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# An experimental comparison of three towed underwater video systems using species metrics, benthic impact and performance

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1 An experimental comparison of three Towed Underwater Video Systems using  
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## 16 **ABSTRACT**

17 1. Managing ecological systems, which operate over large spatial scales is inherently difficult  
18 and often requires sourcing data from different countries and organizations. The assumption  
19 might be made that data collected using similar methodologies are comparable but this is  
20 rarely tested. Here, benthic video data recorded using different towed underwater video  
21 systems (TUVSs) were experimentally compared.

22 2. Three technically different TUVSs were compared on different seabed types (rocky, mixed  
23 ground and sandy) in Kingmere Marine Conservation Zone, off the south coast of England.  
24 For each TUVS, species metrics (forward facing camera), seabed impact (backward facing  
25 camera).and operational performance (strengths and limitations of equipment and video  
26 footage) were compared with the aim of providing recommendations on their future use and  
27 comparability of data between different systems.

28 3. Statistically significant differences between species richness, density, cover and  
29 assemblage composition were detected amongst devices and were believed to be mostly  
30 due to their optical specifications. As a result of their high image definition and large field of  
31 vision both the Benthic Contacting Heavy and benthic tending TUVS provided good quality  
32 footage and ecological measurements. However the heaviest TUVS proved difficult to  
33 operate on irregular ground and was found to cause the most impact to the seabed. The  
34 lightest TUVS (Benthic Contacting Light) struggled to maintain contact with the seabed. The  
35 benthic tending TUVS was able to fly over variable seabed relief and was comparably the  
36 least destructive.

37 4. Results from this study highlight that particular care should be given to sled and optic  
38 specifications when developing a medium or long term MPA monitoring programme.  
39 Furthermore, when using data gathered from multiple sources to test ecological questions,  
40 different equipment specifications may confound observed ecological differences.

41 5. A benthic tending TUVS is recommended for benthic surveys over variable habitat types,  
42 particularly in sensitive areas such as marine protected areas.

43

44 **KEYWORDS:** Underwater imagery, Towed video, Marine Protected Area, Sampling impact,  
45 Environmental management, Meta-analyses.

46

47

## 48 **Introduction**

49 The health of marine ecosystems that deliver resources and services is now of international  
50 concern as a result of increasing pressure from human activities (Halpern et al. 2008).

51 Governments from different countries and management organisations bordering shared  
52 water bodies often need to work together to manage the marine environment. For the  
53 purpose of understanding and managing systems over large scales, data from different  
54 sources need to be utilised for studies relating to e.g. marine renewables, fishing impacts  
55 and marine protected areas (MPAs) (Inger et al. 2009; Collie et al. 2000; Worm et al. 2006;  
56 Stewart et al. 2007). The assumption might be made that data collected using similar  
57 methodologies are comparable but this is rarely tested. An experimental trial was therefore  
58 undertaken to assess the comparability of data recorded using different Towed Underwater  
59 Video Systems (TUVSs), and to make monitoring recommendations for future users.

60 Preservation of MPAs that exclude destructive and economically lucrative activities requires  
61 justification of their effectiveness to stakeholders and governments. This can be achieved by  
62 monitoring and reporting any resulting changes in ecosystem processes and services (Rees  
63 et al. 2013). In recent years, the number, size and coverage of MPAs has increased rapidly  
64 as governments around the world strive to meet international targets to protect the world's  
65 oceans (Spalding et al. 2013; Singleton & Roberts, 2014). As a consequence of the growing  
66 size and coverage of MPAs, monitoring the features within such vast areas, and collecting  
67 meaningful data to assess changes over time, poses both financial and logistical constraints.  
68 Limited budgets to survey MPAs (Ehler, 2003) require survey methods to be cost effective  
69 and provide robust data that can have multiple uses and users (i.e. uses: assess local  
70 habitat recovery and contribute to national ecosystem service assessment; users:  
71 organisations, such as universities, consultancies or government agencies; regions and  
72 countries).

73 Analysis of underwater imagery is used to enumerate species abundance, diversity and  
74 behaviour (Machan & Fedra, 1975; Hughes & Atkinson, 1997) and characterize habitats to  
75 help managers identify and manage vulnerable communities (Larocque & Thorne, 2012;  
76 Fabri et al. 2013). Cost-effective MPA video monitoring programmes have been developed  
77 to detect management effectiveness on seabed habitats (Sheehan et al. 2013 a & b) and on  
78 fish abundance and size (Assis et al. 2007, Tessier et al. 2013), helping managers to  
79 evaluate and adapt their policies (Stevens et al. 2013).

80 To capture benthic footage, video can be deployed in numerous ways, including: "drop  
81 cameras" for stationary imaging of multiple small areas; Remotely Operated Vehicles (ROV);  
82 Autonomous Underwater Vehicles (AUV); manned submersibles (Fabri et al. 2013) or  
83 Towed Underwater Video System (TUVSs) with continuous video recording along a transect  
84 (all systems are reviewed in Rooper, 2008).

85 The most commonly used design for TUVSs is a weighted system using skids or runners  
86 that contact the seabed ("benthic contacting"; Machan & Fedra, 1975; Hughes & Atkinson,  
87 1997; Spencer et al. 2005; Stoner et al. 2007). The platform stability of such TUVSs provides  
88 a fixed field of view from the video camera; however, these TUVSs are limited to fairly  
89 homogenous seabed types as they are prone to snagging on rocks and can damage the  
90 seabed (Sheehan et al. 2010).

91 An alternative TUVS design is a "benthic tending" design (for example see Sheehan et al.  
92 2010). Such a TUVS is suspended above the seabed by the counterbalance of weight and  
93 buoyancy, with a ground chain providing the only seabed contact to achieve a stable  
94 specified altitude. The sled is typically towed at slow speed or allowed to drift with prevailing  
95 currents. The advantage of this type of system is that it can be designed to work over rugged  
96 ground, theoretically having less impact than benthic contacting sleds. Successful operation  
97 of these systems, however, is technically more challenging resulting from the need to

98 achieve neutral buoyancy and constant height above the seabed in variable conditions  
99 (Rooper, 2008).

100

101 Three technically different TUVSs were tested together at one location where three habitat  
102 types could be sampled: rocky, mixed ground and sandy. The following criteria were  
103 assessed: Data comparability of species metrics (Number of taxa, Density, Cover and  
104 Assemblage composition), Impact of sled and Performance (operation and video).

105

## 106 **Methods**

### 107 ***Study site and experimental design***

108 TUVSs were compared in Kingmere Marine Conservation Zone (MCZ, designated under the  
109 UK Marine and Coastal Access Act 2009), a 48 km<sup>2</sup> MPA in ~20 m water depth, ~5 km off  
110 the south coast of England (Fig. 1). Sampling was undertaken from 2nd - 13th September  
111 2013 using an 18 m vessel (owned and skippered by Sussex IFCA).

112 To compare species metrics derived from the video, the impact of each TUVS, and TUVS  
113 performance over different habitats, three habitat types were selected using a broad scale  
114 habitat map, echo-sounder and local knowledge of the IFCA skipper: (1) rock and chalk  
115 outcropping reef "Rock", (2) boulders, cobbles and stones on sediment "Mixed", and (3)  
116 sandy habitats "Sand". For each habitat type, two areas within the MCZ were selected (Fig.  
117 1), though only one area was identified for "Sand". In each area, for each TUVS three 200 m  
118 video tows were recorded. The skipper used the echo-sounder to ensure that tows were  
119 positioned on the correct habitat type. Tows were haphazardly interspersed between TUVSs  
120 to ensure that comparable benthic habitats were assessed. Tows were located a minimum  
121 distance of 350 m apart to ensure that replicates did not overlap each other.

122

123 Species data comparability was assessed using footage from forward facing cameras. To  
124 assess benthic “Impact” on the seabed and associated fauna, a backwards facing HD Hero2  
125 GoPro camera was mounted on each TUVS.

126 “Performance” (operation and video) was assessed throughout the field trial and  
127 subsequent video analysis. Equipment specifications (camera, lights, lasers, CTD  
128 (Conductivity/Temperature/Depth), frame, connection to hardware on the boat, power supply,  
129 sled dimensions, weight and cost), Operational performance (no. of tows per day, potential  
130 deployment in wind and tide, deployment requirements and operator skill required) and  
131 Video performance (speed, camera angle, image quality, information on screen and field of  
132 view) were assessed using the following scale : 1. Room for improvement (criteria were  
133 identified that should be amended for future benthic video survey), 2. Fit for purpose (criteria  
134 were suitable for good quality benthic video survey or 3. Recommended (criteria were  
135 suitable for excellent quality benthic video survey).

136

### 137 ***TUVS specification and deployment procedures***

138 Two benthic contacting sleds, one heavy “BCH” and one light “BCL”, and one benthic  
139 tending sled “BT” were compared. Both benthic contacting sleds had two runners while the  
140 benthic tending sled had one ground chain (Fig. 2).

141 Cameras were positioned forward facing at an oblique angle to the seabed (BCH: 35°,  
142 BCL:50°, BT:30° to the horizontal) to optimise mega- and macro epi-benthic species  
143 identification while maximising the field of view. All TUVSs were fitted with lights set to  
144 illuminate the field of view and two laser pointers were mounted on each TUVS as a scale to  
145 quantify the field of view (see Appendices Table 1).

146 *Benthic Contacting Heavy (BCH)*: This TUVS was developed for opportunistic deployment  
147 on existing stock assessment surveys. It was designed to withstand all types of sea

148 conditions, currents and depth ranges on the European continental shelf (i.e. down to 600 m  
149 depth), and to be easily operated by non-specialist staff. The TUVS comprises a large  
150 stainless steel sled (Length: 1500 mm, Width: 1100 mm, Height: 740 mm, Weight: 290 kg,  
151 Total cost: €14,000). There is no cable connection of this TUVS and so sensors are set  
152 before deployment. Sensors include a 600 m depth rated anodised aluminium housing able  
153 to contain any off the shelf camcorder (here, a Panasonic HC-V700 High Definition 1920 x  
154 1080 p -50 fps, with a 32 GB SD card recording up to 3 hours); two LED lights (underwater  
155 LED SeaLite® Sphere, SLS 5100, 20/36 V, 80 W, 5000 Lumens) were fixed to the sled on  
156 each side of the camera; Two laser pointers (SeaLasers® 100 Dualmount, wavelength 532  
157 nm Green) set 100 mm apart; two subCtech Li-Ion PowerPacks to power lights and lasers  
158 (25Ah, 24V, ~4h autonomy). The weight of this TUVS meant that a winch and three  
159 personnel were required to deploy it.

160 *Benthic Contacting Light (BCL)*: This small TUVS was designed for inshore MPA monitoring  
161 within shallower waters (<50m depth). An umbilical was connected to a RovTech system  
162 topbox comprising a power supply, light control, recording facility and GPS feed. This  
163 enabled real time footage to be viewed from the surface. The BCL TUVS comprises a small  
164 stainless steel sled (Length: 820 mm, Width: 495 mm, Height: 430 mm, Weight: 9 kg, Total  
165 cost: €12,000). Mounted on the sled was a Seacam ultra wide-angle colour camera, one  
166 LED light and lasers set 200 mm apart. This TUVS represents a relatively cheap method of  
167 surveying the seabed for authorities, which may just need to e.g. ground truth habitat, and  
168 therefore, do not require a HD camera, and the associated fibre optic cable and expensive  
169 lights. Deployment of this TUVS was simple and required minimal personnel (one to deploy  
170 the sled and one to monitor the video) and training.

171 *Benthic Tending (BT)*: This TUVS was designed to fly above heterogenous seabed to  
172 monitor sensitive habitats. The umbilical used here was 250 m, which limits it to ~150m. The  
173 umbilical was connected to a Bowtech System control unit, which allows control of the  
174 camera (Surveyor-HD-J12 colour zoom titanium camera, 6000 m depth rated, 720 p) focus,



175 zoom and aperture, the intensity of three lights fixed to the array in front of the camera  
176 (Bowtech Products limited, LED-1600-13, 1600 Lumen underwater LED) and a mini CTD  
177 profiler (Valeport Ltd). Two battery powered laser pointers (wavelength 532 nm Green) set  
178 300 mm apart were also mounted either side of the camera. The frame was made from  
179 aluminium with high strength plastic ballast tubes and ground chain (Sled: Length: 700 mm,  
180 Width: 700 mm, Height: 400 mm, Weight: 30 kg; Ballast tubes: Length: 130 mm, Depth: 100  
181 mm; Chain: L: 3150 mm, W: 33 mm, Weight: 10 kg, Total cost: €35,000). The system floats  
182 above the seabed and altitude is controlled using a drop-weight between the boat and the  
183 sled, and a length of rope that acts as a weak-link between the sled and the ground chain. A  
184 tow rope was used to reduce strain on the cable (detailed methods are described in  
185 Sheehan et al. 2010). The BT TUVS is easy to deploy, though perhaps more technical to tow  
186 than the benthic contacting TUVSs to achieve good quality video. New skippers often need  
187 to practice in shallow sheltered habitats before attempting more extreme conditions. The BT  
188 TUVS is best retrieved using a winch or pot hauler due to the heavy drop-weight.

189

## 190 ***Video analysis***

191 *Data comparability:* To eliminate observer bias contributing to differences between datasets,  
192 the same person analyzed the video from all three TUVSs. To analyze the video, frame  
193 grabs were extracted at five second intervals and a digital quadrat overlaid (5x5 matrix)  
194 (Cybertronix frame extractor). The file format from the BCH TUVS was not compatible with  
195 the frame extracting software and so frame grabs were extracted manually at 5 second  
196 intervals. Frame grabs were discarded if they were not in focus, overlapped each other, or  
197 were not on the appropriate habitat. After this process, 10 randomly selected frame grabs  
198 were analysed for each transect.

199 All organisms present were identified to the lowest taxonomic level possible and their  
200 abundance recorded. Taxonomically similar species, which could not be distinguished with

201 confidence, were grouped. Such groups included: *Inachus* spp. (Weber, 1795) and  
202 *Cerianthus* spp. (Delle Chiaje, 1830) (identified to genus level); Gobies; Hydroids and  
203 Branching sponges. It was concluded that hydroids could not be accurately counted for each  
204 TUVS and so were excluded from the density analysis. The category “Turf” incorporated  
205 hydroids and bryozoans that were <1 cm high. Individual or discrete colonial organisms were  
206 expressed as densities (individuals m<sup>-2</sup>). Densities were calculated using the laser scaling on  
207 each TUVS (BCH: 100 mm, BCL: 200 mm, BT: 300 mm). The BC TUVS have a fixed field of  
208 view per frame grab as the camera is at a set distance from the seabed. The BT TUVS has a  
209 variable altitude and consequently variable field of view; hence the frame area was  
210 calculated per frame grab (See Appendices Table 2.). Cover-forming colonial taxa and Turf  
211 were quantified as percent cover using the number of dots from the overlay that each taxon  
212 covered. As the camera angle on the BCL was set at 50° a proportion of the frame was open  
213 water. To account for this, the mean frame area of open water from the 10 frame grabs for  
214 each tow was used to correct the percent cover data so that values were not underestimated.

215 *Impact:* To assess impact of each TUVS on the seabed, footage from the backward facing  
216 HD Hero2 GoPro was analysed by a single analyst using a bespoke ordinal scale. Where 0  
217 = no impact, 1 = fine sediments disturbed, 2 = stones disturbed, 3 = cobbles disturbed and  
218 sediments re-suspended (Fig. 3). Grain size was modified after the Wentworth Scale (Irving,  
219 2009). Scores 2-3 were cumulative, e.g. if score 3 is awarded for cobbles being disturbed,  
220 this suggests that stones were also disturbed. Five 1 minute observations were made,  
221 haphazardly selected throughout each tow, and scored based on visual assessment of the  
222 seabed disturbance.

223

## 224 ***Data analysis***

225 *Data comparability:* For each habitat type, two areas were identified (only one was identified  
226 for sand) and three transects were recorded for each TUVS, giving 6 replicates per TUVS

227 within each Habitat. A replicate constituted the average of data from 10 frame grabs for each  
228 transect. After examination of data distribution number of taxa and density were left  
229 untransformed, while the cover data were transformed using arcsine transformation ( $y' =$   
230  $\arcsin\sqrt{y}$ ) (Legendre & Legendre, 2012). Permutation Analysis of Variance was preferred as  
231 it is deemed a distribution-free non parametric test (Anderson, 2001). For univariate  
232 response variables, we used two-way permutation ANOVAs between two fixed factors that  
233 both had three levels: TUVS (BCH, BCL and BT) and Habitat type (Rock, Mixed and Sand).  
234 The significance level for this statistic was set at p-values  $\leq 0.001$  with 9999 permutations.  
235 Permutation ANOVA tests were completed by computing effect size values from Generalised  
236 Linear Models (Nakagawa & Cuthill, 2007) corresponding to TUVS and habitat types  
237 multiplicative effects. Poisson and quasi-poisson distributions were chosen for number of  
238 taxa and density response GLMs respectively while Gaussian distribution was applied to  
239 arcsine-transformed cover data. Mean and confidence intervals for each effect were  
240 computed and marked effects were compared to the statistical significance levels obtained in  
241 permutation ANOVA in R. These univariate analyses were implemented in R (R-3.2.1, 2015)  
242 using the *vegan* (Oksanen et al. 2015) and *effects* (Fox, 2003) packages.

243 For each metric raw values, the mean (SD) were reported and data distribution were plotted  
244 as a function of habitat and TUVS type by the mean of standard boxplot.

245 Permutational Multivariate Analysis of Variance in PRIMER 6 (PERMANOVA, Anderson,  
246 2001; Clarke & Warwick, 2001) was used to test for differences in multivariate response  
247 variable (Assemblage composition) between the same factors as above. Multivariate data  
248 (Assemblage composition) were square root transformed and based on the Bray Curtis  
249 similarity index (Bray & Curtis, 1957).

250 *Impact*: Ordinal scale scores were averaged for each transect. Mean scores  $\pm$  standard  
251 deviation (SD) were plotted on the y axis of a histogram. To account for the different sized  
252 footprint of each TUVS, the width of histogram bars represented the width of each TUVS

253 benthic contact point (BCH 2 x 0.12 m runners = 0.24 m, BCL 2 x 0.05 m runners = 0.1 m,  
254 BT 1 x 0.033 m chain). The corrected scale reported (mean and SD) is the original score  
255 multiplied by the total width of contact for each TUVS.

256

## 257 **Results**

258 All three TUVSs surveyed all habitat areas within Kingmere MCZ (Fig. 1). A total of 80 taxa  
259 from nine different phyla were recorded. Common taxa on sand included hydroids and the  
260 sand mason worm *Lanice conchilega* (Pallas 1766). *L. conchilega* was also common on  
261 mixed ground along with the calcareous tube worm *Spirobranchus triqueter* (Linnaeus, 1758)  
262 and dead man's fingers *Alcyonium digitatum* Linnaeus, 1758. *A. digitatum* was also recorded  
263 on rock habitat, along with several algae and bryozoan species such as *Phyllophora crispa*  
264 (Hudson) P.S Dixon, 1964 and *Cellaria fistulosa* (Linnaeus, 1758).

265

## 266 ***Data comparability***

### 267 Number of taxa

268 Trends in the number of taxa differed between TUVSs and Habitat (Fig. 4a; Table 1). On  
269 Rock, the BCL TUVS recorded statistically significantly less taxa than the other two TUVSs  
270 (BCH 6 (1.5) m<sup>-2</sup>; BCL 3.3 (1.9) m<sup>-2</sup>; BT 6.6 (1.7) m<sup>-2</sup>). On Mixed ground, the number of taxa  
271 for the BCH and BT TUVSs were similar and both were greater than the number of taxa  
272 observed using the BCL TUVS (BCH 4.2 (1.9) m<sup>-2</sup>; BCL 1.3 (1.2) m<sup>-2</sup>; BT 4.6 (1.9) m<sup>-2</sup>). On  
273 Sand, however, the number of taxa observed was similar for all three TUVSs (BCH 3.1 (1.1)  
274 m<sup>-2</sup>; BCL 2.3 (1.3) m<sup>-2</sup>; BT 2.1 (1.5) m<sup>-2</sup>). These results were comparable to those obtained  
275 from effect size value comparison that also highlighted the lower performances of BCL on  
276 rock and mixed sediment habitats (Appendices Table 1A).

277 Density

278 Trends in the mean density mostly differed between habitat types (Fig. 4b; Table 1). Density  
279 was greater on the Rock habitat than Mixed and Sand for all TUVSs (Rock: BCH 68.7 (33.5)  
280 nb.m<sup>-2</sup>; BCL 52.0 (46.1) nb.m<sup>-2</sup>; BT 67.1 (48.8) nb.m<sup>-2</sup>; Mixed: BCH 30.1 (31.6) nb.m<sup>-2</sup>; BCL  
281 12.5 (18.3) nb.m<sup>-2</sup>; BT 23.3 (24.6) nb.m<sup>-2</sup>; Sand: BCH 43.2 (29.0) nb.m<sup>-2</sup>; BCL 13.3 (15.0)  
282 nb.m<sup>-2</sup>; BT 19.8 (25.0) nb.m<sup>-2</sup>). Pairwise analyses, however revealed that the BCH TUVS  
283 generally yielded statistically significantly higher densities on mixed and sand grounds.  
284 Effect size value comparison also confirmed these results (Appendices Table 1B).

285 Cover

286 Trends in the surface cover of colonial organisms observed differed between TUVS and  
287 Habitat (Fig. 4c; Table 1). On Rock and Mixed ground, the mean percent cover recorded by  
288 the BCH and BT TUVSs was similar and both were greater than the mean cover observed  
289 using the BCL TUVS (Rock: BCH 36.4 (13.8) %.m<sup>-2</sup>; BCL 6.8 (13.7) %.m<sup>-2</sup>; BT 41.8  
290 (17.3) %.m<sup>-2</sup>. Mixed: BCH 15 (10.2) %.m<sup>-2</sup>; BCL 3.2 m<sup>-2</sup> (7.1) %.m<sup>-2</sup>; BT 21.6 (14.0) %.m<sup>-2</sup>).  
291 On Sand, however, while the BCH TUVS recorded the greatest mean cover, no statistical  
292 difference was detected (BCH 2.5 (4.2) %.m<sup>-2</sup>; BCL 0.3 (1.7) %.m<sup>-2</sup>; BT 1.0 (2.9) %.m<sup>-2</sup>).  
293 Here again the analysis of the effect size value confirmed the lower performance of the BCL  
294 on rock and mixed grounds (Appendices Table 1C).

295 Assemblage composition

296 The assemblage composition observed at each habitat and TUVS was statistically  
297 significantly different (Fig. 5; Table 1), however, data from the BCH and the BT TUVSs were  
298 more similar to each other than to the BCL TUVS ( see nMDS plot Fig. 5).

299

300 **Impact**

301 *BCH*: Visually assessing the damage impact of this TUVS proved difficult as the sediment  
302 plume was often so large that the seabed was obscured from view. The rocky ground in  
303 Kingmere MCZ had large boulders and fragile associated sessile benthos. Consequently, it  
304 was decided that this TUVS was too damaging and prone to snagging to complete the  
305 planned transects. Due to this, the BCH TUVS only completed 2 replicates on rock rather  
306 than the 6 originally planned. When the TUVS did come into contact with large cobbles, the  
307 size and weight of the TUVS dislodged encrusting and sessile species (such as sponges);  
308 thus, it received a mean (standard deviation) score of 0.96 (0) on the corrected impact scale  
309 for rock. Mixed ground was the best habitat type for this TUVS and visibility was better than  
310 on sand, but overall it was still difficult to assess damage impact. Where visibility was clear,  
311 tracks were noticeable from the runners - overall the TUVS scored a mean corrected impact  
312 value of 0.9 (0.1) for mixed ground. On sand, it was very difficult to see any damage impact  
313 as the plumes caused from disturbed sediments clouded the field of view. This TUVS scored  
314 a mean corrected impact score of 0.48 (0) for this habitat (Fig. 3 & 4d).

315

316 *BCL*: As this TUVS was light, the damage impact from this sled was relatively low. On rock,  
317 this sled was not heavy enough to maintain contact with large boulders, and as a result it  
318 flew through the water column and did not spend much time on the seabed. Occasionally, it  
319 would collide with large cobbles, which caused damage to some sponge species and ross  
320 coral *Pentapora foliacea* (Ellis & Solander, 1786). However, because of the weight of the  
321 TUVS, it rarely disturbed large cobbles - hence was awarded a mean corrected impact score  
322 of 0.33 (0.05) for rock. On mixed ground, this TUVS generally ran across the top of stones,  
323 only dislodging them occasionally – resulting in a mean corrected impact score of 0.24 (0.07)  
324 for this habitat. On sand, it received a mean corrected impact score of 0.2 (0) as it disturbed  
325 fine sediments, but only created small plumes (Fig. 3 & 4d).

326

327 *BT*: This TUVS was the most consistent on all habitat types. The advantage of the *BT* TUVS  
328 is that it had only one point of contact with the seabed. This TUVS flew better over the rock  
329 habitat than the other TUVS, consistently staying on the seabed. Occasionally, this sled  
330 disturbed large cobbles when the chain became stuck, but this was rare and generally large  
331 cobbles were undisturbed. The chain itself caused some disturbance, dislodging some  
332 sponges and ross coral, resulting in a mean corrected impact score of 0.11 (0.02) for rock  
333 habitat, 0.10 (0) and for mixed. The impact of this TUVS on sand was relatively low, with a  
334 corrected mean score of 0.07 (0) as it disturbed fine sediments creating relatively small  
335 plumes (Fig. 3 & 4d).

336

### 337 ***Performance (operation and video)***

338 Below is a summary of the equipment specification and performance for operation and video.  
339 The complete breakdown of the scores is shown in Appendices Table 2.

340 *Equipment specification scores out of 27: BCH (24), BCL (19), BT (25)*

341 The quality of the HD cameras and lighting on both the *BCH* and the *BT* were of a high  
342 enough standard to recommend to future users while the *BCL* was not HD, which made a  
343 difference to the image quality for analysis (Fig. 6). The main difference of equipment  
344 between the three TUVS was that the *BT* surface connection allowed real time viewing with  
345 remote adjustment of the camera focus, zoom and lighting intensity, this allowed the quality  
346 of the footage to be maximised as conditions and habitat changed throughout a transect and  
347 any obstacles to be avoided.

348 *Operational performance scores out of 15: BCH (12), BCL (10), BT (11)*

349 All three TUVS scored similarly on operational performance, with variability in the scores  
350 related to potential deployment in wind and tide and the level of operator skill required to  
351 work the equipment. *BCH* was the most labour intensive to deploy, due to its size and weight,

352 but this allowed it to have a greater potential for deployment in greater depth, wind and tide  
353 conditions. The BCL was the simplest to deploy as this could be done by hand, but it  
354 required constant attention throughout the transect in rocky areas to avoid getting snagged.  
355 The BT was relatively straightforward to deploy, but inexperienced users required some  
356 familiarisation with the bridle set up and the hardware prior to deployment.

357 *Video performance scores out of 15: BCH (14), BCL (5), BT (13)*

358 The BCH had a better image quality and camera positioning whilst filming thus resulting in a  
359 large exploitable field of view. However the quality of images of both BCH and BCL TUVSs  
360 could be affected by irregular towing speed during the transects as uncontrolled fast speed  
361 resulted in blurred images. In contrast the BT tended to maintain a constant speed as a  
362 result of the skipper's ability to monitor the video screen. The light weight of the BCL frame  
363 resulted in the sled rarely being flat on the seabed, particularly when towed at speed. This  
364 resulted in the camera frequently pointing outwards rather than towards the seabed, making  
365 identification of benthic fauna difficult.

366

## 367 **Discussion**

### 368 ***Data comparability***

369 The results of this experimental trial demonstrated that, despite the three TUVSs recording  
370 transects from comparable habitats, statistically significant differences in benthic metrics  
371 were recorded. The BCL TUVS recorded consistently lower values for each univariate metric  
372 compared to the other TUVSs across all habitat types. These differences were not  
373 statistically significant on Sand, however, where the three TUVS performed most similarly,  
374 presumably as a result of Sand being the most homogenous habitat. Likewise, in a study  
375 comparing different habitats and image resolutions, results from 'Simple' sandy habitats  
376 were found to be more similar than those from 'complex' reef (Coggan et al. 2007). The BCL



377 TUVS was the only non HD camera and so it was expected to not perform as well as other  
378 systems as analog cameras have lower image quality (Harvey et al. 2010). The weight of the  
379 BCL also meant that on complex habitat, the sled spent little time on the seabed and often  
380 was pointing up into the water column. Combined with the difference in resolution from a HD  
381 camera, data users of remote cameras should be aware that lower quality footage is likely to  
382 yield relatively lower species metrics than those with greater video quality and operational  
383 performance.

384 More encouragingly, the BT and BCH TUVS tended to record similar and higher values for  
385 univariate metrics across the different habitat types, indicating that data collected from these  
386 two systems were more comparable and valuable for ecological measurements. The BCL  
387 sled also recorded a markedly different assemblage composition than BCH and BT TUVS.  
388 This further indicated that the BCH and BT TUVSs were most comparable for sharing survey  
389 data. Even after standardisation, species richness is known to be related to the area  
390 sampled (Gotelli & Colwell, 2001), therefore, differences in the average field of view and  
391 image resolution of the different TUVS could explain the observed differences.

392 Differences observed in benthic metrics between video transects recorded using three  
393 different TUVS has therefore highlighted a potential issue when combining data from  
394 different video equipment to compare species metrics between treatments, places or times.

395

### 396 ***Impact***

397 Despite similarities in the data collected between the two largest TUVSs, the Impact of the  
398 gear on the seabed was markedly different. Across habitat types the BCH TUVS caused  
399 more damage than the other two TUVSs, while the BT had the least impact. While heavy  
400 benthic contacting TUVSs can still be suitable within areas where demersal trawling  
401 generally occurs (most of the shelf area), monitoring rocky reefs (boulders over 1m) requires  
402 benthic tending systems (or drop down). Benthic tending systems would be particularly more

403 appropriate for operation in sensitive habitats such as MPAs where any damage to the  
404 seabed needs to be avoided and to monitor habitat recovery.

405

406 ***Performance (operation and video)***

407 Deployment ease was often related to the weight of the TUVS. The lighter TUVS was easily  
408 deployed and recovered, but the heavier TUVS was found to be more stable on the seabed,  
409 and would be suitable for deployment during more severe weather conditions and larger  
410 tides. The benefit of the BCH TUVS was that the height above the seabed was constant and  
411 the technology and power was housed on the sled so there are few surface requirements,  
412 other than ensuring appropriate speed was maintained and that crew were alert to the  
413 potential of the gear snagging. While this sled was large, it could be modified to be lighter by  
414 adding floats, and therefore cause less impact, while maintaining constant contact with the  
415 seabed still collecting cost effective, high quality data. The main disadvantage of this TUVS  
416 was that the footage quality was unknown until the data were recovered and the risk of  
417 snagging over complex habitats was high. Benthic contacting TUVSs were not found to be  
418 operational on high rock boulders unless used only as drop down devices.

419 On the other hand, the BT TUVS proved to be extremely adaptable over a range of habitat  
420 types, and can be deployed over a range of weather and tide conditions. If the ground chain  
421 was to be snagged on wreckage or rocks, the weak link would ensure that it is only the chain  
422 that is lost while the expensive kit returns to the surface. If the seas were large or the tidal  
423 flow was strong, the equipment can be stabilised by adding to the drop-weight or chain. If the  
424 visibility is poor, the BT can be flown closer to the seabed. However, the BT sled was also  
425 the most expensive and complex system to set up. It is essential that benthic tending TUVSs  
426 are connected viewing hardware on the research vessel as they require constant monitoring  
427 to ensure that the height above seabed is appropriate, the camera is focused and that the

428 camera does not snag on ghost fishing gear or rocks (Sheehan et al. 2010). This requires  
429 specialised staff that further increases the cost of deployment of this type of TUVS.

430

## 431 Conclusions

432 TUVSs provide a valuable, relatively non-destructive method to monitor habitat, biodiversity  
433 and human impact. TUVSs are cost-effective, simple to operate and survey, deployment and  
434 analysis protocols may be easily adapted. Archiving of videos allows for sharing and re-  
435 analyses of data whenever required (e.g. change in scope or methodology); however, not all  
436 TUVSs function the same and statistically significant differences in the measured benthic  
437 metrics were highlighted between each of the three gear types investigated. Rocky or  
438 sensitive seabed types were best surveyed using a benthic tending TUVS, where stable  
439 footage with relatively low impact can be achieved. On soft sediment areas, bottom  
440 contacting TUVS constitute a more cost-effective alternative assuming deployment and  
441 analysis costs are similar. Particular care should be given to sled and optics specifications  
442 when developing a middle or long term monitoring programme. Considering their significant  
443 impact on the data extracted from the video footage, it is not recommended to change the  
444 gear specifications over the monitoring period if the purpose of the study is to detect trends  
445 over time. For the purpose of combination of videos obtained from different TUVS  
446 specification, we recommend only using HD resolution and steady TUVS to enable unbiased  
447 comparison.

448

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454 Rodriguez-Rodriguez and the anonymous reviewers for their help and contribution to the  
455 project.

456

#### 457 **Data Accessibility**

458 Data deposited in the Dryad repository <http://dx.doi.org/10.5061/dryad.bb7q8>

459

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549 Table 1. Results of permutation ANOVA to test the differences in Number of taxa: Density  
 550 (excluding hydroids) and Cover; between Habitat type and TUVS. Pairwise tests were used  
 551 to examine statistically significant interactions. Bold values indicate statistically significant  
 552 differences ( $p \leq 0.001$ ).

Source	df	Variance	F	P	Pair-wise comparison	F	P	F	P	F	P
<b>Number of taxa</b>											
TUVS (TU)	2	1.23	87.58	<b>0.001</b>	TUVS x Ha	Rock		Mixed		Sand	
Habitat (Ha)	2	1.17	83.30	<b>0.001</b>	BCL, BCH	29.5	<b>0.001</b>	88.9	<b>0.001</b>	8.59	0.008
TU x Ha	4	0.36	12.89	<b>0.001</b>	BCL, BT	100.7	<b>0.001</b>	108.7	<b>0.001</b>	0.21	0.70
Residual	388	1.72			BCH, BT	1.54	0.23	0.98	0.38	10.0	0.003
Total	394										
<b>Density</b>											
TUVS (TU)	2	24.9	4.31	0.016	TUVS x Ha	Rock		Mixed		Sand	
Habitat (Ha)	2	358	61.87	<b>0.001</b>	BCL, BCH	1.94	0.162	12.04	<b>0.001</b>	25.0	<b>0.001</b>
TU x Ha	4	10.8	0.93	0.451	BCL, BT	3.04	0.082	6.60	0.008	1.48	0.238
Residual	388	1121			BCH, BT	0.0159	0.904	1.72	0.193	11.2	0.002
Total	394										
<b>Cover</b>											
TUVS (TU)	2	0.026	170	<b>0.001</b>	TUVS x Ha	Rock		Mixed		Sand	
Habitat (Ha)	2	0.024	156	<b>0.001</b>	BCL, BCH	63.8	<b>0.001</b>	72.7	<b>0.001</b>	7.90	0.009
TU x Ha	4	0.007	24.1	<b>0.001</b>	BCL, BT	185	<b>0.001</b>	141	<b>0.001</b>	1.70	0.281
Residual	388	0.030			BCH, BT	1.06	0.31	10.4	0.003	2.55	0.128
Total	394										

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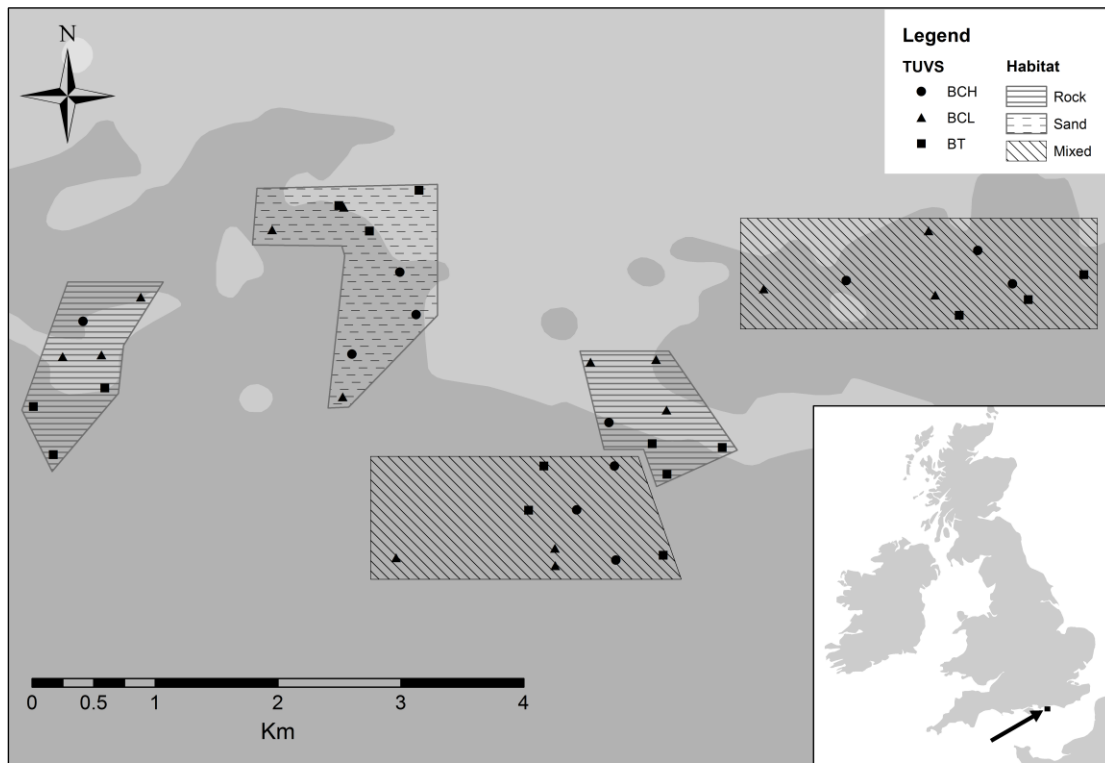
560

561 Table 2. Results of PERMANOVA to test the differences in Assemblage composition;  
 562 between Habitat type and TUVS. Pairwise tests were used to examine statistically significant  
 563 interactions. Bold values indicate statistically significant differences.

<i>Source</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P</i>	<i>Pair-wise comparison</i>	<i>F</i>	<i>P</i>		<i>F</i>	<i>P</i>
Assemblage					TUVS			Habitat		
TUVS (TU)	2	10097	7.14	<b>0.00</b>	BCL, BCH	2.65	<b>0.00</b>	Mixed, Rock	2.97	<b>0.00</b>
Habitat (Ha)	2	13007	9.2	<b>0.00</b>	BCL, BT	3.29	<b>0.00</b>	Mixed, Sand	2.93	<b>0.00</b>
TU × Ha	4	1871.6	1.32	0.08	BCH, BT	1.58	<b>0.01</b>	Rock, Sand	3.25	<b>0.00</b>
Residual	31	1413.8								
Total	39									

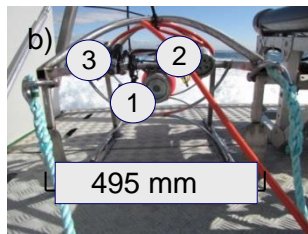
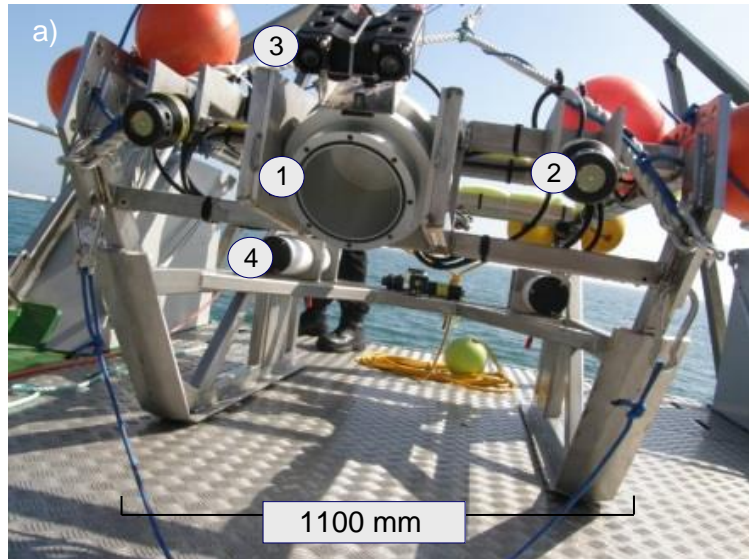
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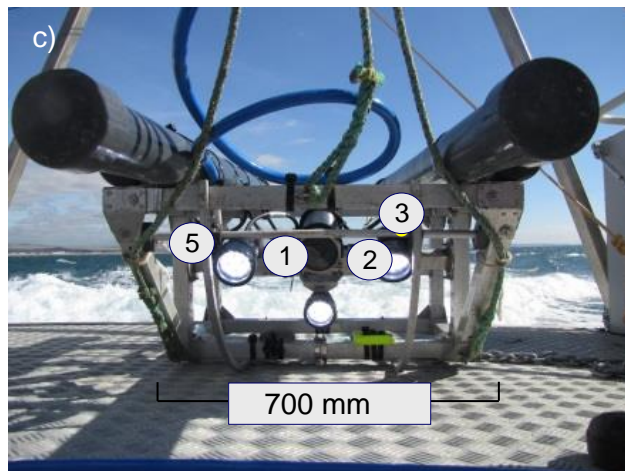


566

567 Fig. 1. Location of sites within the Kingmere MCZ. Southern England. TUVS = Towed  
 568 Underwater Video System; BCH = Benthic Contacting Heavy; BCL = Benthic Contacting  
 569 Light; BT = Benthic Tending.

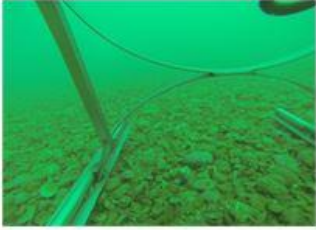
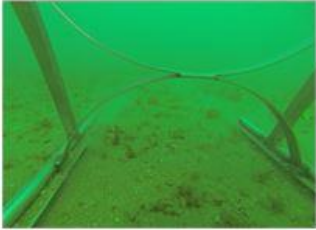




- 1 = Video Camera
- 2 = LED Lights
- 3 = Laser scaling
- 4 = Power pack
- 5 = CTD



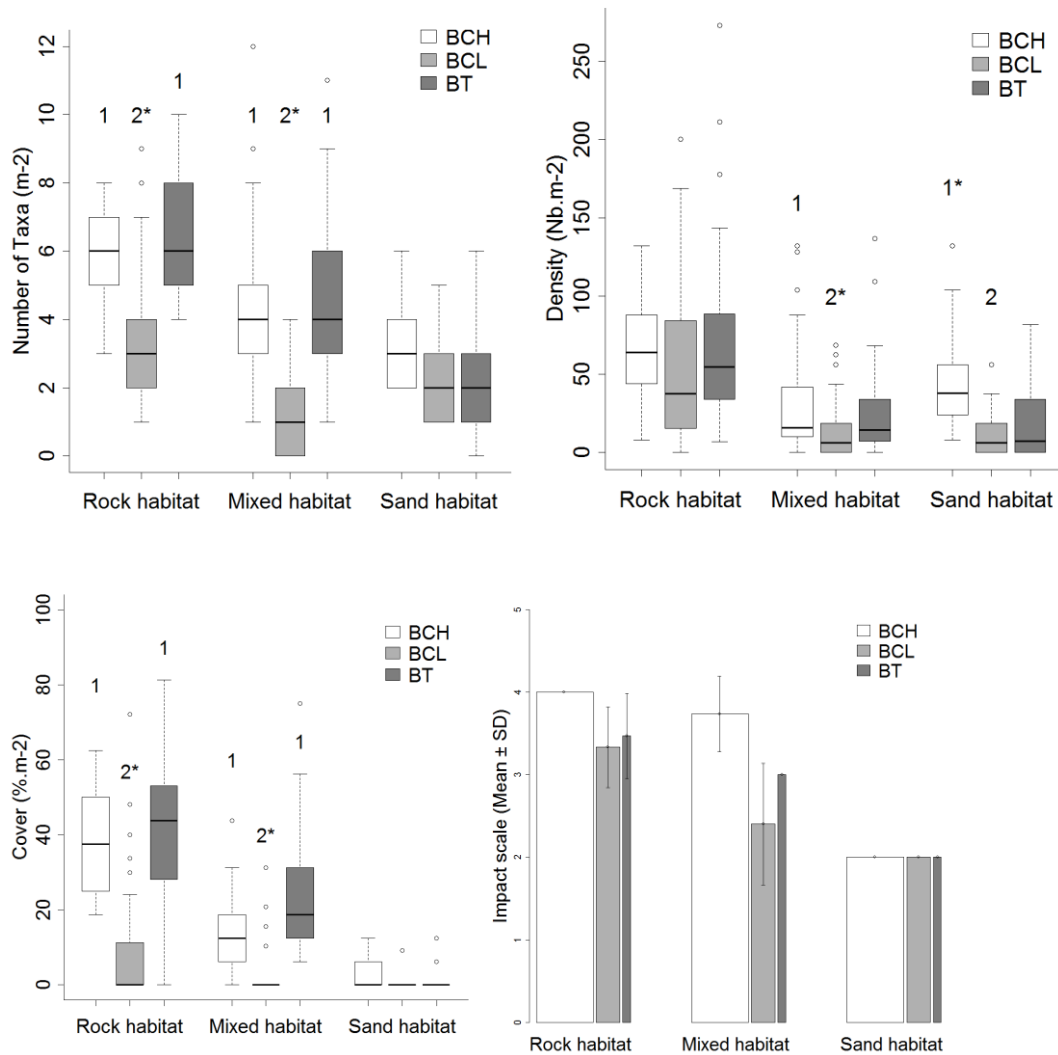
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571 Fig. 2. Images to depict proportional sizes of the Towed Underwater Video Systems: a)  
 572 Benthic Contacting Heavy (BCH), b) Benthic Contacting Light (BCL) and c) Benthic Tending  
 573 (BT) See Sheehan et al. (2010) for deployment schematic. Actual widths are shown below  
 574 each TUVS.

Scale	Image of disturbance
<p data-bbox="284 546 469 607">0 No disturbance</p>	
<p data-bbox="225 808 528 869">1 Fine sediments disturbed</p>	
<p data-bbox="272 1088 477 1149">2 Stones disturbed</p>	
<p data-bbox="229 1335 523 1435">3 Cobbles disturbed and sediments re-suspended</p>	

575

576 Fig. 3. Ordinal scale of impact. Images from backward facing HD Hero2 GoPro camera.



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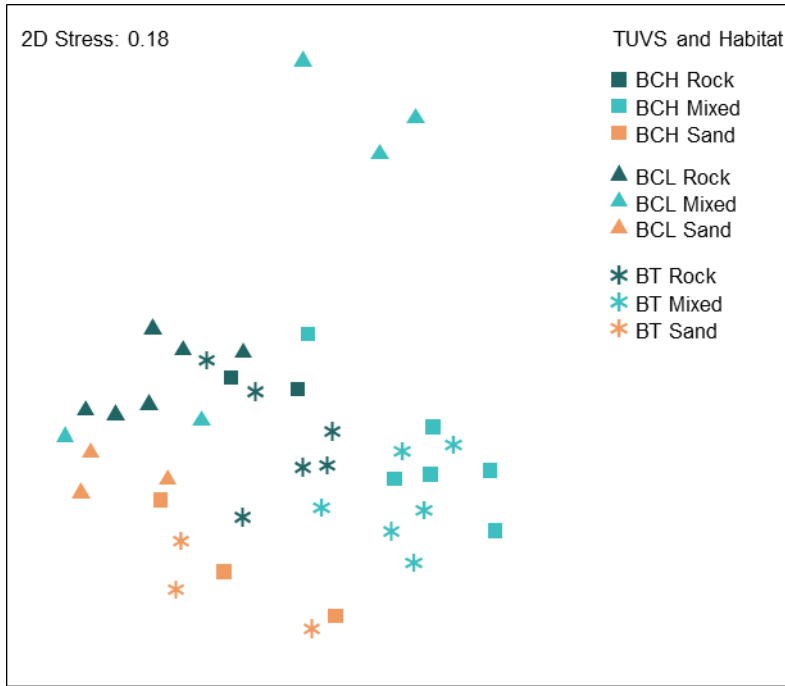
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579 Fig. 4. Boxplot (box ranging from first to third quartile and showing median value, whiskers  
 580 extending to values equal to 1.5 the interquartile distance, and circles highlighting outliers) of  
 581 a) Number of taxa; b) Density (excluding hydroids); c) Cover between each TUVS on  
 582 different habitat types. For a) and c) Results from the pairwise tests used to interpret a  
 583 significant interaction are shown, where different numbers indicate that  $P < 0.001$  between  
 584 TUVS within each Habitat and \* indicate no overlap in the confidence intervals in the effect  
 585 size values; d) Barplot (Mean  $\pm$  SD) of damage impact based on an ordinal scale (Fig. 3),  
 586 width of bars indicate width of contact point of each TUVS.

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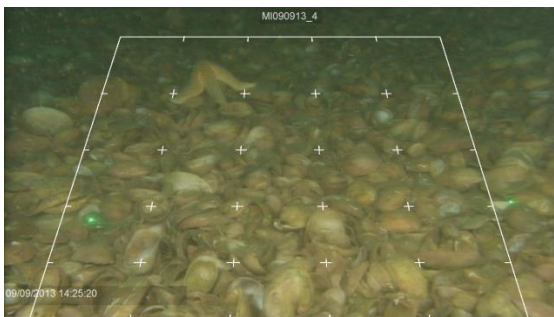
Fig. 5. nMDS ordination illustrating similarities in Assemblage Composition between TUVS and Habitat types (as displayed on the key). TUVS codes as shown in Figure 2.



Benthic Contacting Heavy



Benthic Contacting Light



Benthic Tending

593 Fig. 6. Example frame grabs from the three TUVs.



## Appendices

Table 1. Effect size value estimated from GLM analyses (marked differences between TUVs are highlighted in grey)

A) GLM Formula = NbTaxa ~ TUVS + Habitat + TUVS:Habitat

Family = Poisson		R <sup>2</sup> = 0.50			Effects : Mean (95% Confidence Interval)						
Coefficient	Estimate	SE	z value	Pr(> z )		MIXED		ROCK		SAND	
(Intercept)	0.2311	0.126	1.834	0.067	BCL	1.26	(0.98- 1.61)	3.28	(2.86- 3.78)	2.27	(1.79- 2.87)
BCH	1.2079	0.1408	8.579	>0.001	BCH	4.22	(3.73- 4.77)	6.00	(4.94- 7.29)	3.17	(2.59- 3.87)
BT	1.2877	0.1397	9.216	<0.001	BT	4.57	(4.06- 5.14)	6.57	(5.95- 7.25)	2.10	(1.64- 2.69)
ROCK	0.9577	0.1447	6.617	<0.001							
SAND	0.5872	0.1749	3.358	0.001							
BVH:ROCK	-0.605	0.1863	-3.248	0.001							
BT:ROCK	-0.5945	0.1647	-3.609	<0.001							
BVH:SAND	-0.8736	0.2123	-4.115	<0.001							
BT:SAND	-1.364	0.2238	-6.094	<0.001							

B) GLM Formula = Density ~ TUVS + Habitat + TUVS:Habitat

Family = Quasipoisson		R <sup>2</sup> = 0.26			Effects : Mean (95% Confidence Interval)						
Coefficient	Estimate	SE	z value	Pr(> z )		MIXED		ROCK		SAND	
(Intercept)	2.5257	0.2182	11.575	<0.001	BCL	12.5	(8.1- 19.2)	52.0	(42.9- 63.0)	13.3	(7.8- 22.8)
BCH	0.8777	0.2532	3.467	<0.001	BCH	30.1	(23.4- 38.7)	68.7	(50.2- 94.0)	43.2	(32.1- 58.2)
BT	0.6222	0.2625	2.370	0.018	BT	23.3	(17.5- 31.0)	67.1	(56.7- 79.5)	19.8	(12.8- 30.8)
ROCK	1.4251	0.2391	5.961	<0.001							
SAND	0.0645	0.3493	0.185	0.854							
BVH:ROCK	-0.5987	0.3148	-1.902	0.058							
BT:ROCK	-0.3667	0.2930	-1.252	0.211							

BVH:SAND	0.2979	0.4018	0.741	0.459
BT:SAND	-0.2258	0.4397	-0.514	0.608

C) GLM Formula = Cover\* ~ TUVS + Habitat + TUVS:Habitat, \*arcsine-transformed values

Family = Gaussian		R <sup>2</sup> = 0.26			Effects : Mean (95% Confidence Interval)					
Coefficient	Estimate	SE	t value	Pr(> z )		MIXED		ROCK		SAND
(Intercept)	0.0815	0.0248	3.289	0.001	BCL	0.08 (0.03- 0.13)		0.15 (0.10- 0.19)		0.01 (0.00- 0.07)
BCH	0.2822	0.0336	8.411	<0.001	BCH	0.36 (0.32- 0.41)		0.64 (0.56- 0.73)		0.09 (0.02- 0.15)
BT	0.3840	0.0336	11.44	<0.001	BT	0.46 (0.42- 0.51)		0.69 (0.65- 0.74)		0.04 (0.00- 0.10)
ROCK	0.0655	0.0336	1.953	0.051						
SAND	-0.0712	0.0405	-1.759	0.079						
BVH:ROCK	0.2124	0.0587	3.620	<0.001						
BT:ROCK	0.1636	0.0464	3.528	<0.001						
BVH:SAND	-0.2058	0.0563	-3.654	<0.001						
BT:SAND	-0.3569	0.0563	-6.338	<0.001						

## Appendices

Table 2. Equipment specification, Operational and Video performance of the three TUVSs. Criteria is scored 1-3: 1. Room for improvement; 2. Fit for purpose; 3. Recommended.

Criteria	Benthic Contacting Heavy		Benthic Contacting Light		Benthic Tending	
<b>Equipment specification</b>						
Camera	3	Panasonic HC-V700 HD (1080p). Max depth: 600m	1	RovTech RSL portable camera system. Seacam (480p) wide angle. Max depth: 150m	3	Bowtech Surveyor HD set to 720p zoom and focus controllable at surface. Max depth: 6000m
Lights	3	2 x Projectuer LED Sealite® Sphere de Deep Sea Power and Light Corps. Max depth: 6000m	1	1 x RovTech Seabeam Ultra LED light. Max depth: 150m	3	3 x Bowtech LED lamps with light intensity controllable from the surface. Max depth: 3000m
Lasers	3	2 x SeaLaser® 100-5 (green), 532nm <5mW. Max depth: 2000m	2	2 x Trident SCUBA lasers (red). Max depth: 50m	2	2 x Z-Bolt SCUBA - (green). Max depth: 60m
CTD	-	None	-	None	-	Valeport mini CTD rated to 500m
Frame	3	Stainless steel sled with anodised aluminium housing. Contact with seabed: 2 runners	3	Stainless steel sled based on Salacia Marine/ Seafish design. Contact with seabed: 2 runners	3	40 mm box section aluminium, with ballast tubes to lift from the seabed. Contact with seabed: 1 central chain
Connection to viewing hardware	1	No connection	2	90m umbilical; Bowtech system top box with a Sony DVD recorder; recorder; GPS feed; and light control	3	200m umbilical; Bowtech System which allows control of camera focus, zoom, aperture, and intensity of lights
Power supply	3	SubCtech Li-Ion Powerpacks (25Ah 24V, ~3h autonomy) powering lights and lasers	3	Boat mains electrical supply or generator (see BT example)	3	Boat mains if electrical supplies clean electricity to power a computer or a 2KVA Honda generator through a 1000VA with a UPS (Uninterrupted

						power supply
Dimensions	3	L= 1500mm, W=1100mm, H=740mm	3	L=820mm, W=495mm, H=430mm	3	Frame: L=700mm, W=700mm, H=400mm. Ballast tubes: L=130mm, D=100mm. Chain: L=3.15M, W=33mm
Total weight: Fit for purpose	2	290kg	1	9kg	3	Frame=30kg, Chain=10kg. Total=40kg
Cost	3	€14,000	3	€12,000	2	€35,000
Subtotal (27)	<b>24</b>		<b>19</b>		<b>25</b>	
<b>Operational performance</b>						
Average No. of 200m tows per 8 hour day	2	6-8	3	8-10	3	8-10
Potential deployment in wind and tide	3	Force 7 No current restriction	1	Force 2 ≤ 1 knot tide	2	Force 6 ≤ 2.5 knot tide
Max deployment depth	3	600m	1	Depending on umbilical (here ~30m)	2	Depending on umbilical (here ~70m)
Deployment requirements	1	Requires two winches capable of lifting 300kg and 2 personnel under all scenarios	3	Deployed by hand. Can be deployed by 1 person, though 2 personnel optimal for cable management	2	Can be deployed by hand in shallow waters, requiring a winch or pot-hauler in deeper waters. 3 personnel required for optimal deployment

Operator skill required	3	Technician to deploy kit and a technician to operate camera	2	Technician to deploy kit and a Research assistant to operate camera	2	Technician to deploy kit and a Research assistant to operate camera
Subtotal (/15)	<b>12</b>		<b>10</b>		<b>11</b>	
<b>Video performance</b>						
Speed	2	Dependent on boat speed. Fast in places as not possible to monitor	1	Fast in places as it was light and left seabed easily	3	Constant and steady as long as the boat was controlled
Camera angle	3	35° to the horizontal. Good angle to the seabed to observe benthos	1	50° to the horizontal. Angle often pointed outwards to the water column	3	30° to the horizontal. Good angle to seabed to observe benthos
Image quality	3	Excellent when sled was at a steady speed	1	Low resolution of camera produced low quality images, difficult to ID some taxa	2	Consistently good, able to identify most taxa
Information on screen	3	No information on screen to insure maximum visibility . Time could be added if required.	1	Too much information, obscured image for analysis	3	Time and sample label
Field of view	3	Altitude 55cm; low camera inclination, giving a FOV of approximately 1.3 m <sup>2</sup>	1	Altitude 30cm; giving a FOV of approximately 0.16m <sup>2</sup>	2	Altitude 30 cm – 70 cm; giving FOV range of 0.074 m <sup>2</sup> to 0.387m <sup>2</sup>
Subtotal (/15)	<b>14</b>		<b>5</b>		<b>13</b>	
Total score (/57)	<b>50</b>		<b>34</b>		<b>49</b>	

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