m. Dimensions: 76 cm (length)

Appendix 2. CBVS Use Protocol

Pre-mission – System calibration

- The BRUV system must be calibrated prior to departure with the SeaGIS CAL software (see the video calibration of the BRUV system section).
- After the calibration is completed, **the camera housing** and **the camera bar** on which the camera is installed should not **be removed from the system** in order to maintain the camera positioning established during calibration.
- When transporting, maintaining and handling cameras (batteries and memory cards), remove only the viewports from the housings. Maintain the camera's position in relation to the viewport.
- If the camera position must be changed, make note of the time the change occurred. After the mission, perform a calibration to quantify the change in position and to ensure the measurements were not affected during the analysis.

At the sampling site

1. Check that all system components are secure.
    a. Check that all camera bar bolts are securely screwed in.
    b. Check that the screws on the shackles attaching the connecting lines, the main line and the buoy line are tight and secure.
    c. Check that the light mounts are securely fastened and correctly positioned on the frame.
    d. Check that the mounting screws on the lighting mounts are correctly screwed in and that the mount is positioned at the appropriate angle.
    e. Check that all securing pins are in place (housings and ballast bars).

2. Check the various lines.
    a. Check that the main line is long enough for the depth of the site.

Factors to consider when estimating the required length of rope:	
• Station depth + 5 m	Standard length
• Steepness of the site • Wave height • Tide range • Currents	Safety length

**The deeper the station is, the longer the safety line should be.*

    b. Check the knots on the main line if it has multiple sections.
    c. Check the condition of the ropes on the BRUV connecting lines.

Before the BRUV is deployed

3. Prepare the cameras.

   a. Remove the viewports that would be in front of the cameras, **and leave the housing in place.**
   b. Insert the new memory cards in the cameras.
   c. Connect the camera to the battery with the USB 90° cable.
   d. Format memory cards using the GoPro.
   e. Check camera settings.
   f. Place the battery in the battery holder.
   g. Install the viewports and battery on the housings.

4. Prepare the lights.
   a. Place the batteries on the lights.
   b. Install the lights on the light mounts.
   c. Attach the safety knob (coastal version) to both lights.

Deploy the BRUV system

5. Prepare the bait.
   a. Put 1 kg of bait in the bait cage.
   b. Secure the cage closing mechanism in the closed position.
   c. Check the condition of the coupling or the condition of the welding securing the cage.
   d. Install the bait arm on the BRUV.

6. Turn on the lights.

7. Deploy the BRUV system.
   a. Start the cameras manually or using the remote control.
   b. Display a blackboard with the station information in front of the cameras.

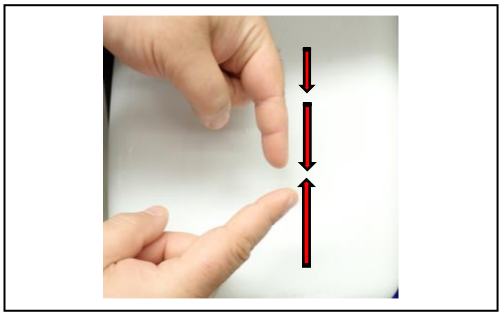
Mission:

Station:

System name + sampling position (P1 - P2)

Date/time

c. To synchronize the cameras, make a gesture directly in front of each camera at the height of the bait cage. This gesture can simply be to touch your fingers slowly.



d. Place the BRUV in the water. Check that the buoys on the BRUV mounting lines float.
e. Let the BRUV sink slowly. Make sure that the main line does not get tangled. You will feel a slight slack in the rope when it hits the bottom.
f. Deploy the surface buoys. Make sure they do not get tangled as you throw them in the water.

Data acquisition

8. Wait for the time established in the mission protocol.

9. Complete the station form and metadata.
   a. Record the position of the deployed equipment.
   b. Record the depth of the deployed equipment.
   c. Record the time that the equipment was put in the water.
   d. Record the time that the equipment was retrieved.
   e. Record the weather conditions.
   f. Record any circumstantial information deemed relevant or likely to affect sampling.

Retrieval of BRUV

10. Approach the set (varies according to the type of boat).
    a. Use a grapple or pike pole to retrieve the line of surface buoys.
    b. Run the rope through the lifting device.
    c. Move the boat closer to the site until the main line is vertical.
    d. Pull in the first few metres of the main line up fast enough that the equipment does not drag along the bottom.
    e. Store the line of surface buoys next to the holder, and store the rope in its holder as you retrieve it.
    f. Slow the retrieval of the equipment when you start seeing indicators (15, 10 and 5 m).
    g. Secure the system on the bridge.
    h. Place the buoys on top of the rope holder.

   i. Check that the cameras are still running.
   j. Stop the cameras manually or using the remote control.
   k. Empty the bait cage.

<u>After retrieval</u>

11. Prepare material for the next deployment.
    a. Replace the light batteries.
    b. Check the condition of the external camera batteries and replace them if necessary.
    c. Check available memory card space and remaining recording time. Replace the memory card if necessary.
    d. Wait until you reach the next station, and repeat steps 5 to 9.

<u>At the end of the sampling day</u>

12. Check the equipment
    a. Remove the viewports from the camera housing.
    b. Remove the lights.
    c. Rinse lights and dry thoroughly.
    d. Recover external camera batteries and light batteries.
    e. Recharge all batteries.
    f. Retrieve the memory cards and identify **the associated pairs in the system** and **the enclosure number (e.g., Frame #1 – Camera#1).**

<u>Data retrieval and recording</u>

13. Copy the contents of each memory card to the primary external hard drive.
14. Group the video files according to the station/system/sampling position/camera.
15. Save a copy of the main drive to the spare hard drive.

Recommended file structure

File named according to the mission
- Sampling date
  - File named according to the station
    - File named according to the system (BSVC 1 or BSVC 2)
      - File named according to the housing (C#1)

End of mission

16. Rinse all components thoroughly with fresh water.
17. Disassemble the various components.
    a. Remove the lights and light mounts.
    b. Remove the viewports from the housing.
    c. Install housing guards.
    d. Recover ballast bars and securing pins.
    e. Remove the buoys from the side support ropes.
18. Thoroughly dry all components.
19. Apply oil to the various metal components (mainly the bolts).
20. Store the various components in their transport boxes.
21. Return the buoys, the ballast bars and the buoy line to their respective holders.