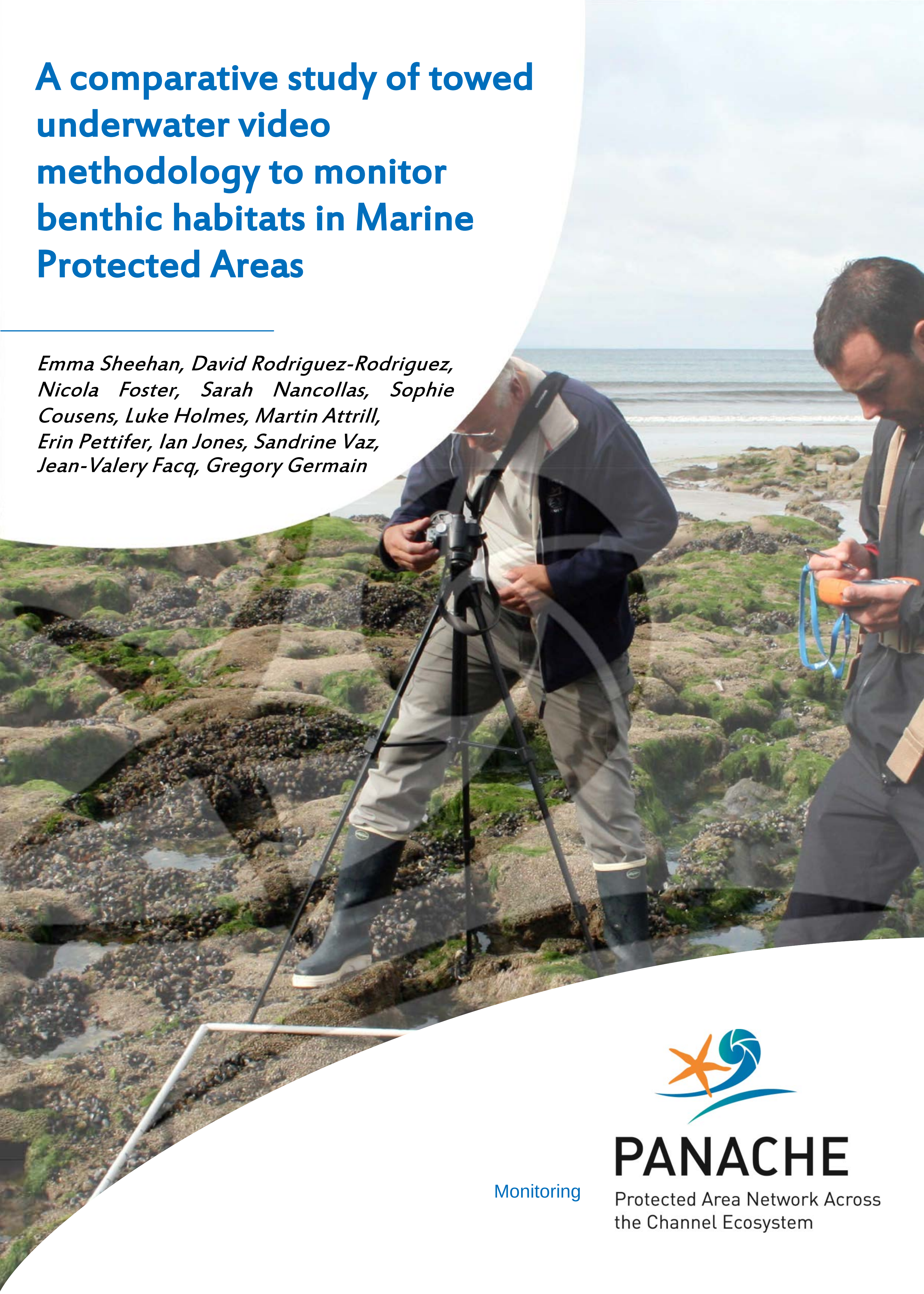
A comparative study of towed underwater video methodology to monitor benthic habitats in Marine Protected Areas

Emma Sheehan, David Rodriguez-Rodriguez, Nicola Foster, Sarah Nancollas, Sophie Cousens, Luke Holmes, Martin Attrill, Erin Pettifer, Ian Jones, Sandrine Vaz, Jean-Valery Facq, Gregory Germain



Monitoring

PANACHE
Protected Area Network Across the Channel Ecosystem

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In the frame of / dans le cadre de

PANACHE

Protected Area Network Across the Channel Ecosystem

Work Package 2

Work quotation: Sheehan, E., Rodriguez-Rodriguez, D., Foster, N., Nancollas, S., Cousens, S., Luke Holmes, Attrill, M., Pettifer, E., Jones, I., Vaz, S., Facq, J.-V., Germain, G. 2014. A comparative study of towed underwater video methodology to monitor benthic habitats in Marine Protected Areas. Report prepared by Ifremer, Sussex IFCA and Marine Institute for the Protected Area Network Across the Channel Ecosystem (PANACHE) project. INTERREG programme France (Channel) England funded project,, 46 pp.
Cover photo: C. Lefeuvre / Agence des aires marines protégées

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This publication is supported by the European Union (ERDF European Regional Development Fund), within the INTERREG IVA France (Channel) – England European cross-border co-operation programme under the Objective 4.2. "Ensure a sustainable environmental development of the common space" - Specific Objective 10 "Ensure a balanced management of the environment and raise awareness about environmental issues".

A comparative study of towed video methodology to monitor benthic habitats in Marine Protected Areas: assessment of gear suitability and data comparability

Une étude comparative de la méthodologie de vidéo remorquée pour la surveillance des habitats benthiques dans les Aires Marines Protégées: Évaluation de la pertinence des engins et de la comparabilité des données

ABSTRACT

Underwater imagery studies are increasingly being used to identify vulnerable communities and ecosystems and help designate and manage marine protected areas (MPAs). This method also provides a valuable range of tools that can be used to assess many descriptors of the Good Environmental Status in European waters.This study tests the use of towed underwater video systems as effective, non-destructive and efficient techniques for the monitoring of marine ecological features within these especially sensitive areas. Three technically different towed video sledges were tested on different seabed types (rocky, mixed ground and sandy) in the same MPA, Kingmere Marine Conservation Zone, West Sussex, UK. Each sled was assessed to compare the different characteristics, strengths and limitations of each device with the aim of providing recommendations on their future use and comparability of data between different systems. Heavy frames are more adaptable in all kind of depth and sea conditions but proved difficult to operate on irregular grounds and were found to significantly impact the seabed. Significant differences in terms of species richness, densities or cover as well species composition were highlighted and are believed to be due to the deployment limits of each gear as well as difference in their optical specifications. Good lighting intensity, and the use of HD resolution are believed to increase the taxonomic power of the video footages. As a result from this study, particular care should be given to sledge and optics specifications when developing a middle or long term MPA monitoring programme.

RÉSUMÉ

L'imagerie sous-marine est de plus en plus utilisée pour identifier les communautés et les écosystèmes vulnérables et pour choisir et gérer des Aires Marines Protégées (AMP). Cette méthode procure également un ensemble d'outils qui peuvent être utilisés pour évaluer plusieurs descripteurs du Bon Etat Environnemental dans les eaux européennes. Cette étude examine l'utilisation d'engins de vidéo sous-marine remorqués en tant que technique efficace et non destructive pour la surveillance d'attributs écologiques marins dans des zones particulièrement sensibles. Trois traineaux vidéo remorqués techniquement différents ont été testés sur différents fonds (rocheux, mixte et sableux) dans la même AMP : Kingmere Marine Conservation Zone, West Sussex, UK. Chaque traineau a été évalué pour comparer les différentes caractéristiques, les points forts et les limitesde chaque engin de façon à émettre des recommandations sur leurs futurs usages et sur la comparabilité des données obtenues par chaque système.Les traineaux lourds sont plus adaptable dans toutes conditions de profondeur et de mer mais ils sont difficiles à utiliser sur des fonds irréguliers et impactent significativement les fonds. Des différences significatives en termes de richesse spécifique, de densité ou couverture ainsi qu'en termes de composition ont été soulignées et sont probablement dues aux limites de déploiement de chaque engin ainsi qu'aux différences dans leurs spécifications optiques.Une bonne intensité d'éclairage, et l'utilisation de résolution HD ont certainement permis d'accroitre la résolution taxonomique des vidéos. Aux vues de cette étude, un soin particulier devrait être porté aux choix des spécifications physiques et optiques du traineau si l'objectif est la mise en place d'un programme de suivi d'AMP sur le moyen ou long terme.

KEYWORDS: Underwater imagery, towed video, MPA designation and management.

MOTS-CLÉS : Imagerie sous-marine, vidéo remorquée, choix et gestion d'AMP

Contents

Rationale

The Protected Area Network Across the Channel Ecosystem (PANACHE) project (PANACHE, 2014) aims at the better understanding and management of the network of marine protected areas (MPAs) in the English Channel (La Manche) by joint actions between French and English organizations.

This report was completed as a result of the second phase of the project's Work Package 2 that deals with the development and trialing of innovative monitoring techniques for MPAs.
Current national (UK Government, 2009; Code de l'Environnement, 2013) and international laws and policies (CBD, 1992; OSPAR, 1992; EU, 1992; EU, 2000; CBD, 2004; EU, 2008) state the need to monitor the status of the marine and coastal environments. Additionally, the inherent complexity to monitor sea submerged features and shortages in financial resources for environmental management (Ehler 2003) make it necessary to develop cost-effective tools for the monitoring of marine features of conservation importance.

This study tests the use of towed underwater video devices as effective, non-destructive and efficient techniques for the monitoring of marine ecological features within these especially sensitive areas. Three technically different towed video sledges were tested on different seabed types (rocky, mixed ground and sandy) in the same MPA, Kingmere Marine Conservation Zone, west Sussex, UK. Each sled was assessed to compare the different characteristics, strengths and limitations of each device with the aim of providing recommendations on their future use and comparability of data between different systems.

The work portrayed here is the result of a collaborative effort between three project partners: the Plymouth University Marine Institute(England, leading partner), Institut français de recherche pour l'exploitation de la mer (IFREMER) (France), and the Sussex Inshore Fisheries and Conservation Authorities (IFCA) (England).

I. Introduction

1.1 Evolution of underwater imagery

The first development of underwater imagery dates back to the end of the nineteenth century with the early use of underwater photography; however, photography and video measurements really took off in the 1940s and 50s (Solan et al, 2003, Shortis et al, 2007, Mallet & Pelletier, 2014). Early scientific effort in the field was often limited to geological studies as underwater imagery was mostly used for ground-truthing acoustic imagery systems for seabed characterisation (Smith and Rumorh, 2013 in Eleftheriou 2013). Since the 1990s, the evolution of the technology has reduced the cost and size of equipment and underwater video has increasingly been used in the field of marine biology (Jonhson et al 2009, Shortis et al., 2007, Dahms and Hwang, 2010, Mallet & Pelletier, 2014).

For such applications, video can be deployed as a "drop camera" for stationary imaging of multiple small areas of the seafloor where each still image represents a videographic sample of the bottom, as a towed unit with continuous video recording along a transect (Grizzel et al, 2008, Rooper, 2008, Tran, 2013), or using remotely operated vehicles (ROV), autonomous underwater vehicles (AUV), or manned submersibles (Fabri et al., 2013). Such studies can develop further into benthic epifaunal assemblage characterisation and distribution, where target species density, activity or overall biodiversity may be explored using underwater video (Manchan and Fedra, 1975; Patterson, 1984; Hugues and Atkinson, 1997).

1.2 Uses of underwater imagery

Human pressures on natural marine resources and the demand for marine ecological services are considered excessive and adverse impacts to vulnerable marine ecosystems have now become of international concern (Fabri et al, 2013). Underwater imagery may therefore be used to map and quantify various indicators of human impacts on marine habitats such as anthropogenic litter, lost fishing gears and trawling and dredging impacts (Fabri et al, 2013; Carbines and Cole, 2009; Smith et al, 2007; O'Neil et al, 2009).

For the management of marine stocks, it is necessary to undertake appropriate resource management strategies based on accurate estimations of population size and structure, and community diversity. Underwater imagery is increasingly seen as a new non-destructive sampling tool to evaluate fish abundance and size spectrum for the management of marine stocks. *In-situ* observations using dropped and towed camera arrays, submersibles or diver operated systems have been developed to this end. Classical applications of underwater video for size and density evaluation included primarily exploited benthic invertebrates, such as shellfish and crustaceans (Larocque and

Thorne, 2012, Rozenkranft and Byerdorfer, 2004; Watanabe, 2002). In order to overcome the difficulty of reliably using video-graphic measurements of fast reacting organisms, a large number of techniques have been deployed to study fish, each with advantages and weaknesses. Diver operated video recording is slowly replacing initial visual census surveys in shallow areas (Pelletier et al. 2013, Holmes et al. 2013, Tessier et al., 2013). Low cost ROVs (Norcross and Mueter, 1999) or towed camera sleds are often preferred for studying benthic fish association to the seabed (Spencer et al., 2005; Stoner et al, 2007; Shucksmith et al., 2006). Towed systems maintained close to the bottom may also be used for demersal fish and be deployed at day or night depending on fish behaviour (Morisson and Carbine, 2006; Assis et al, 2008; Shanner et al., 2009). Drop down cameras usually have low spatial coverage reducing their usefulness for monitoring highly mobile species. In order to circumvent this difficulty, baited cameras attracting carnivorous fish have also been used, although the resulting behavioral and observed assemblage biases are well recognized by its users (Stobbart et al., 2007, Watson et al. 2010; Langlois et al., 2010). As a result this technique is still often used in conjunction with divers' observations. However, further improvements of the drop down design have been proposed, such as the use of a rotating system increasing the observation field with little behavioral impact on the fish and other fauna (Pelletier et al. 2012; Mallet et al., 2014).

Additionally, underwater imagery studies are increasingly being used to identify vulnerable communities and ecosytems and help designate and manage marine protected areas (MPAs) (Fabri et al, 2013, Larocque and Thorne, 2012). The ability to identify and monitor ecological and spatial change within a given MPA is central to conservation management (Tran, 2013). Cost-effective MPA video monitoring programs are being developed to detect management effect on habitats (Sheehan et al., 2013) and on fish abundance and size (Assis et al. 2008, Teissier et al., 2013), helping managers to evaluate and adapt their policies (Stevens et al., 2013). As budgets to survey MPAs are limited (Ehler 2003) it is important that information gathered is cost effective and can be shared between potential users (i.e. organisations, regions and countries). Video data can be archived and can therefore be used in the future for other applications.

This method also provides a valuable range of tools that can be used to assess many descriptors of the Good Environmental Status in European waters, such as: biological diversity (1), non-indigenous species (2), population of commercial fish/shellfish (3), sea floor integrity (6), alteration of hydrographical conditions (7), or marine litter (10) (EU, 2008). Biological MPA effects may be evaluated by monitoring the density and biomass of some targeted species or developing some biodiversity indicators of the health and functioning of the ecosystems (Tessier, 2013).

II. Materials and methods

2.1 Comparison of existing underwater imagery techniques for monitoring MPAs

2.1.1 Broadly used underwater imagery techniques

Marine protected areas (MPAs) are increasingly seen as a management tool to preserve marine biodiversity and other resources and to prevent environmental degradation (Hilborn et al 2004). In tropical or mediterranenean waters, underwater visual census is commonly used to monitor MPAs (Pelletier et al., 2011; Tessier, 2013). However, high quality optical surveys are needed to monitor MPAs beyond the range of safe SCUBA diving operations or under less favourable conditions (Seiler, 2013).

Compared to other platforms for capturing underwater video for habitat mapping purposes, such as Autonomous Underwater Vehicles (AUVs), Remotely Operated Vehicles (ROVs), manned submersibles, or divers' operated video, towed video designs hold some distinct advantages. The technology needed to create a simple camera sled is easily accessible to the untrained professional. A simple camera sled can be constructed, deployed, and maintained for significantly less cost relative to AUVs, ROVs and manned submersibles. When components are simple, camera sleds can be easily maintained and updated with technological advances (i.e., moving to high definition from analog cameras) or with changing project objectives (i.e., from mapping applications to fish density estimation) (Rooper et al 2008). Additionally, it has the advantages of unrestricted bottom time and can survey larger expanses of seafloor compared to SCUBA (Tran, 2013) or drop camera. When water clarity is not limiting, towed video allows straightforward image interpretation and processing, and little or no need for ground-truthing (Grizzel et al, 2008). The size of these sleds is limited only by the ability to deploy and retrieve them successfully at sea, and they can be designed small enough for deployment from a small vessel. They are typically large enough that accessory equipment and sensors can easily be added to the frame. Well-designed camera sleds are also resilient to damage from hitting objects on the seafloor and other harsh conditions at sea because the important components (cameras, lights, etc.) are contained within a protective frame. Camera sleds can also be designed to be more resilient to high currents than ROV or manned submersibles.

The most commonly used design for underwater towed video is a bottom-contacting system using skids or runners. Such a system is often heavily weighted to keep it in contact with the seafloor and cameras are typically mounted facing forward within the sled frame to protect the video equipment from damage (Manchan and Fedra, 1975; Patterson, 1984; Hugues and Atkinson, 1997; Larocque and thorne, 2012, Spencer et al., 2005; Stoner et al, 2007; Shucksmith et al., 2006). The platform stability of bottom contacting sleds allows determination of the size of the field of view of the video camera. However, this sled type is often limited to smooth seafloors and, when the bottom is irregular, it can easily get fouled on obstacles or impact seabeds (Sheehan et al. 2010).

The second available used sled design is a bottom-tending sled (for example see Sheehan et al. 2010). Such a sled is suspended just off the seafloor by the counterbalance of weight and buoyancy, with a tail drag-chain which maintains contact with the sea bed so that it achieves neutral buoyancy at a specified height from the bottom. The sled is typically towed at slow speed or allowed to drift with prevailing currents. Cameras are generally mounted looking forward or downward within the sled frame. The advantage of this type of system is that it can be designed to work over rough or rugged seafloor and has little impact on the seafloor. These systems require more skill to deploy as tuning of the system is required to calibrate the sled to maintain a constant height off the seafloor (Rooper, 2008).

Finally, a fully flying towed design has also been developed for the sole purpose of fish census. These very light, cost effective systems are usually only equipped with a downward facing camera, with or without an associated altimeter, fixed on a fin shaped body (Carabine et cole 2009, Shanner 2009). Such a design may not be very useful for the survey of benthic habitats and is limited to shallow waters since it is not equipped with lights.

2.2 Comparison of the three Towed Underwater Video (TUV) systems tested

Here we introduce the three Towed Underwater Video (TUV) systems for comparison. The largest is a benthic sled with two contact runners the Pagure, funded by the PANACHE project, being trialled by IFREMER. The smallest sled, also operates on two runners and is being trialled by Sussex IFCA. The third sled is a flying array, that has a ground chain and is being trialled by Plymouth University Marine Institute (MI) (Fig. 1).

a) b) c)

Fig.1. Approximate scale comparison of the three TUV for comparison, a) IFREMER, b) IFCA, c) MI.

The userbility, impact assessment and data compariability was compared during a field survey for the PANACHE project. Firstly, a detailed description of each sled now follows and their technical specifications are summarised in a table (see Table 1).

2.2.1 Demersal towed heavy IFREMER

In the context of increasing need for benthic habitat characterisation and monitoring, both for the purpose of an ecosystem approach to fishery management and biodiversity monitoring, the development of an underwater imagery tool, capable of being deployed opportunistically on existing stock assessment surveys, was envisaged. Such gear should be able to withstand all types of sea conditions, currents and depth ranges that are usually encountered during recurrent bottom trawl scientific surveys on the European continental shelf (i.e. down to 600 m depth). It also has to be easy enough to operate so that specialist staff are not required to work it, and it should not to be too cumbersome so that it can be taken on board relatively small (>15 m) research or monitoring vessels as complementary equipment. The optical efficiency of the gear in terms of quantitative census should be such that accurate biodiversity and density indices may be produced in most conditions. Ultimately, its design should be flexible enough so as to keep up with the accelerating pace of improvement of the digital imagery realm.

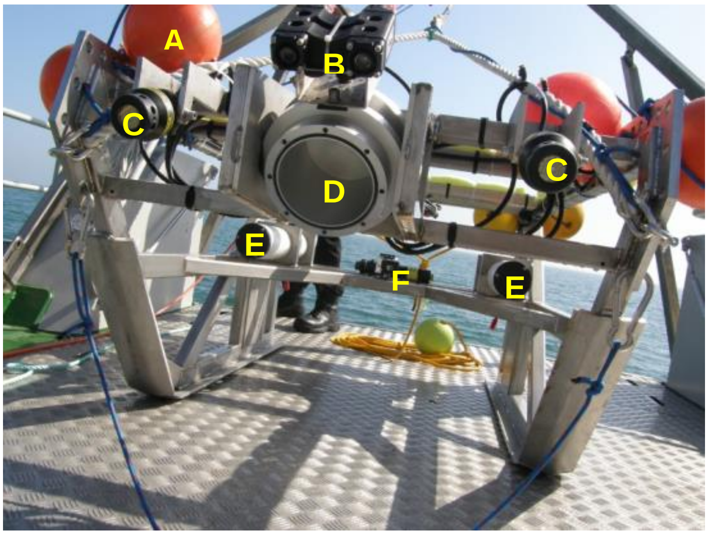


Fig.2. IFREMER's TUV. A = Buoyance aids, B = Lasers, C = LED lights, D = Camera housing, E = Powerpacks, F = GoPro and light.

The system, named "PAGURE" (Fig. 2.), was designed as a benthic sledge that is towed over the seabed to ensure that the surface monitored is relatively constant in every sea condition. This dragged system mostly targets "trawled or trawlable" areas and has little impact on such seabeds as only the two 12 cm wide runners are in contact with the ground. Moreover, its initial weight in water is approximately 150 kg and may be further reduced by the addition of buoys. It is able to survey a range of habitats from small boulders and pebbles to mud and may also be used as fixed frame on bedrock and large boulder areas. The system has no live connection with the surface and only requires a towing rope or cable to be operated. The camera objective is 55 cm above the seabed, which is close enough to identify many mega- and macro-epibenthic species in varying visibility, but still offers a large enough field of view for habitat description. The HD video system comprises a 600 m depth rated anodised aluminium housing able to contain any off the shelf camcorder (here, a Panasonic HC-V700 HD 1920x1080 p -50 fps, with a 32 Gb SD card recording up to 3 hours) positioned at an oblique angle of 35° to the horizontal. Two LED lights (underwater LED SeaLite® Sphere, SLS 5100, 20/36 V, 80 W, 5000 Lumens) are fixed to the sledge on each side of the camera with an appropriate converging angle targeting the entire field of view of the camera to both avoid light reflection of water particles in front the camcorder and casting shadows on the surveyed field. Two laser pointers (SeaLasers® 100, wavelength 532 nm Green) set 10 cm apart (SeaLasers® 100 Dualmount) were also mounted above the camera case to allow size measurement of observed biota. The lights and the laser are connected to two subCtech Li-Ion PowerPacks (25Ah, 24V, ~3h autonomy).A backwards Hero 2 GoPro camera was attached to assess the damage impact of the TUV on the benthic habitat.

2.2.2 Demersal towed light Sussex IFCA

For the current study, Sussex IFCA trialled their new towed underwater video TUV (Fig.3.), specifically purchased for inshore MPA monitoring and gathering evidence to inform management measures within their district. The TUV comprises a small stainless steel sledge system (L=830 mm, W=495 mm, H=430 mm), designed by Salacia Marine and fabricated by C-Mor Marine. Mounted on the sledge, at an oblique angle to the seabed, is a Seacam ultra wide-angle colour camera, an LED light for better definition and colour, and lasers set 20 cm apart for scale. The umbilical is connected topside to a RovTech system topbox comprising a power supply, light control, recording facility and GPS feed. This enables real time footage to be viewed from the surface. A backward facing GoPro was also attached to the sled to enable the assessment of gear impact on the seabed.

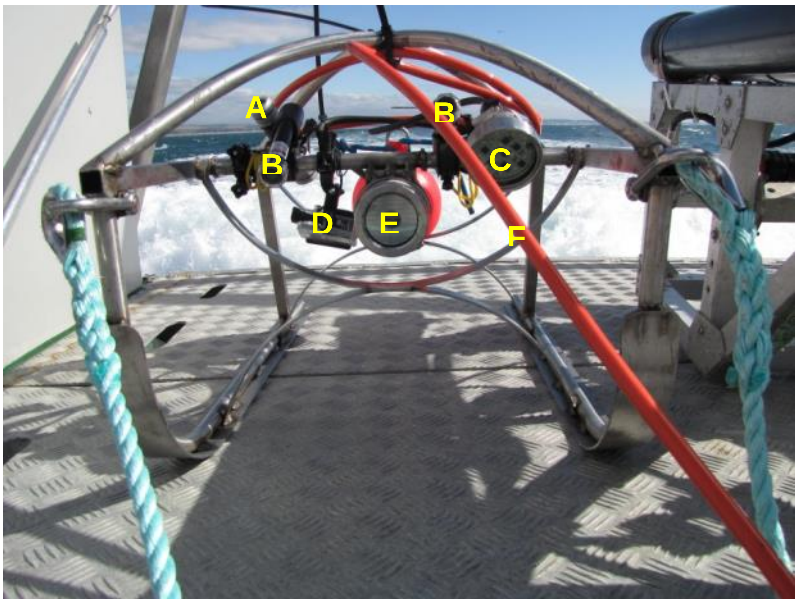


Fig.3. IFCA's bottom towed TVS. A = GoPro light, B = Lasers, C = LED light, D = GoPro, E = Camera and housing, F = Umbilical cord.

Deployment of the Sussex IFCA TUV is simple and requires minimal personnel and training. The lightness of the design means just one person is required on deck for deployment and retrieval, with a skipper and an additional person in the wheelhouse to monitor the footage and record data.

The TUV is designed to be towed along the seabed and the camera is close enough to identify conspicuous epi-fauna and flora and subsequently biotope areas from freeze frames. The system can be utilised over a variety of substrates, from finer sediments to bedrock, cobbles and small boulders, but is vulnerable to snagging or being overturned on larger boulder areas. This small TUV is designed for inshore MPA monitoring within shallower waters as the vast majority of UK sites are located inshore.

2.2.3 Flying array MI

A High Definition (HD) video camera was mounted on a towed flying array to survey benthic communities (Fig.4.) (detailed methods are described in Sheehan et al. 2010 adapted from Stevens & Connolly 2005). The system floats above the seabed and altitude is controlled using a drop-weight between the boat and the sled, and a length of rope that acts as a weak-link between the sled and a drag-chain. The flying system is relatively non-destructive, which is important for sampling protected areas, and is able to survey a range of habitats from bedrock and boulders to sediments without snagging. The height of the sled can be adapted depending on survey requirements and water visibility. The HD video system comprises a camera (Surveyor-HD-J12 colour zoom titanium camera, 6000 m depth rated, 720p) positioned at an oblique angle to the seabed, three LED lights (Bowtech Products limited, LED-1600-13, 1600 Lumen underwater LED) fixed to the array in front of the camera to provide improved image definition and colour, a mini CTD profiler (Valeport Ltd) and two laser pointers (wavelength 532 nm Green) set 30 cm apart. The sled is grounded by a drag chain that can be altered to adjust the height of the sled from the seabed. The umbilical is connected topside to a Bowtech System power supply/control unit, which allows control of the camera, focus, zoom and aperture, and intensity of the lights. The sled is easy to deploy using two to three people, and is best retrieved using a winch or pot hauler.

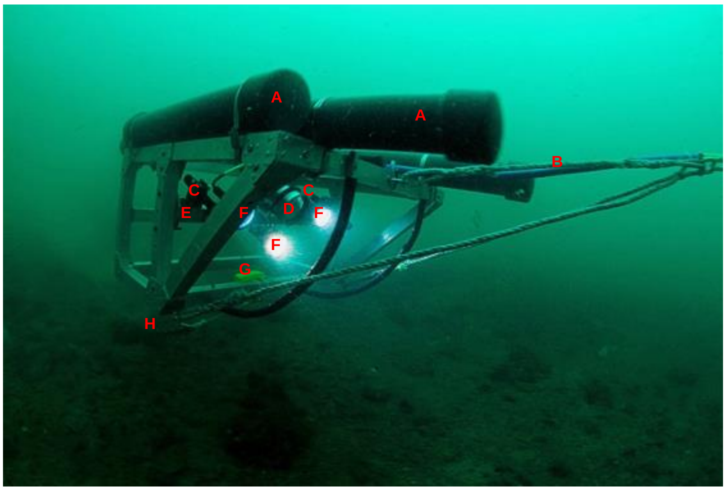


Fig.4. Marine Institute's Flying array. A = Buoyancy aids, B = Umbilical cord, C = Lasers, D = HD Camera and housing, G = Weight, H = Drag chain.

Table1. Technical characteristics of the three towed video systems (TUVs) that were tested.

Specifications	**IFREMER**	**IFCA**	**Marine Institute**
Name	Pagure: Demersal towed heavy	Demersal towed light	Flying array: floating with drag chain
Camera	Panasonic HC-V700 HD (1080p) movies	RovTech RSL portable camera system. Seacam (480p) wide angle camera (colour), standard definition. Max depth: 150 m.	Bowtech HD set to 720p zoom and focus controllable at surface. Max depth 6000 m

Lights	2 x Projecteur LED SeaLite® Sphere de Deep Sea Power and Light Corps. Depth immersion 6000m	1 x Rovtech Seabeam Ultra LED light. Max depth: 150 m	3 x Bowtech LED lamps with light intensity controllable from surface Max depth 3000 m
Lasers	2 x SeaLaser® 100-5 (green), 532nm <5mW. Max depth 2000m	2 x Trident SCUBA lasers (red). Max depth: 50 m	2 x Z-Bolt SCUBA-1 (green). Max depth 60 m
CTD	None	None	Valeport miniCTD rated to 500 m
Frame	Stainless steel sledge designed by IFREMER plus anodised aluminium housing made by BARON Productique (France). Contact with seabed: 2 runners	Fabricated by C-Mor Marine. Based on Salacia Marine / Seafish design Stainless steel. Contact with seabed: 2 runners	40 mm box section aluminium, with ballast tubes to lift from seabed. Fabricated by Plymouth University. Contact with seabed: 1 central chain
Connection topside	No topside connection	1 x 300ft umbilical Bowtech system topbox: sony DVD recorder; mini SD card recorder; GPS feed for overlay; light control	1 x 200m umbilical connected to Bowtech System control unit which allows control of the camera, focus, zoom, apeture, and intensity of lights. This is connected to a CPU and Samsung monitor to view the live video feed.
Power supply	subCtech Li-Ion PowerPacks (25Ah, 24V, ~3h autonomy) powering lights and lasers	Boat mains electrical supply.	2KVA Honda generator through a 1000VA UPS (Uninterrupted Power Supply)
Dimensions	L=1500mm W=1100mm H=740mm	Length=820mm Width=495mm Height=430mm	L=1000mm W=1000mm H=500mm
Total weight	290 kg	9 kg	50 kg
System cost	€14,000	€12,000	€35,000

III. Field test to assess userbility, data comparability and impact assessment between TUVs.

3.1 Materials and methods

3.1.1 Survey design

To compare the userbility and data comparability of the TUVs, all three were deployed over a two week period between 2nd and 13th September 2013. The survey was carried out using Sussex IFCA's 18m Patrol boat "Watchful" (Fig.5) in Kingmere Marine Conservation Zone, an inshore site measuring 48 km^2 (Fig.6), off West Sussex. It has rocky reef, subtidal chalk outcropping reef and sandy habitats. Habitat specific areas to survey were selected from a broadscale habitat map (Appendix 1), echosounder and local knowledge of the IFCA skipper. Three habitat types were selected: Rock (mostly bedrock, but has some sediments/boulders/cobbles), Mixed (boulders and cobbles) and Sand (mostly sand, but has some boulders or cobbles). For each habitat type, two Areas within the MCZ were selected. In each area, three 200 m replicate tows were conducted for each TUV, allowing us to compare video footage between each TUV (Fig.7). Replicate tows were located a minimum distance of 350 m apart to ensure independence between replicates.

To compare userbility of each sled, preselected criteria were assessed during the field test (see Table 2).

To assess data comparability the following response variables were compared between video taken from the three TUV systems: Number of taxa, Abundance (count organisms), Abundance (cover organisms) and Assemblage composition.

To assess impact of each sled on the seabed, backward facing Go-pros video cameras (Hero 2) were mounted on the TUVs and the disturbance to each habitat type was assessed using an ordinal scale designed for this study named Sheehan-Vas-Jones scale of disturbance (see 3.1.4).

Fig. 5. Sussex IFCAs Patrol boat "Watchful" and some members of the PANACHE field survey team.

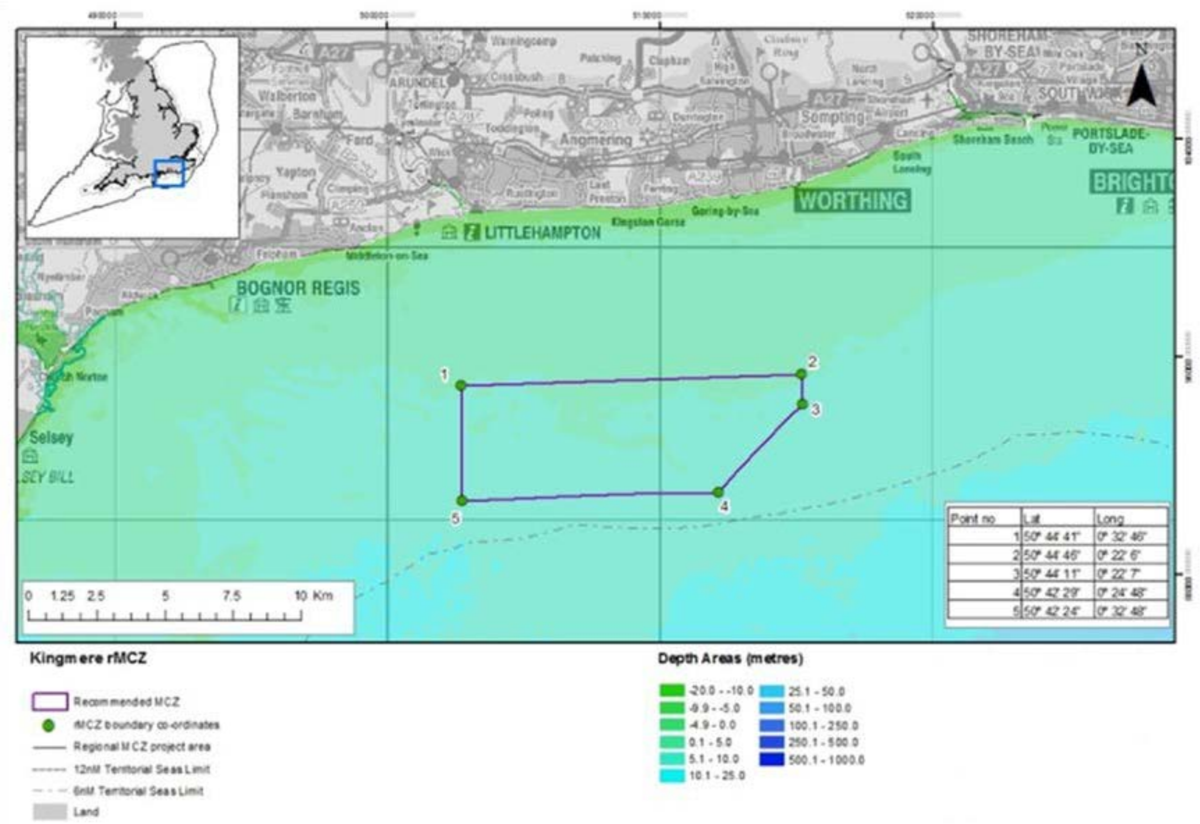


Fig.6. Location of Kingmere MCZ. Information from Ordnance Survey © copyright and database right 2012. Ordnance Survey 100022021. UKHO data © British.

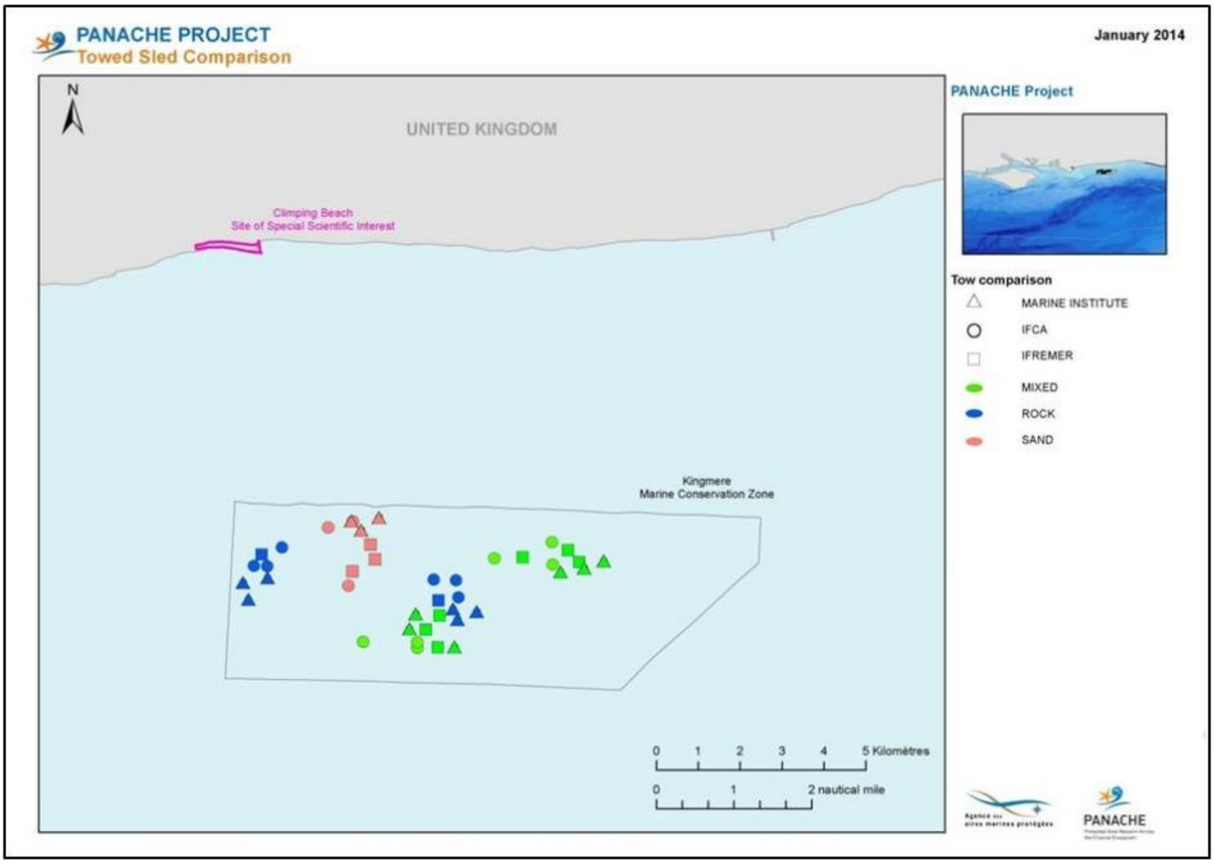


Fig.7. Location of sites within the Kingsmere MCZ.

3.1.2 Video Analysis

To analyze the video, frame grabs were extracted at five second intervals (Cybertronix frame extractor) and a digital quadrat overlaid. This process was successful for IFCA and MI video files, but the IFREMER file type was not compatable with the Cybertronix Frame Extractor and the 3Dive Digital Overlay Software. Freeze frames at 5 second intervals were manually taken from the video and the digital quadrat was overlaid accordingly. Frame grabs were discarded if they were not in focus, overlapped each other, or not on the appropriate habitat. Images would therefore only be selected if the camera was at an oblique angle to the seabed, which reduces potential error that may be introduced as a result of changing seabed slope. However, due to the camera position, many of IFCA's frame grabs included a proportion of open sea, which was noted down. After this process, 10 randomly selected frame grabs were analysed for each transect.

All organisms present were identified to the lowest taxonomic level possible and their abundance recorded. Taxonomically similar species, which could not be distinguished with confidence, were grouped. Such groups included: *Inachus* spp. and *Cerianthus* spp. (identified to genus level); Gobies; Hydroids and Branching sponges. It was concluded that hydroids could not be accurately counted for each TUV and so hydroids were excluded from the Abundance (count) analysis. The category Turf incorporated hydroids and bryozoans that were <1 cm high. Individual or discrete colonial organisms were expressed as densities (individuals m^{-2}). Density was calculated by determining the true frame area for each TUV system. This was done by using the known distance of the laser spacing of each system (IFREMER=10cm, IFCA-20cm, MI=30cm). IFREMER and IFCA have a fixed system where the camera is consistently the same distance from the seabed, so the frame area is the same for all frames. Due to the flying nature of the MI's array, the camera can be different heights from the seabed, so frame area is calculated for each individual frame. Cover-forming colonial taxa were quantified as percent cover by dividing the number of dots from the overlay (16 in total) that each taxa covered by the total number of dots for the quadrat.

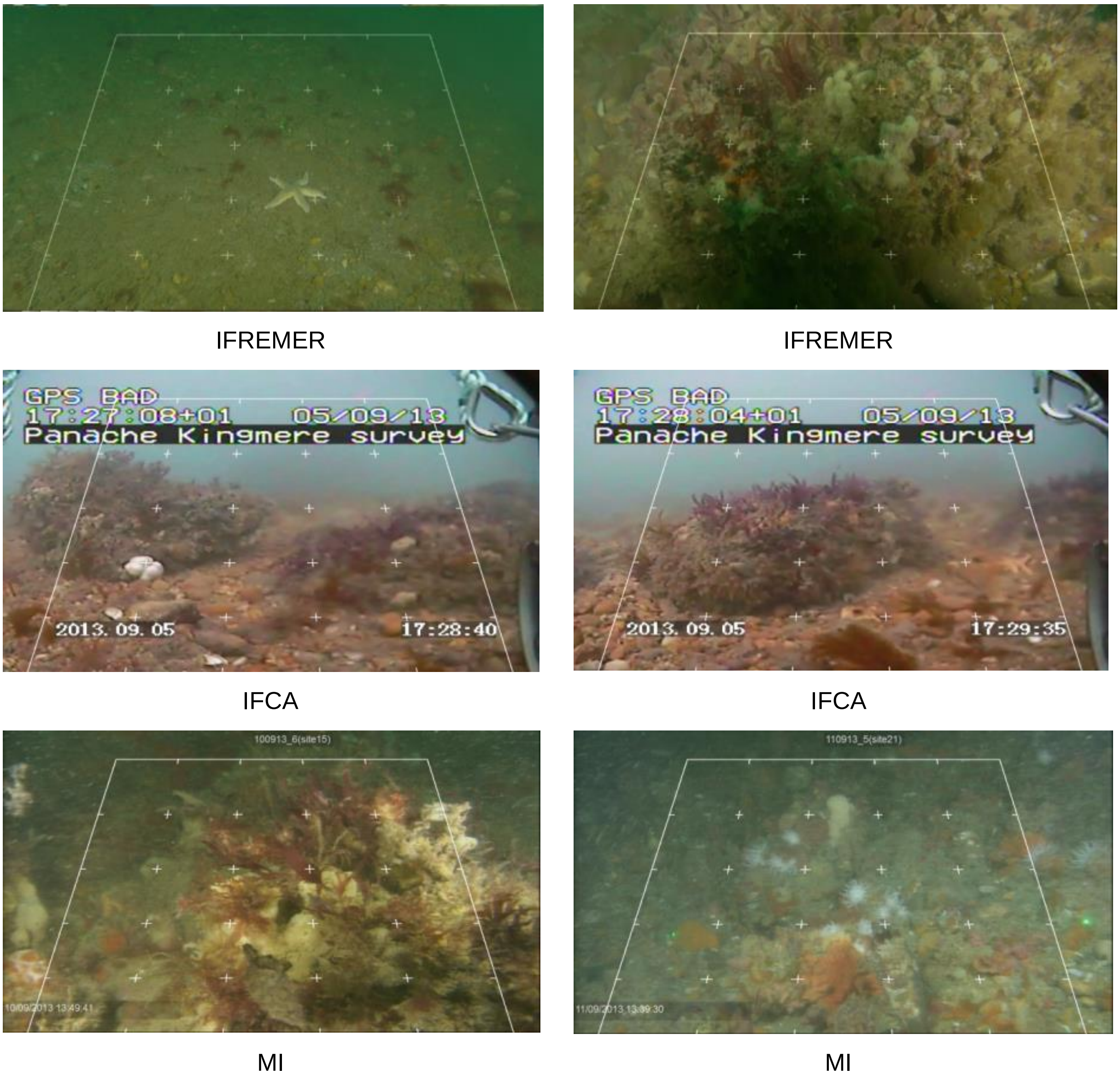


Fig.8. Front facing camera images with the digital quadrat overlay from the three TUVs.

3.1.3 Data Analysis

The null hypothesis of no significant difference between TUV Type and Habitat was examined for the following response variables: Number of taxa, Abundance (count organisms), Abundance (cover organisms) and Assemblage compostion. Univariate (Number of taxa, Abundance (count), Abundance (cover) and multivariate analyses (Assemblage composition) were conducted using Permutational Multivariate Analysis of Variance (PERMANOVA, Anderson, 2001; Clarke, 2001) in PRIMER 6 (Clarke & Warwick, 2001), based on similarity matrices (univariate = Euclidean distance, multivariate = Bray Curtis similarity). Univariate data were Log (x+1) transformed and for multivariate analysis were square root transformed (Anderson and Millar, 2004). Factors TUV Type and Habitat were fixed. The 10 frame grabs per site were averaged to avoid pseudo replication.

3.1.4 Impact assessment

To assess the impact that the TUVs have on the seabed, a secondary backwards facing camera (GoPro Hero 2) was installed on each TUV. For each habitat type, the impact of the TUV was assessed on the Sheehan-Vaz-Jones scale of disturbance: 1 = no impact, 2 = fine sediments resuspended, 3 = cobbles disturbed, 4 = boulders disturbed and 5 = visibility impaired due to disturbance. Grain size was according to the Wentworth Scale, where fine sediments were <64mm, cobbles were 64-256mm and boulders were >256mm (Irving, 2009). The scale of disturbanceis cumulative (not including 1), e.g. if score 3 is awarded for cobbles being disturbed, this suggests that sediments are also being resuspended. Five observations of 1 minute each were made throughout each tow on each habitat type. A score from the Sheehan-Vaz-Jones scale was allocated to each minute measurement based on visual assessment of the disturbance being caused. These scores were then corrected to account for points of contact for each TUV on the seabed, assuming that runner contact is having double the impact as a single point and that this impact will extend laterally beryond the camera frame. Both IFREMER and IFCA have one point for each runner, so the impact score is multiplied by 2. MI only has 1 point of contact so the score is not altered.

1	2	3	4	5
No impact	Fine sediments disturbed	Cobbles disturbed	Boulders disturbed	Visibility reduced due to impact caused

Fig.9. The Sheehan-Vaz-Jones scale for damage impact. Images from backward facing GoPro camera.

3.2 Results from testing

3.2.1 Userbility of devices

Each of the three TUV systems were successfully assessed for their userbility. The details are summerised below in Table 2.

Table 2. The main operational results from the deployment of the three devices.

Operations	**IFREMER**	**IFCA**	**Marine Institute**
Average number of 200 m tows per 8 hour day	6-8	8-10	8-10
Min. personnel	2 + skipper	1 + skipper	2 + skipper
Vessel requirements	15 m vessel with gantry, 2 x winches capable of lifting 300 kg	No winches necessary. TUV lowered by hand	Winch/pot hauler capable of lifting 50 kg
Environmental tolerances	Force 7 No current restriction	Force 2 ≤ 1 knot tide	Force 6, < 2.5 knot tide
Ease of deployment	*Moderately difficult:* Deployment requires two winches under all scenarios. Simple setup of bridle and warp.	*Easy:* Deployed by hand. Can be deployed by 1 person, though 2 people optimal for cable management. Simple setup of bridle and warp.	*Moderately difficult:* Can be deployed by hand in shallow waters, requiring a winch or pot-hauler in deeper waters. Complicated setup with drop-weight and buoys.

Operator skill required	*Moderate – low*: Minimal skill required as camcorder is used to capture video, requiring only single button operation. Assessment of visibility only possible following tows or with the use of supplementary equipment.	*Moderate*: Dependent on bottom type. In rocky areas, sled must be lifted from seabed if large obstacles encountered, requiring one operative to monitor live feed and instruct crew on the deck.	*Moderate – High*: Light intensity, zoom and focus operable from surface, requiring a period of familiarisation with topside equipment for inexperienced users.

3.2.2 Sampling results

All three TUVs successfully surveyed all habitat areas within Kingsmere MCZ. 80 taxa from 9 different phyla were recorded. Common taxa on sand included hydroids and the sand mason *Lanice conchilega. L. conchilega* was also common on mixed ground along with the calcerous tube worm *Spirobranchus triqueter* and dead man's fingers *Alcyonium digitatum. A.digitatum* were also common on rock habitat, along with several algae and bryozoan species such as *Phyllophora crispa* and *Cellaria fistulosa.* Within this section we will firstly assess the quality of the video that was analysed and then present the results from data comparaibility (number of taxa, abundance mean count, abundance mean cover, and assemblage) and impact assessment.

a) Quality of video

A range of criteria are assessed below to review the quality of video recorded using the three TUV systems.

Table 3. Range of criteria assessd to determine quality of video recorded. Quality range: 1 = poor; 2 = intermediate; 3 = excellent.

Feature	**IFREMER (15/24)**	**IFCA (12/24)**	**Marine Institute (22/24)**
Speed of video footage	1 (very fast in places)	2 (fast in some areas)	3 (generally good and steady)
Camera angle	3	1 (points outwards)	3
Image quality (seabed/organisms in focus)	3 (excellent)	1 (very poor, pixelated, out of focus)	2 (out of focus sometimes)
Information on screen (e.g time, GPS, file name)	2 (no info)	1 (too much info)	3
Ease of species identification	3	1	2
Ease of extracting frame grabs	1	3	3
Ease of manipulating video speed during playback	1	1	3
Live camera feed to surface	1 (no live feed)	2 (only tiny screen)	3

b) Number of taxa

Trends in the number of taxa observed differed between TUVs and Habitats (Fig.10; Table 4). On Rock, the MI TUV recorded significantly more taxa than the other two TUVs (IFREMER 15.5 m^{-2} ± 0.25; IFCA 11 m^{-2} ± 0.8; MI 21.8 m^{-2} ± 0.6). However, only two transects out of the 6 initially planned were available for IFREMER TUV due to the difficulty of deployment of this gear on rocky grounds. On Mixed ground, the number of taxa for the IFREMER and MI TUVs were similar and both were greater than the number of taxa observed using the IFCA TUV (IFREMER 14 m^{-2} ± 0.7; IFCA 4.2 m^{-2} ± 0.6; MI 12.8 m^{-2} ± 0.7). On Sand, however, the number of taxa observed was similar for all three TUVs (IFREMER 10.3 m^{-2} ± 0.4; IFCA 7.7 m^{-2} ± 0.7; MI 8.3 m^{-2} ± 1.1).

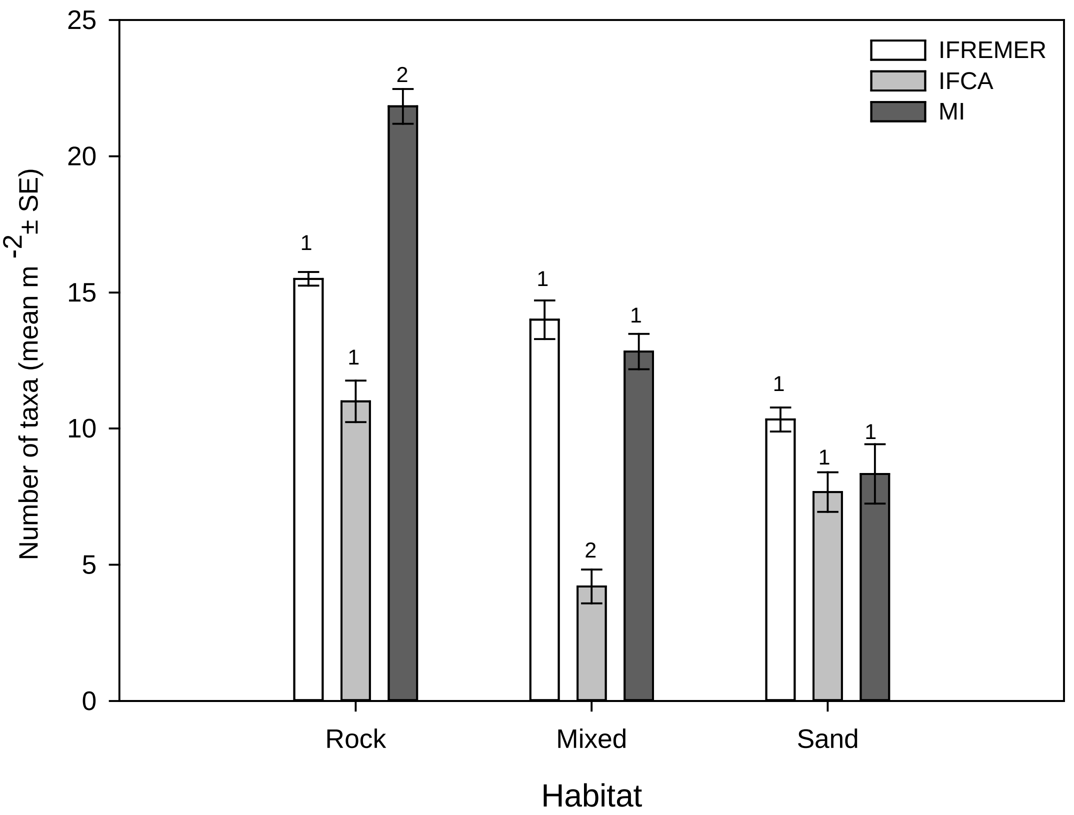


Fig.10. Mean number of taxa observed (± SE) using footage from each TUV (IFREMER, IFCA, MI) on three habitat types (Rock, Mixed, Sand). Different numbers indicate statistically significant difference (P<0.05).

Table 4. Permanova to test the differences in number of taxa between Habitat type and TUV. Pairwise tests were used to examine significant interactions between fixed factors. Bold values indicate significant differences.

		Number of taxa			
Source	*df*	SS	MS	*F*	*P*
TUV TU	2	3.6768	1.8384	19.047	**0.0001**
Habitat Ha	2	2.8905	1.4453	14.974	**0.0001**
TU × Ha	4	1.4154	0.35384	3.6661	**0.0158**
Residual	31	2.9921	9.6518E^{-2}		
Total	39	10.975			
		Pair-wise for term TUV x Habitat within level Rock of factor Habitat type		*t*	*P*
		IFCA, IFREMER		1.2191	0.3291
		IFCA, Marine Institute		3.8813	**0.0022**
		IFREMER, Marine Institute		2.97	**0.0342**
		Within level Mixed of factor Habitat type			
		IFCA, IFREMER		5.4358	**0.0029**
		IFCA, Marine Institute		5.0225	**0.0032**
		IFREMER, Marine Institute		0.64406	0.5536
		Within level Sand of factor Habitat type			
		IFCA, IFREMER		1.2417	0.4974
		IFCA, Marine Institute		0.10622	0.9008
		IFREMER, Marine Institute		0.74687	0.6918

c) Abundance (count)

Trends in the mean count of abundance differed between TUVs and Habitats (Fig.11; Table 5). Although not significantly so, the IFREMER TUV generally yielded the highest abundance counts. The IFCA and MI TUVs were significantly different between habitat types ($P<0.05$), with MI having a greater abundance than IFCA in all habitat types. Abundance (count) was greater on the Rock habitat than Mixed and Sand for all TUVs (Rock: IFREMER 72.5 m^{-2} ± 10.6; IFCA 51.9 m^{-2} ± 6.7; MI 67.1 m^{-2} ± 2.5; Mixed: IFREMER 30.1 m^{-2} ± 6.0; IFCA 12.5 m^{-2} ± 3.7; MI 23.3 m^{-2} ± 3.4; Sand: IFREMER 43.2 m^{-2} ± 3.1; IFCA 13.3 m^{-2} ± 2.2; MI 19.8 m^{-2} ± 0.3).

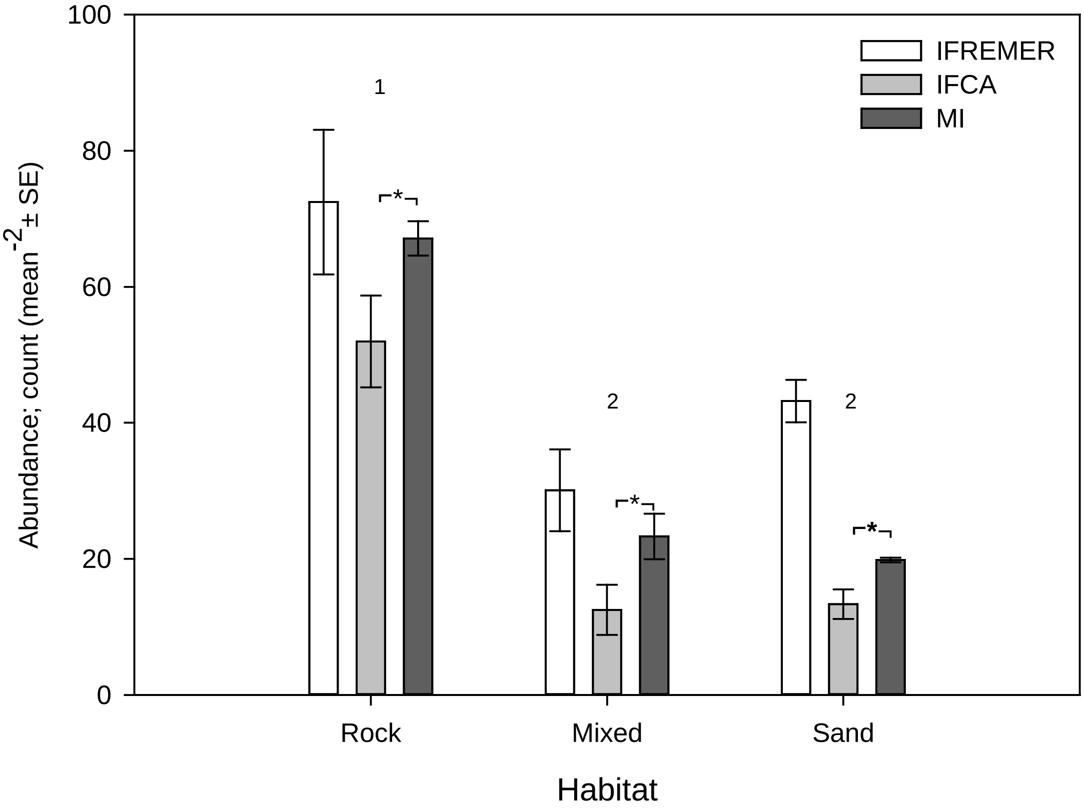


Fig.11. Mean (± SE) abundance of organisms(excluding hydroids) between each TUV on different habitat types. Asterisk indicates significance between TUVs, numbers indicate significance between habitat types.

Table 5. Permanova to test the differences in Abundance (count; excluding hydroids) between Habitat type and TUV. Pairwise tests are used to examine significant interactions between fixed factors. Bold values indicate significant differences.

		Abundance; count			
Source	*df*	SS	MS	*F*	*P*
TUV TU	2	3.2864	1.6432	3.7236	**0.0385**
Habitat Ha	2	15.371	7.6856	17.416	**0.0002**
TU × Ha	4	1.0761	0.26902	0.60961	0.6582
Residual	31	13.68	0.4413		
Total	39	33.414			
		Pair-wise for TUV		*t*	*P*
		IFCA, IFREMER		1.958	0.064
		IFCA, Marine Institute		2.3755	**0.0255**
		IFREMER, Marine Institute		0.10453	0.9164
		Pair-wise for Habitat			
		Mixed, Rock		5.2299	**0.0001**
		Mixed, Sand		1.2752	0.2161
		Rock, Sand		5.7649	**0.0001**

d) Abundance (cover)

Trends in the abundance of colonial organisms observed differed between TUVs and Habitats (Fig.12; Table 6). On Rock and Mixed ground, the mean abundance cover for the IFREMER and MI TUVs were similar and both were greater than the mean abundance cover observed using the IFCA TUV (Rock: IFREMER 34.9 m^{-2} ± 4.1; IFCA: 3.9 m^{-2} ± 0.7; MI: 41.8 m^{-2} ± 1.4. Mixed: IFREMER 15 m^{-2} ± 0.75; IFCA: 1.75 m^{-2} ± 0.65; MI 21.6 m^{-2} ± 2.2). On Sand, however, the mean abundance cover was similar for all three TUVs (IFREMER: 2.5 m^{-2} ± 0.4; IFCA 0.2 m^{-2} ± 0.1; MI 1.0 m^{-2} ± 0.1).

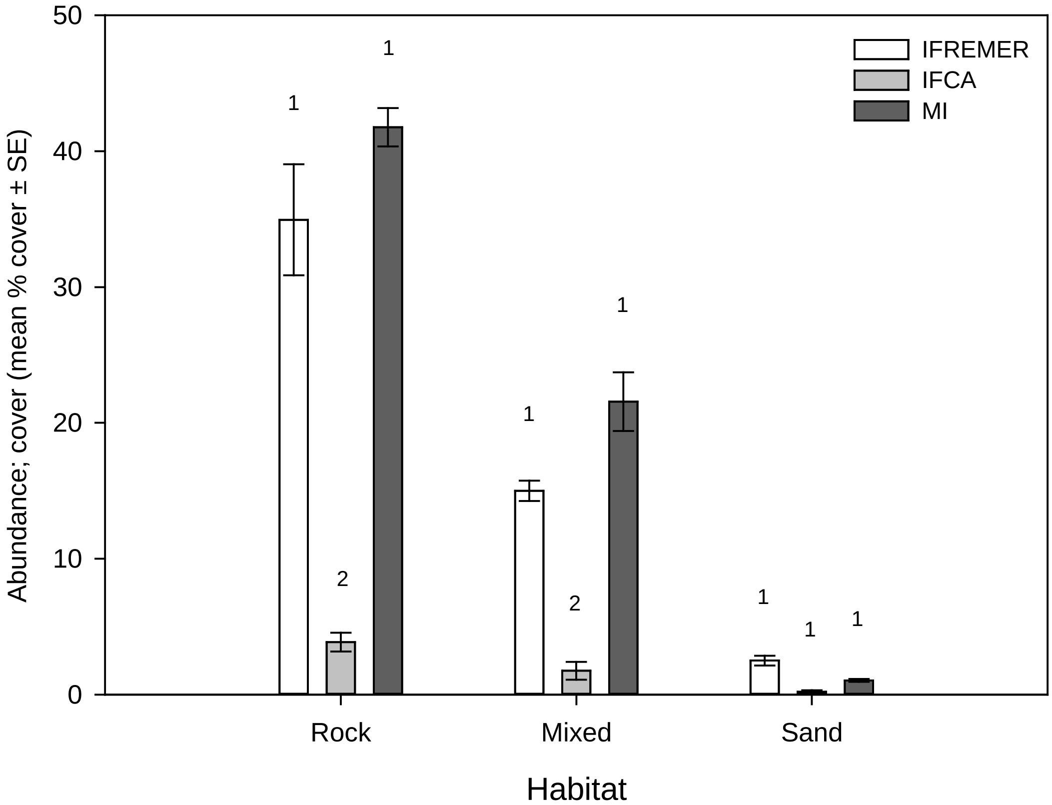


Fig.12. Mean percentage cover (± SE) of encrusting species by each TUV on the different habitat types. 1 shows similarity 2 shows significant difference.

Table 6. Permanova to test the differences in Abundance (cover) between Habitat type and TUV. Pairwise tests are used to examine significant interactions between fixed factors. Bold values indicate significant differences.

		Abundance; cover			
Source	*df*	SS	MS	*F*	*P*
TUV TU	2	32.294	16.147	55.731	**0.0001**
Habitat Ha	2	25.066	12.533	43.257	**0.0001**
TU × Ha	4	4.1803	1.0451	3.607	**0.0174**
Residual	31	8.9817	0.28973		
Total	39	70.522			
		Pair-wise for term TUV x Habitat within level Rock of factor Habitat type		*t*	*P*
		IFCA, IFREMER		3.3489	**0.0353**
		IFCA, Marine Institute		6.6206	**0.0017**
		IFREMER, Marine Institute		1.2017	0.2869
		Within level Mixed of factor Habitat type			
		IFCA, IFREMER		5.8165	**0.0013**
		IFCA, Marine Institute		5.789	**0.0024**
		IFREMER, Marine Institute		1.2614	0.2378
		Within level Sand of factor Habitat type			
		IFCA, IFREMER		3.8631	0.0978
		IFCA, Marine Institute		2.7749	0.2033
		IFREMER, Marine Institute		2.0817	0.2962

e) Assemblage composition

The assemblage composition between each habitat was siginificantly different (Fig.13 nMDS, Table 7) Assemblages recorded from each sled sled were also significantly different. However, the two larger TUVs record more similar assemblages based on clustering observed in the nMDS (Fig.13) than the smaller TUV.

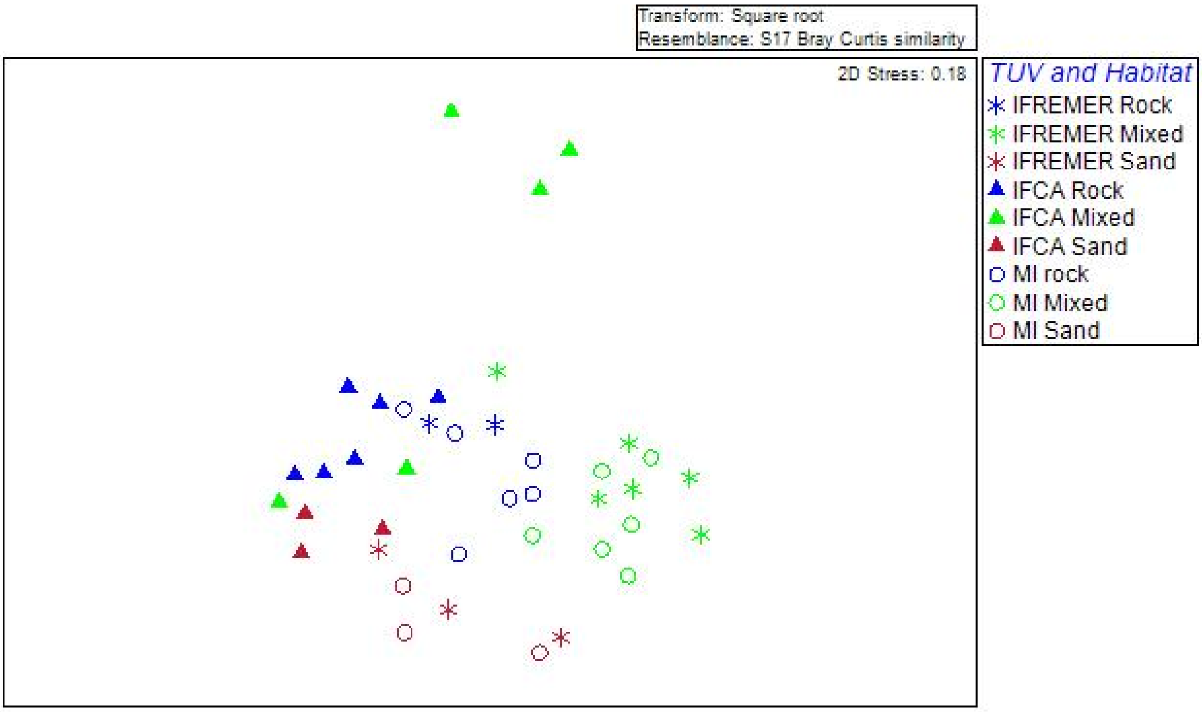


Fig.13. nMDS ordination illustrating similarities in Assemblage Composition between TUV and habitat types (as displayed on the key).

Table 7. Permanova to test the differences in Assemblage composition between Habitat type and TUV. Pairwise tests are used to examine significant interactions between fixed factors. Bold values indicate significant differences.

		Assemblage			
Source	*Df*	SS	MS	*F*	*P*
TUV TU	2	20193	10097	7.1415	**0.0001**
Habitat Ha	2	26103	13007	9.1999	**0.0001**
TU × Ha	4	7486.5	1871.6	1.3238	0.0788
Residual	31	43827	1413.8		
Total	39	97520			
		Pair-wise for TUV		*t*	*P*
		IFCA, IFREMER		2.6453	**0.0001**
		IFCA, Marine Institute		3.2899	**0.0001**
		IFREMER, Marine Institute		1.5804	**0.005**
		Pair-wise for Habitat			
		Mixed, Rock		2.9712	**0.0001**
		Mixed, Sand		2.9341	**0.0001**
		Rock, Sand		3.2541	**0.0001**

3.2.3 Impact data from GoPro footage

Qualitative observations on the disturbance of each TUV on the different habitats are summarised below. Scores given based on the Sheehan-Vas Jones scale of disturbance are the mean and standard error of all observations on each particular habitat type for each sled that are corrected for points of imact from the TUV (IFREMER and IFCA x 2, MI x 1).

a) IFREMER

This TUV resulted in difficulties in visually assessing the damage impact as often the sediment cloud was so much that it was not possible to see the seabed. The rocky ground in Kingsmere MCZ was bouldery and consequently this TUV was not suitable for ground this hetereogenous. Due to this, IFREMER only completed 2 replicates on rock rather than 6. It was unable to obtain 5 x 1 minute sections for analysis for each transect on the target habitat. When the TUV did come into contact with boulders, the size and the weight dislodged or scraped some encrusting and sessile species (such as sponges), thus, it received a mean score of 4.75 on the Sheehan-Vaz-Jones scale - a mean total of 9.5 when corrected for points of contact. Mixed ground was the best habitat type for this TUV and was slightly better for visibility, but overall it was still difficult to assess damage impact. Where visibility was clear, trenches were noticeable from the runners (Fig.15) - overall the TUV scored a mean value of 8.9. On sand it was very difficult to see any damage impact, as the plumes caused from disturbed sediments clouded the field of view. Due to a lack of visibility on Sand, this TUV scored a mean score of 9.6 on the corrected Sheehan-Vaz-Jones scale.

b) IFCA

With this TUV being relatively light, the damage impact overall from this sled was low. On rock, this sled was not heavy enough to keep contact with the big boulders, and as a result it flew through the water column and did not spend much time on the seabed. Occasionally, it would collide into boulders, which caused damage to some sponge species and ross coral *Pentapora foliacea*. However, because of the weight of the TUV, it rarely disturbed boulders - so received a mean score of 6.53. On mixed ground, this TUV was lighter than the MI and IFREMER counterparts and it generally ran across the top of cobbles, only dislodging them occasionally - it had a mean score of 4.8. On sand, it received a mean score of 4 on the corrected Sheen-Vaz-Jones Scale as it disturbed fine sediments, but only created small plumes. This TUV also dislodged some algae, which were caught on the runners.

c) MI

This TUV was the most consistent on all habitat types. The advantage of the MI TUV was that it only had one point of contact with the seabed and followed the path of least resistance. This TUV flew better over the rocky seabed than the other TUVs, consistently staying on the seabed. Occasionally, this sled disturbed a boulder when the chain got stuck, but this was rare and generally boulders were undisturbed. The chain caused some disturbance, dislodging some sponges and ross coral. This gave it a mean score of 3.47. The chain from the TUV was relatively heavy as it was sampling through large spring tides, which meant on mixed ground cobbles were disturbed fairly frequently - giving this habitat a mean score of 3. When this sled is using during weaker neap tides, then lighter chain is used, which would cause less damage. The damage impact from this TUV on sand was relatively low, with a mean score 2 on the corrected Sheehan-Vaz-Jones scale as it disturbed fine sediments, but only created relatively small plumes. Other damage caused was the dislodgment of some algae growing in the sand.

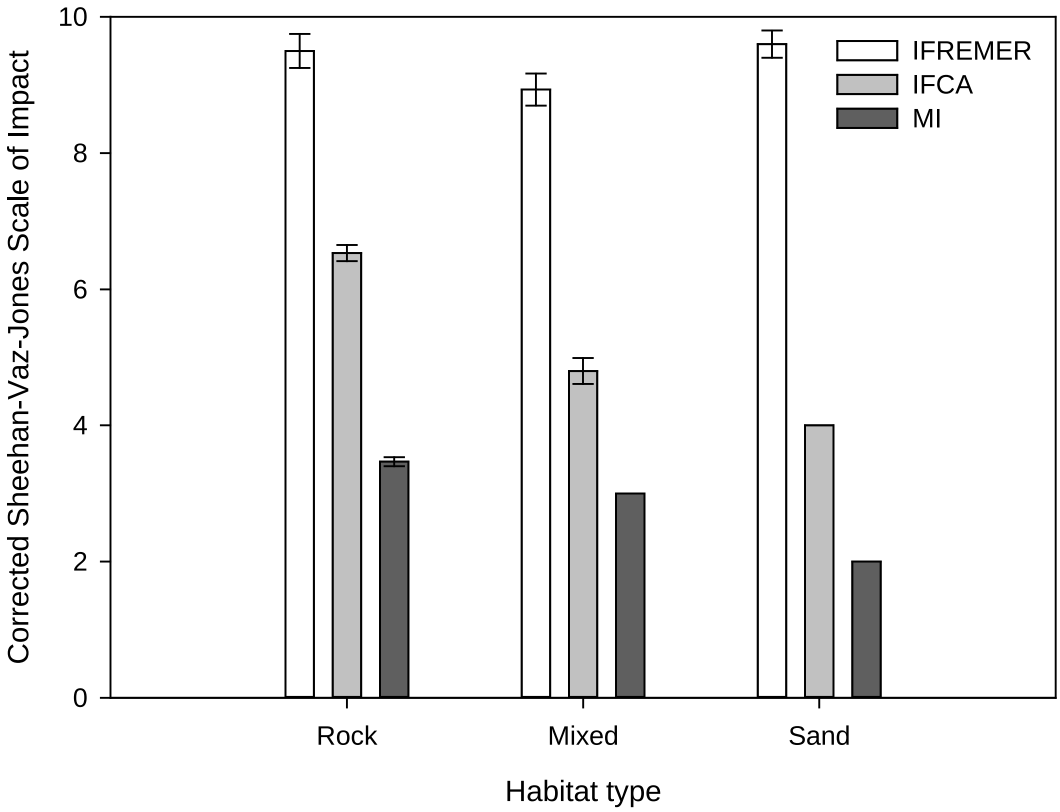
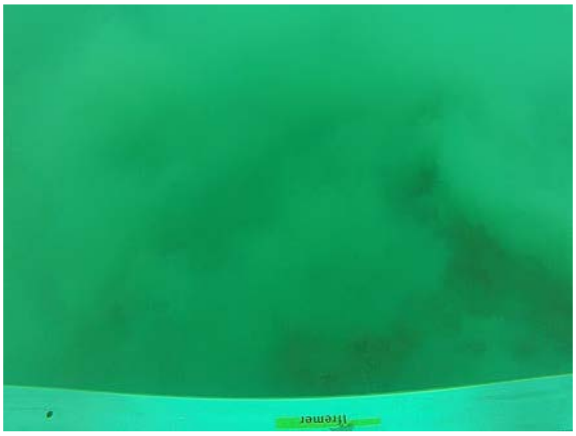
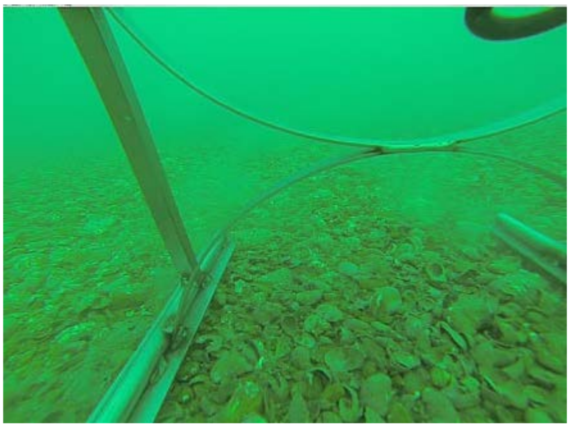


Fig.14. Graph showing the mean (± SE) of damage impact based on the Sheehan-Vaz-Jones scale, corrected for points of impact, of each sled on the different habitat types.

IFREMER on mixed ground.



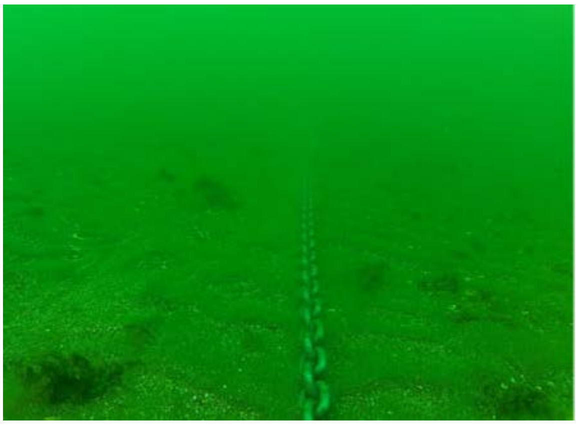
IFREMER on sand.



IFCA on mixed ground.

IFCA on sand.

MI on mixed ground.



MI on sand.

Fig.15. Comparison of the three TUVs on mixed ground and sand.

IV. Recommended methodology

Significant differences in term of species richness, densities or cover as well species composition were highlighted between each of the three gears. Some of these differences are due to the deployment limits of each gear (IFREMER TUV could not be adequately deployed on rocks, SIFCA TUV was often too light and unstable to yield exploitable images). However, some of these differences may also be related to differences in the surface of vision field (higher for MI TUV) and the camera resolution (higher for IFREMER TUV). Particular attention should be given to the sledge (and the resulting video footage) stability, although heavier frame are more difficult to operate on irregular grounds and were found to significantly impact the seabed. Also, good lighting intensity, and the use of HD resolution is believed to increase the taxonomic power of the video footages. The effect of the resolution was already highlighted in the Soufflet (2013) study comparing analogue and HD cameras fixed on the same drop down system and which concluded that even with a smaller vision field and poorer lighting, HD camcorder (1080p) yielded better results than analogue cameras (720p).

As a result from this study, particular care should be given to sledge and optics specifications when developing a middle or long term MPA monitoring programme. Considering their significant impact on the data extracted from the video footage, it is not recommended to change the gear specifications over the monitoring period if the purpose of the study is to detect trend over time.

4.2 Lessons learnt & recommendations

Each TUV system was found to have positive and negative points that depend on survey conditions. It is therefore not possible to conclude which TUV is best for all benthic surveys. Below, is a summary of how each of the TUV systems performed and as a result of the trial what modifications will be made to improve the design for future MPA monitoring.

4.2.1 IFREMER

The IFREMER TUV design was driven by the will to use it as a complementary tool in pre-existing monitoring surveys, and particularly on stock assessment surveys. The knowledge of the conditions of work experienced during such surveys greatly constrained its design as it had to be heavy and robust enough to be used on a wide range of depths, seabed types, currents and weather conditions. Complementary testing has already confirmed that the IFREMER TUV could probably be used safely in sea conditions up to Force 7 and in any type of current, as long as it is towed against it.

The present study was the first trial of the IFREMER TUV at sea and highlighted many areas that needed improvement. Although heavier and larger than the two other devices tested in the present study, the IFREMER TUV is not too cumbersome relatively to other types of gears usually taken on board stock assessment surveys, which often require vessels larger than 15 m, and should not pose storage difficulties on deck in most cases. However, on vessels that are not equipped for towing heavy gear, its deployment may become problematic as it requires at least a gantry and two winches capable of lifting 300 kg. The ease of its use and deployment also ensure that no specialised member of staff is required to deploy it during on-going surveys as additional manpower is often difficult to obtain (in terms of limited financial and ship capacity). Nevertheless, the visualisation of the IFREMER TUV impact on the bottom revealed that it was unnecessarily heavy for these conditions of use (low currents, shallow areas). Thus, it was decided to lighten it for future use, in particular in sensitive areas such as MPAs. The addition of trawl floats (several spherical plastic buoys of 4 l each equivalent to 2.5 l of buoyancy) further reduced its weight in the water and its impact on the seabed. Due to being primarily designed for use on stock assessment surveys, the IFREMER TUV was mostly aimed at seabeds with soft sediment. It may be difficult to operate on hard substrata (such as large boulders or canyons) although it was found to be capable of operating over low lying rocky grounds and boulders lower than 1 m in height. However, in such conditions, both the impact of the runners on the habitat and the risk of damaging or even losing the sledge are increased. To compensate for this particular weakness, the frame was designed to allow its use for still vertical drops.

Following this survey, the video quality acquired was greatly improved by using the integrated stabilisation capabilities (hybrid OIS +) of the camcorder. Furthermore, the field of view was enlarged by decreasing the horizontal angle of the camera to 29° and by the addition of a wide angle conversion lens (Panasonic VW-W4607H x0.7, 46mm Adapter Ring), which both result in an apparently reduced projection speed. The towing speed on the bottom was found to be optimal between 0.8 and 1.2 knots, while the tow length was found to depend on both the depth and the weight of the tow or cable used (shooting between 1.5 and 3 times the sounded depth for a 16 mm diameter trawl cable or a 10 mm, 9 t rated, nude dyneema rope, respectively). Operations using this new setting and protocol are believed to greatly improve subsequent image analyses and the visible underwater surfaced is $4.8 m^2$. The use of a supplementary HD HERO2 GoPro (960p-50fps, with a 32Gb SD card recording up to 5 hours) in its original diving case aiming forward between the runners was found to be very useful and a 600 m depth rating casing was developed to perpetuate its regular use. The GoPro camera allows the monitoring of both the impact and the trim of the IFREMER TUV and the subsequent adjustment of its buoyancy and height of “attach point” to all kind of depth and towing cable weight. Further to this improvement of the gear behaviour, new optical gears were added to obtain more information on the nature of the seabed and increase the resolution of the information obtained for small biotas. A vertical still camera (Canon G15, fitted with a 4Gb SD card recording up to 240 still images) and 2 flashs (Vivitar 285HV), were fitted into appropriate casings at a 70 cm height (underwater surface 63 x 44 cm. Flashes are slaved to the camera through wired connections and powered by a Williamson Electronique Li-Ion pack (9.6Ah, 7.5V converted to 6V, about 800 flash autonomy) enclosed in the camera casing. The camera time lapse and resolution is programmed using Canon Hack Development Kit and adequate scripting. An oblique 532nm Green Line Laser Module (AGLL2, 0.3A) powered by a Williamson Electronique Li-Ion pack (2.6Ah, 4.2V converted to 3V, about seven hours of autonomy) was also added, aimed at the still camera vertical field to allow measurement of the seabed complexity (O'Neill et al, 2009). For this particular application, the HD HERO2 GoPro may be enclosed in the still camera casing to capture the change in the shape of the projected beam line along the transect. This may also allow detection and measurements of physical impacts encountered on the bottom and filmed with the forward facing HD camcorder. The IFREMER TUV frame is also large enough to accommodate other types of sensors, such as CTD probes or small supra benthic nets. Finally, the question of the accurate positioning of the videos to allow crossing with seabed morphometric layers produced by multibeam echosounders and side scan sonar is also particularly important and the addition of an underwater acoustic positioning device may be envisaged, although the cost of such piece of equipment is high and its use requires careful calibration on-board each ship.

Another difference with the two other gears tested in this survey is that there is no live link to the vessel during the deployment. The success of the operation can only be assessed after the retrieval of the system and in situations when adjustments are needed, it may constitute a loss of time at sea. However, the use of an optical cable, ideally also capable of powering and towing the sledge, at depths down to 600 m was deemed far too expensive and cumbersome for this particular application.

4.2.2 IFCA

Following the current study, and comparisons with the IFREMER and MI TUV, a number of potential modifications to the available Sussex IFCA systems were highlighted.

This study was the first trial of the new Sussex IFCA RovTech system and sledge at a site further from the coast. Whilst still within the inshore area, Kingmere is between 5 and 10 km from the coast, at depths of up to 20 m and encompasses some raised rocky reef, with boulders of up to 3 m high. This trial demonstrated limitations with the new IFCA TUV's configuration for monitoring MPA sites further from the coast. At depth, over rocky ground, it was found that the sledge snagged on rocks, was vulnerable to overturning and was difficult to land on the seabed in greater than a Force 2 and at tides of more than 1 knot. This may be due to a combination of factors, primarily the lightness of the system, which is designed for use in shallower waters. In addition, the Sussex IFCA vessel Watchful is relatively large at 18 m. It can be harder to control the speed of larger vessels, while smaller vessels are easier to keep on station in any kind of weather. A new warp and umbilical were also utilised which are both likely to have had twists in, further contributing to the sledge turning and its instability.

A similar system deployed in equivalent depths was utilised by Salacia Marine off Selsey and was found to operate in up to a Force 5. However, differences in gear configuration and deployment may have contribute to observed operational variations in Selsey survey including: deployment of the system from a smaller vessel; surveying soley during neaps over less rocky substrate; attachment of more floats to the sledge rear to aid stability and taping of the entire umbilical to the warp in contrast to just the first section, as was done in the current study. Some deployment techniques that can aid stability (and therefore produce more consistent video footage) and increase utility in different conditions include:

- Towing into the tide;
- Trying different speeds in the water – keeping the boat in gear, slowly steaming away and reeling the gear out behind;
- Adding different buoy configurations to the top of the sledge;
- Attaching weights to the sledge base;
- Adding a tail of buoys to the back of the sledge;
- Ensuring the bridle has an equilateral triangle to give the gear stability on the seabed. If the triangle is smaller the gear jerks and if greater the gear is less stable.

As a result of these trials, adaptations will be made to the new IFCA TUV to increase its stability and keep it upright, with the addition of weights and a buoy configuration on top of the sledge. In addition umbilical will be taped to the warp over its entire extent.

Difficulties were also experienced with positioning the camera so that the sledge runners or front cross bar beneath the camera attachment point were not partially obscuring the image. To minimise the amount of image obscured by sledge parts the camera was not positioned at the optimal angle resulting in a proportion of open sea in each image, effectively constituting 'wasted' analysis area. Subsequent adaptations of the new IFCA TUV may also include the removal of the front cross bar to help alleviate this issue.

Additional modifications to be made to the Sussex IFCA TUV following these trials are the incorporation of fixed, more expensive laser holders, similar to those utilised in both the IFREMER and MI systems, to ensure lasers do not move and increase confidence in scale estimations. Extra lights will also be incorporated to improve image definition and colour. In addition, plastic connectors will be added to the camera and light connections on the umbilical to improve robustness. While the utilisation of an underwater acoustic positioning device to enable accurate video footage positioning is desirable, the cost is prohibitive.

One of the major outcomes of the current study and sharing of best practice between organisations, was learning about the neutrally buoyant design of the MI TUV. This design is especially beneficial over raised rocky reef, enabling systems to 'fly' over the feature thereby reducing the likelihood of snagging or damage to the reef while still being able to capture footage within these more challenging environments.

Due to the presence of rocky reef within a number of recommended and designated MCZs in the Sussex IFCA district, the ability to monitor these environments using TUVs is highly desirable and officers recognise the utility of developing such a system. Subsequent deliberation deemed the light TUV utilised within the present trials unsuitable for the neutrally buoyant adaptations needed and instead a larger, heavier 50 kg sledge already owned by the authority will be modified. Details of the required modifications for a neutrally buoyant system are contained within the paper by Sheehan *et al*, (2010).

The intended modifications following this study will equip Sussex IFCA with two bespoke TUVs for monitoring the district's MPAs, a smaller lighter system for shallower, near shore sites, and a larger neutrally buoyant system for sites further offshore, in particular for rocky environments.

The utility of attaching both backward and forward facing GoPros to a TUV was also clearly illustrated in the current study. The forward facing camera for capturing a wider perspective of the surrounding environment and the backward facing camera to assess the impact of the sledge and view the mobile fauna following the TUV, which were observed at times in the current study. GoPros can also be set to capture underwater stills, which would provide higher quality images than the video freeze frames for subsequent analysis.

4.2.3 MI

Following the trial and working with IFREMER and Sussex IFCA, it was clear that a Flying array was a good technique for surveying inshore, variable, sensitive seabed habitats. No problems were encountered as this TUV had been trialled in a number of other different locations and sea conditions. The trial spurred some ideas for modications that could be made to the flying array to increase its potential. Following discussion with IFREMER and IFCA, the MI team will look to add on an independent stills camera to capture higher quality images for additional analysis and for publication purposes. The MI team are also interested to use the sled to assess the effect of seabed heterogenity on benthic assemblages and so will develop the use of a laser line to measure complexity.

The backwards facing go-pro confirmed that even in a strong tide the drag-chain caused minimal damage; however, use of a lighter chain would cause less damage. The MI team will therefore continue to try and reduce the impact of the chain, by working with skippers that can help develop techniques to control the speed of the sled using the boat rather than than the drag chain.

4.3 Conclusions

TUVs are expected to provide accurate quantitative information on encountered biota and seabeds in order to measure taxonomic diversity, size of individuals and impact indices. For this particular reason, the use of a flexible sledge design composed of a robust frame and as many device and housings as necessary seemed the most appropriate to answer these particular objectives. This design, coupled with the use of laser pointers, ensures that the monitored fields are known and may be calibrated in such a way that features may be measured accurately or expressed as a function of the surface surveyed. Moreover, the system flexibility ensures that the optical devices themselves may be easily replaced as the technology improves.

In the frame of the PANACHE project, a new TUV was designed and tested. The IFREMER TUV system was developed in the context of increasing need for benthic habitat characterisation and monitoring, both for the purpose of biodiversity monitoring within MPA networks but also for any type of benthic indicator and exploited species monitoring. The IFREMER TUV needed to remain relatively cheap to produce and maintain, and is designed to allow the evolution of both the number and nature of sensors used. Overall, it is a very flexible, robust, simple gear that can be used across the continental shelf, both in coastal and offshore areas, to monitor seabed biota status and evolution as a complementary device to stock assessment surveys.

The comparison of this system with two other pre-existing systems highlighted areas that needed improvement to further increase its efficiency. It also highlighted the superiority of bottom tending design (i.e MI TUV) in rocky areas for which a towed deployment of the IFREMER TUV is not adapted. Heavy benthic frames are more stable and flexible in all kind of depths and sea conditions but proved difficult to operate on irregular grounds and were found to impact significantly the seabed. Significant differences in terms of species richness, densities or cover as well species composition were highlighted and are believed to be due to the deployment limits of each gear as well as difference in their optical specifications. Good lighting intensity, and the use of HD resolution are believed to increase the taxonomic power of the video footages. As a result from this study, particular care should be given to sledge and optics specifications when developing a middle or long terme MPA monitoring programme. Considering their significant impact on the data extracted from the video footage, it is not recommended to change the gear specifications over the monitoring period if the purpose of the study is to detect trend over time.

V. Acknowledgements

We would like to acknowledge the watchful and IFCA crew members (Charlie Hubbard, Erin Pettifer, Alberto Kavadellas, Kat Nelson, Alice Tebb, Matt Wisemen, Andy McMahon) and Benoit Gomez (IFREMER) for support at sea, Rob Clark for his contribution to setting up the project and survey site information, Richard Larocque (Institut Maurice Lamontage, Fisheries and Oceans Canada) for expertise and technical advice in the "IFREMER TUV" development. We wish to acknowledge Tom Hooper for his role in the development of PANACHE. We also wish to acknowledge the financial support from the INTERREG IV A France-England cross-border European cooperation programme, co-financed by the European Regional Development Fund as part of the Protected Area Network Across the CHannel (PANACHE) project.

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Appendix

Appendix 1: Detailed characteristics of Kingsmere MCZ

Surficial geology

Clark *et al*, (2013) describes the surficial geology within the Kingmere MCZ, inferred from sidescan sonar data collected by Sussex IFCA, Tarmac Marine Ltd and Hanson Marine Ltd, and informed by Sussex Seasearch data published by Irving 1999. The site contains important outcropping chalk areas and two marine Sites of Nature Conservation Importance (mSNCI), Worthing Lumps and Kingmere Rocks. Linear chalk outcrops are exposed to the south of Kingmere Reef (within the MCZ) and extend >1 km, forming what appears to be preferential bream nesting habitat. Surrounding the principal reef exposures and infilled palaeochannels the bedrock is of Tertiary Bracklesham Group (and associated lignite), and the chalk is covered with a veneer of coarse sediment. Smaller areas of coarse sand are associated with depositional areas near to the exposed reefs.

Worthing lumps, in the south east corner of Kingmere MCZ, is the best example of an exposed chalk outcrop and consists of two separate northerly facing chalk exposures ranging in height from 2-3 m. Kingmere rocks is a sandstone boulder reef of moderate energy infralittoral rock, rich in encrusting marine life. The reef extends 2-3 m off the seabed and ranges in depth from 6-14 m BCD.

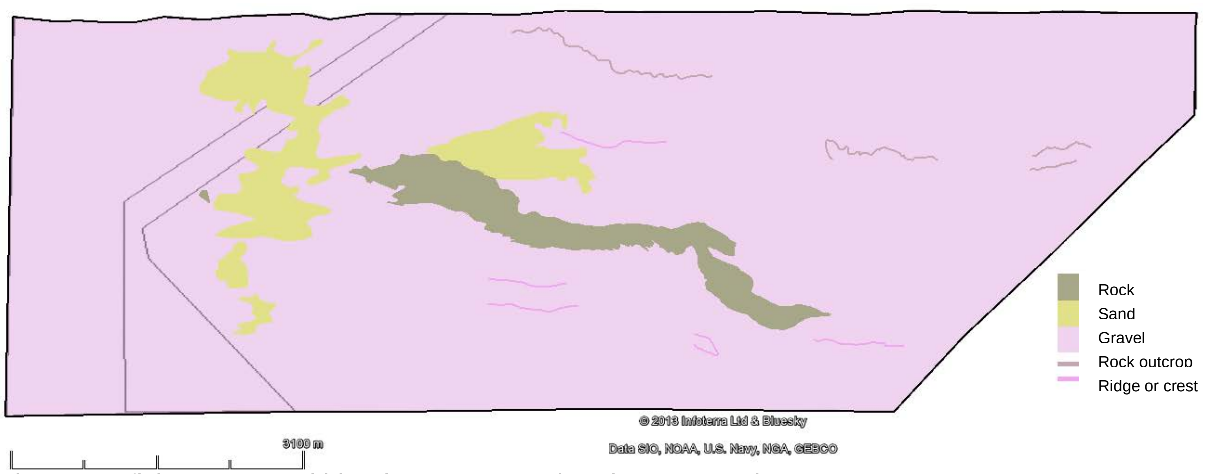


Fig.16 .Surficial geology within Kingmere MCZ (Clark *et* al, 2013).

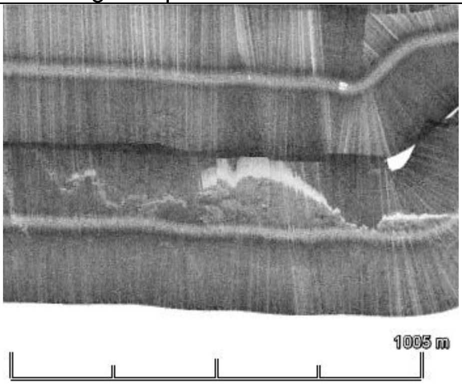
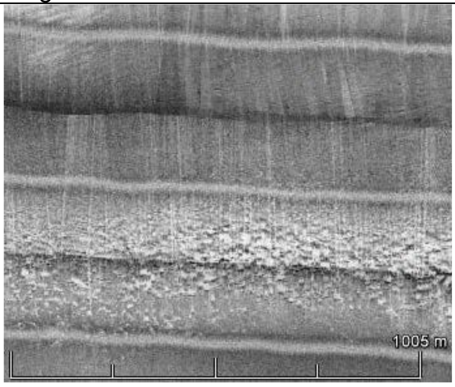
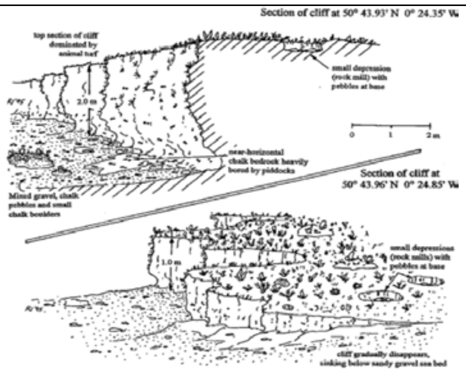
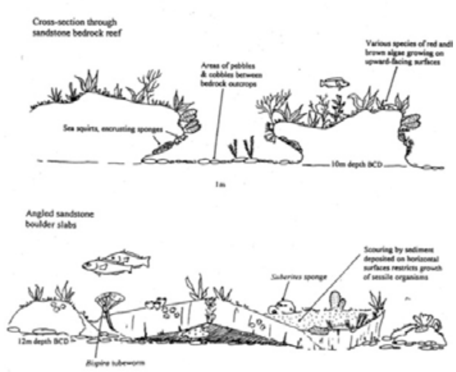
Worthing Lumps	Kingmere Rocks
 Sonar record	 Sonar record
 As described in Irving, 1999	 As described in Irving, 1999

Fig.17. Sidescan sonar and illustrations of Worthing Lumps and Kingmere Rocks mSNCI.

MCZ features

The features designated for protection within Kingmere MCZ include subtidal chalk, black bream and infralittoral rock with mixed sediment. Kingmere is one of the most well-known (and potentially the most important in the UK) spawning sites for black bream (*Spondyliosoma cantharus*) with the bedrock covered by sediment veneers habitat providing preferred nesting habitat.

Fishing activities

Trawling

The commercial black bream fishery off West Sussex, in terms of landings, is dominated by pair trawling with approximately 3 pairs of trawlers currently pursuing the fishery. Pair-trawling occurs round the edges of Kingmere Rocks, within the boundary of the MCZ. Traditionally the trawlers go around the eastern edge of Kingmere and between Kingmere and Shelley Rocks to the east. One or two <10 m single boat otter trawlers may go into the site targeting cuttlefish (May-July).

Netting

A general netting fishery occurs within the site targeting bream, sole, plaice and bass. At the start of the black bream season there may be localised high intensity static and set-net fisheries, with 3-4 fleets of nets across Kingmere Rocks. Currently, the fishery is relatively limited in its economic extent and is not large scale.

Potting

Potting for lobster is the biggest fishing activity in Kingmere over the summer months (end May–September).

Sea angling

Recreationally black bream is very significant at Kingmere and the site is exceptionally important to the local angling community. The area is extremely popular with private boat anglers and charter boat operators. In the spring / summer in excess of 20 boats are regularly recorded by IFCOs on patrol, and up to approximately 30 boats.

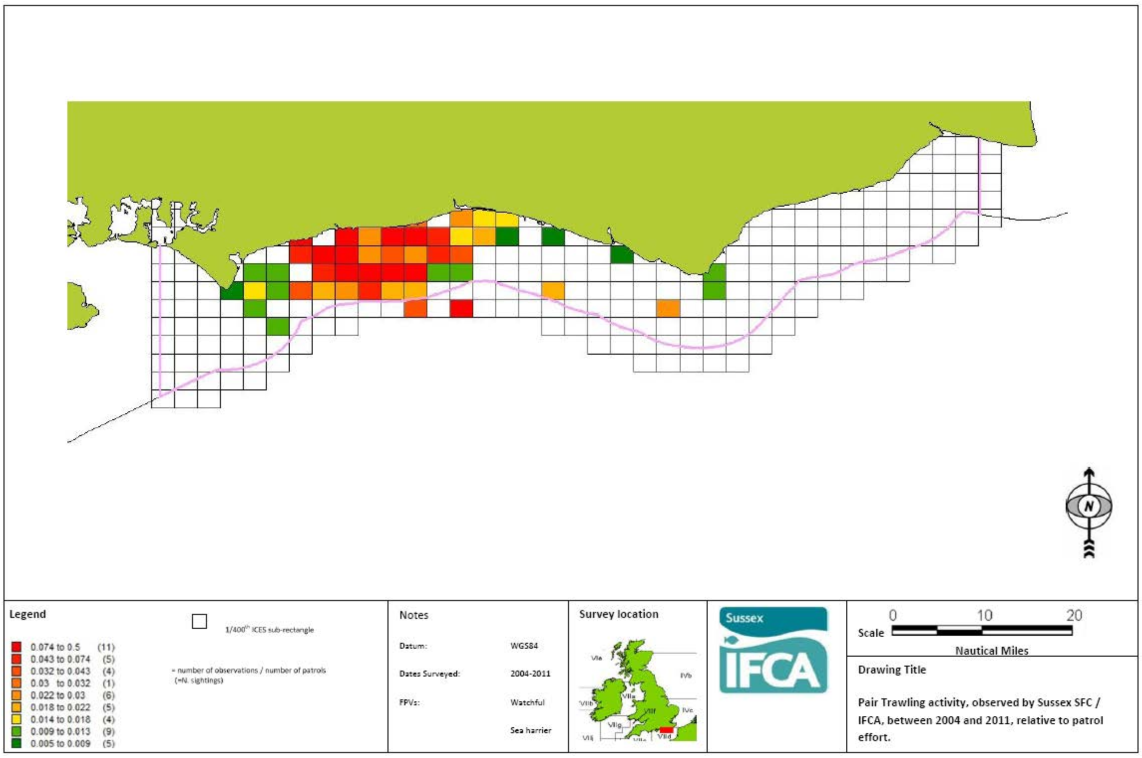


Fig.17. Sussex IFCA fishing effort map illustrating pair trawling activity observed by Sussex SFC / IFCA between 2004 and 2011.

Appendix 2: Transferability questions

1. **A brief description of the study and data collected.**

This study tests the use of towed underwater video devices as effective, non-destructive and efficient techniques for the monitoring of marine ecological features within these especially sensitive areas. Three technically different towed video sledges were tested on different seabed types (rocky, mixed ground and sandy) in the same MPA, Kingmere Marine Conservation Zone. Each sled was assessed to compare the different characteristics, strengths and limitations of each device with the aim of providing recommendations on their future use and comparability of data between different systems.

2. **At what level can this methodology be used? For example can the collected data be used at an individual MPA site level, regional level, national level, European level and/or international level?**

This methodology can be used at an individual MPA site level, regional level, national level, European level and/or international level as the results are not specific to the MPA where the fieldwork was done.

3. **Can the methodology be transferred to different MPA sites? Please also consider which sites/MPA features or species this methodology would/would not be suitable for.**

This study is relevant where it is suitable to use towed underwater video systems.

4. **How does this methodology and the data fit with/inform existing MPA monitoring programmes in the UK and France?**

This methodology and these data provide relevant information for future monitoring programmes in the UK and France. It provides advice on appropriate equipment selection, and things to be aware of with regards to data sharing between organisations and countries.

5. **What are the current similarities/differences between how the methodology is used in the UK and France.**

Both England and France are using towed underwater video to enumerate benthic assemblages in Marine Protected Areas. The differences between gear types such as, impact, cost, userbility etc is the main focus of this report.

6. **What are the current similarities/differences between how the data is analysed in the UK and France.**

N/A : All the data in this report were analysed by Plymouth University Marine Institute as the focus of the study was on the differences between the sampling methodologies.

7. From this collaborative study please make recommendations as to how this methodology and the data collected be compared between English and French MPA sites?

We have learnt that if data is to be shared between English and French sites that either identical TUVs should be deployed in both sites, or that the data need to be calibrated before analysis.

8. How much has this study cost….

The total cost of this project was 220,702.03 Euros. IFREMER : 186,182.00 Euros; IFCA = 16,285.58 Euros; UoP = 18,234.44 Euros.

9. How is this methodology cost effective for monitoring MPAs? Please also suggest ways this methodology can become more cost efficient.

These methods are extremely cost effective for monitoring MPAs. Kilometres of sea bed can be recorded per day in a repeatable and robust way. Recorded data can also be used for multiple functions, and if stored provide an ecological historical catalogue that can be used for future purposes.

In future, benthic monitoring may become more cost effective through the use of Automated Underwater Video or automated video analysis. However, both of these applications are in still in development, whereas the towed underwater video systems are currently fit for purpose and effective tools for monitoring MPAs. They continue to become more cost efficient through advances in technology and deflating hardware and data storage costs.

10. How was information and expertise exchanged between partners? Please document meetings, e-mail exchanges, face to face meetings, working groups etc. that led to the development of this.

Exchanges between project partners were initiated through phone calls and emails, then all partners met at a PANACHE meeting before we co-located for our fieldwork in Sussex. Following a number of phone calls and emails, the group had two further project meetings before the report was completed.

1st Meeting Le Havre Nov 2011
2nd Meeting Le Harve November 2012
3rd Meeting Plymouth March 2013
Fieldwork in Sussex Summer 2013
4th Meeting Boulogne-sur-Mer November 2013
5th Meeting Dover March 2014

11. How has this collaboration built capacity within your organisation for monitoring MPAs?

This collaboration has formed important connections between organisations and countries so that future MPA monitoring can be undertaken in collaboration and a more effective way. We have now made useful relationships that we plan to use for future collaborative grant opportunities. The funding also gave us the opportunity to test the impact of our research equipment on the environment. This has helped us to ensure that we are using cost-effective, time effective and non-destructive equipment to monitor MPAs across the channel and further afield.

12. How can this collaboration be developed in the future?

We would like to develop these collaborations in future to answer research questions with regards to MPA science. Our collaboration will allow us to conduct more robust science that uses multiple MPA sites across borders rather than single site specific surveys. The expertise from the different organisations and countries is also varied, which has made our science stronger as a result of the collaboration.

13. Please can you make suggestions as to how the results of your study can be shared to give a greater overall indication of how MPAs are impacting humans and biodiversity?

The results of this study can be used to promote effective, non-destructive monitoring that is fit to robustly measure MPA effectiveness of promoting healthy sustainable ecosystems. By understanding whether MPAs are performing as they should, informed management decisions can be made regarding human impact control in the marine environment. Results of this report will now be published in the peer reviewed scientific literature so that this information can be disseminated across a wide international audience. The results of this study will also be presented to relevant stakeholders at the PANACHE and VALMER final project meeting in 2015.

PANACHE

Protected Area Network Across the Channel Ecosystem

PANACHE is a project in collaboration between France and Britain. It aims at a **better protection** of the Channel marine environment through the **networking** of existing marine protected areas.

The project's five objectives:

- **Assess** the existing marine protected areas network for its ecological coherence.
- **Mutualise** knowledge on monitoring techniques, share positive experiences.
- **Build** greater coherence and foster dialogue for a better management of marine protected areas.
- **Increase** general awareness of marine protected areas: build common ownership and stewardship, through engagement in joint citizen science programmes.
- **Develop** a public GIS database.

France and Great Britain are facing similar challenges to protect the marine biodiversity in their shared marine territory: PANACHE aims at providing **a common, coherent and efficient reaction**.

PANACHE est un projet franco-britannique, visant à une **meilleure protection** de l'environnement marin de la Manche par la **mise en réseau** des aires marines protégées existantes.

Les cinq objectifs du projet :

- **Étudier** la cohérence écologique du réseau des aires marines protégées.
- **Mutualiser** les acquis en matière de suivi de ces espaces, partager les expériences positives.
- **Consolider** la cohérence et encourager la concertation pour une meilleure gestion des aires marines protégées.
- **Accroître** la sensibilisation générale aux aires marines protégées : instaurer un sentiment d'appartenance et des attentes communes en développant des programmes de sciences participatives.
- **Instaurer** une base de données SIG publique.

France et Royaume-Uni sont confrontés à des défis analogues pour protéger la biodiversité marine de l'espace marin qu'ils partagent : PANACHE vise à apporter **une réponse commune, cohérente et efficace**.

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