Journal of Experimental Marine Biology and Ecology 445 (2013) 93–98

Contents lists available at SciVerse ScienceDirect

Journal of Experimental Marine Biology and Ecology

journal homepage: www.elsevier.com/locate/jembe

Performing fish counts with a wide-angle camera, a promising approach reducing divers' limitations

J. Assis *, B. Claro, A. Ramos, J. Boavida, E.A. Serrão

CCMAR, CIMAR-Laboratório Associado, University of Algarve, Portugal

A R T I C L E I N F O

Article history:
Received 11 October 2012
Received in revised form 15 April 2013
Accepted 16 April 2013
Available online 11 May 2013

Keywords:
Fish surveys
Underwater video
Underwater visual census
Wide-angle camera

A B S T R A C T

Visual standardised methods for census of reef fishes have long been used in fisheries management and biological surveys. However, these tools have inherent sources of bias and the SCUBA divers who perform them are highly constrained in terms of survey time, maximum depth and frequency of sampling. Alternatives like underwater video are thus being recommended in a wide range of configurations. Yet, all these techniques are still limited in field of view, particularly when compared to the ability of a SCUBA diver performing censuses. In this scope, we evaluated the potential of an underwater wide-angle camera (UWC) to survey fish assemblages by testing it against instantaneous underwater visual census (UVC). Our results showed minimal yet significant differences between methods, mainly because of the camera's loss of resolution when under extreme visibility conditions. Both approaches had the same consistency and ability to detect changes in fish assemblages but, to estimate total species richness, the UWC needed less field effort. Moreover, a SCUBA diver performing census had an effect on fish assemblages which introduced differences of greater magnitude than those found between methods. The removal of the diver effect, the proven ability to detect changes in fish assemblages and the verified gain in field effort, pointed the wide-angle camera as a promising tool to perform census of reef fishes.

1. Introduction

Underwater visual censuses (UVC) of reef fishes are the most accepted and widely used methods for both ecological and fishery-based field surveys. These are suitable tools to detect changes in species abundance, diversity and community structure (e.g., Bortone et al., 2000; Samoilys and Carlos, 2000), and have long been suggested to evaluate the effectiveness of fisheries management like Marine Protected Areas (MPAs; Lipej et al., 2003). Such a broad use is mainly due to the inadequacy of some traditional approaches and to the increasing need for reliable, nondestructive sampling techniques (Bortone et al., 1986). Yet, numerous studies question the validity of such surveys (e.g. Kulbicki, 1998; Sale and Sharp, 1983; Thresher and Gunn, 1986), stressing several sources of bias and inaccuracy. These include imprecise counts of abundant species (De Girolamo and Mazzoldi, 2001; Richards and Schnute, 1986), different counts between-divers (Watson and Quinn, 1997), the influence of divers on fish behaviour (Cole, 1994), the diver's experience and training level (Mapstone and Ayling, 1998; Williams et al., 2006), the low precision of estimates due to physiological effects related to SCUBA diving (Baddeley, 1971), the effect of ocean waves and currents (Harmelin-Vivien et al., 1985; Lincoln-Smith, 1989) and whether censuses are conducted instantaneously or not (see Ward-Paige et al., 2010). Moreover, while performing the surveys, SCUBA divers are highly constrained by limited bottom time, maximum depth, frequency of sampling and exposure to cold water (Hiscock, 1987; Langlois et al., 2010).

Given these limitations, researchers have compared the ability of different remote sampling methods in order to enhance the accuracy, precision and repeatability of field surveys (e.g. Cappo et al., 2004; Harvey et al., 2004; Tessier et al., 2005; Willis and Babcock, 2000). On specific contexts, underwater video may be a valid alternative to improve fish surveys. Specifically, when dealing with demersal fish communities, such approach may decrease the sources of inaccuracy (e.g., Harvey et al., 2004; Watson et al., 2005; Willis et al., 2000) and increase the efficiency of field effort (Watson and Harvey, 2007). This technique is being proposed in a wide range of configurations such as single video (e.g. Cappo et al., 2003), stereo-video (e.g. Lines et al., 2001), baited video (e.g. Collins et al., 2002; Westera et al., 2003), swimmable video (Bortone et al., 1991), remote operated vehicles (e.g. Trenkel et al., 2004) and ocean observatories (e.g. Aguzzi et al., 2011). However, all of these rely on video cameras with limited field of view, which may preclude species identification and limit the estimation of abundance (Tessier et al., 2005). The present study is the first attempt to evaluate the ability of an underwater wide-angle camera (UWC) to survey fish assemblages, by simulating the field of view of a SCUBA diver while performing counts. Furthermore, since divers may influence fish behaviour, we hypothesise that a stand-alone camera can overcome such a source of inaccuracy. In this scope, data driven from UWC and UVC was tested under the following null hypotheses: (1) There is no difference in demersal fish abundance, community

---

* Corresponding author at: CCMAR, CIMAR-Laboratório Associado, University of Algarve, Campus de Gambelas, 8005-139 Faro, Portugal. Tel./fax: +351 289800051.
E-mail address: jorgemfa@gmail.com (J. Assis).

0022-0981/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jembe.2013.04.007

structure and species richness between methods. (2) The presence of a diver doesn't have an effect on demersal fish abundance and community structure.

2. Methods

2.1. Study site and data collection

Underwater surveys were performed from November 2011 to February 2012 in Praia da Luz, Lagos, Portugal (coordinates WGS 84: 37.07743° −8.74316°) at 4 separate sites, 100 m apart. These surveys were conducted over the same habitat type (rocky reef) and depth range (from 5 to 7 m) because fish assemblages generally have strong relationships with landscape heterogeneity and depth (Anderson and Millar, 2004; Hyndes et al., 1999). Fish counts were made by a single trained diver that performed 40 surveys of instantaneous *underwater visual census* (UVC) at each site (160 surveys; 12 surveys per dive). Instantaneous counts were chosen to reduce at most the bias introduced by the movement of fish per se, which may be attracted to or avoid the stationary diver (Ward-Paige et al., 2010; Watson and Quinn, 1997). The surveys were accomplished by swimming into one of the 4 sites and rapidly scan an area of 180° with a radius of 3 to 5 m, depending on the visibility (adapted from Bennett et al., 2009). All demersal fish observed were recorded in as short a time as possible (Barrett and Buxton, 2002). Fish that entered the survey area after the census started were not counted (e.g. Ward-Paige et al., 2010). Using the visibility records of each survey, counts were transformed to fish density.

Video records were conducted with a 180° angle video system consisting of two GoPro High Definition cameras mounted side by side over a tripod. The system was deployed before the surveys, in the exact same sites where the visual censuses took place. In the laboratory, the digital files from the two cameras were synchronised and merged into single wide-angled video records (proportion of 32:9 with 3840 × 1080 pixels). Counts were performed by recording all demersal fish observed in video fractions of less than 10 s. This allowed comparisons with the UVC and enhanced species identification, while avoiding for the entrance of new fish into the survey area. For surveys considering the absence of a diver (see below), records were made at least 2.5 min after the diver leave the survey area. Video records were transformed into fish density, using the visibility records of the UVC surveys.

2.2. Data analysis

2.2.1. Testing the ability of the underwater wide-angle camera

The ability of the UWC was tested by a permutation multivariate ANOVA (PERMANOVA; Anderson, 2001) with 2 factors ("survey method" with 2 levels nested on "site" with 4 levels). This analysis was performed on a Bray–Curtis similarity matrix, computed with square-root transformed data (e.g. Lowry et al., 2012) of fish density from UWC and UVC, obtained at the same precise sites and instants (2 × 160 surveys). The factor "site" was introduced to isolate the analysis from possible sources of variance originated by differences in reef topography among sites. Differences caused by this factor were not subject to further analysis or discussion. Since PERMANOVA uses similarity measures, the rejection of the null hypothesis suggests that groups may differ due to their location (in the multivariate space), their relative dispersion, or both (Anderson, 2004). To unravel the reason for rejecting the null hypothesis, a permutation analysis of multivariate dispersion (PERMDISP; Anderson, 2004) was performed on the same Bray–Curtis matrix (e.g. Bunn et al., 2010; Pease et al., 2011).

If the PERMANOVA revealed differences for the factor "survey method", a SIMPER analysis (Clarke, 1993; Clarke and Gorley, 2006) was conducted to ascertain the species that most contributed to the dissimilarities found and to weight differences in terms of average abundance. Furthermore, a two-way Analysis of Similarity (ANOSIM; Clarke, 1993) was performed with the same model ("survey method" with 2 levels nested on "site" with 4 levels) and Bray–Curtis matrix (UVC versus UWC) to measure dissimilarities between methods (e.g. Smale et al., 2010; Tuya et al., 2005). A non-metric multidimensional scaling ordination (nMDS; Clarke, 1993) was plotted to illustrate such differences. PERMANOVA, PERMDISP, ANOSIM, SIMPER and nMDS were computed on R version 2.15.0 (R Foundation for Statistical Computing) using the Vegan and ecodist packages.

The potential of UWC to estimate species richness was evaluated by plotting rarefaction curves (randomised richness plot against the number of surveys). These were computed with Rich (Rossi, 2011) on R software, using data from 160 surveys of the UWC and UVC, obtained at the same precise sites and instants. The total species richness, the average species richness per survey and the number of surveys needed to estimate 95% of total richness (i.e. field effort) were determined for the UWC and UVC by means of bootstrapping with Rich. Comparisons between the rarefaction curves and the average richness per survey were also tested with Rich package.

2.2.2. The effect of a diver on fish assemblages

The effect of a diver on fish assemblages was tested by PERMANOVA with 2 factors ("diver's presence" with 2 levels nested on "site" with 4 levels). This was performed on a Bray–Curtis similarity matrix computed with square-root transformed data of UWC density records, obtained at the same precise sites, in the presence and complete absence of a diver (2 × 160 surveys). PERMDISP was then performed on the same Bray–Curtis matrix to test for differences in the multivariate dispersion.

If the PERMANOVA revealed differences for the factor "diver's presence", a SIMPER was conducted to ascertain the species that most contributed to dissimilarities. To measure these differences, an ANOSIM was performed with the same model and Bray–Curtis matrix (presence versus absence of a diver). Moreover, nMDS of this matrix was plotted to illustrate the potential differences.

To better understand the diver's effect on fish, a simulation of instantaneous UVC was conducted with a diver taking exactly 1 min to census an area of 180° × 5 m. A pairwise PERMANOVA with the 2 factors ("diver's presence" with 3 levels nested on "site" with 4 levels) was performed on a Bray–Curtis similarity matrix computed with square-root transformed data driven from 160 replicates of UWC. Variance components were extracted for records taken 1 min before the diver got into the survey site, on the exact moment the diver entered the site and 1 min after his entrance (3 × 160 surveys). PERMDISP was performed on the same Bray–Curtis matrix to test for differences in the multivariate dispersion.

3. Results

The surveys conducted at the 4 sites of Praia da Luz retrieved 580 records of UVC (2711 individuals counted; approximately 12 h of underwater counts; 15 taxa) and 1140 records of UWC (3859 individuals counted; approximately 36 h of continuous digital video; 15 taxa). Due to the impossibility to visually identify individuals of Mugilidae at the species level, records were made at the family level. In the UWC records, 2.84% of the individuals could not be identified and thus were not included in the analysis. This was not an issue for UVC, where all individuals were assigned to the species/family level.

3.1. Testing the ability of the underwater wide-angle camera

Fish assemblages differed significantly between the UWC and UVC (PERMANOVA p-values < 0.05; Table 1). The analysis of dispersion suggested that this difference was caused by a shift in the assemblage structure (i.e. a location effect), and not by variation around the mean composition within groups (Anderson, 2004; PERMDISP between

Table 1
PERMANOVA and PERMDISP based on a Bray–Curtis similarity matrix of square-root transformed fish density (factors ST for "site" and SM for "survey method").

	PERMANOVA						PERMDISP	
Source	df	SS	MS	Pseudo-F	p-Value	Unique perms	F	p-Value
ST	3	41,643	8328.6	10.484	0.001	998	5.6243	0.001
SM (ST)	4	35,902	5983.6	7.532	0.001	997	0.51953	0.516
Residuals	206	1.64E + 05	794.43					
Total	217	2.41E + 05						

sites: F 5.6243, p-value 0.001; PERMDISP between methods: F 0.51953, p-value 0.516; Table 1).

ANOSIM found dissimilarities between the UWC and UVC, yet these were barely separable (Global R: 0.112; Significance level: 0.01; Clarke and Gorley, 2006). The nMDS illustrated no clear differentiation between methods (Fig. 1). Yet, the stress measure indicated a poor to nearly random ordering of the nMDS points (Stress: 0.223; R^2: 0.842; Clapham, 2011). The average similarity among surveys (SIMPER analysis) was 58.50% and 57.11% for the UWC and UVC, respectively. The average dissimilarity between methods was 41.23%. SIMPER analysis also showed that 7 species contributed to more than 90% of the dissimilarity found between methods and that all these species were more abundant on UVC (Appendix A).

Both rarefaction curves and bootstrapping showed that the UWC and UVC had the same ability to estimate total species richness (Fig. 2; p-value: 0.263). Yet, the average richness per survey was different, with 2.82 and 3.22 species per survey for the UWC and UVC, respectively (p-value < 0.05). To estimate 95% of the total species richness, the UVC required 88 ± 3 field surveys while the UWC required 72 ± 4 surveys (a gain of 9 to 23 surveys, which is equivalent to 1 or 2 UVC dives with 12 surveys).

3.2. The effect of a diver on fish assemblages

The presence of a SCUBA diver changed the composition of fish assemblages (PERMANOVA p-values < 0.05; Table 2). This effect occurred on both assemblage structure and variation around the mean composition within groups (i.e. a location and dispersion effect; PERMDISP: F 57.89, p-value 0.001).

ANOSIM also found dissimilarities in fish assemblages due to the diver's presence. These differences were barely separable (Global R: 0.175; Significance level: 0.01) but of greater magnitude than those found between methods ($0.175 > 0.112$). The nMDS illustrated this differentiation, yet, with a poor ordering of points (Stress: 0.207; R^2: 0.862; Fig. 3).

The similarity of surveys was 62.63% when the diver was present and 42.06% when he was absent (SIMPER analysis; Appendix B). The dissimilarity between these two groups of data was 61.66%, a higher value than that found between methods ($61.66 > 41.23$). Eight species contributed to more than 90% of the dissimilarities found. The species *Coris julis* and *Sarpa salpa* were more abundant (on average) when the diver was present, while all the other species were less abundant.

In the UVC simulation, fish assemblages changed when the diver got into the survey area, yet during his permanence on site, no further effect was detected (Pairwise PERMANOVA tests; Table 3). In terms of dispersion, his entrance resulted in differences in assemblage structure and variation around the mean composition (Table 3).

4. Discussion

This paper shows that an underwater wide-angle camera can be a suitable tool to assess fish assemblages, with increased efficiency of field effort while reducing the negative effect of divers. Yet, it is widely recognised that there is no single technique to census fish assemblages without its own sources of biases (Kingsford and Battershill, 1998; Lincoln-Smith, 1989). The results from our study showed that the UWC had lower resolution than the traditional visual census, counting fewer individuals and retrieving lower species richness per survey. It is well documented that, compared to the human eye, underwater video has a lower ability to record fish in their natural environment (e.g. Bailey and Priede, 2002; Pelletier et al., 2011; Sainte-Marie and Hargrave, 1987; Tessier et al., 2005). This was particularly evident in records made under extreme visibility conditions. On surveys with low visibility, mimetised fish were impossible to distinguish from the

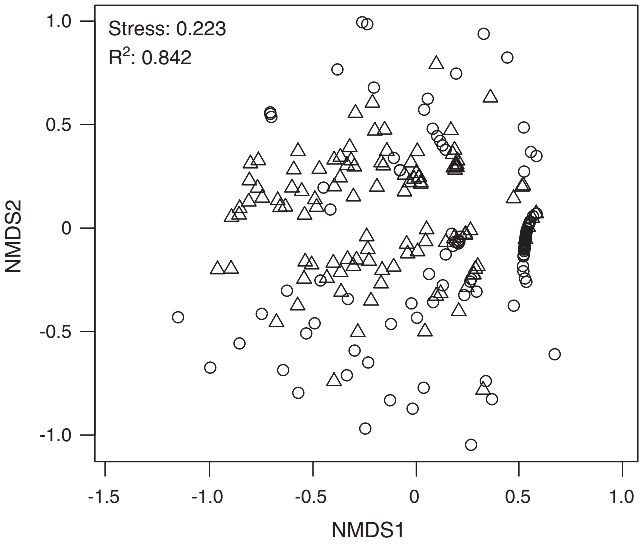

Fig. 1. nMDS of the Bray–Curtis square-root transformed data matrix of fish density from UVC (triangles) and UWC (circles).

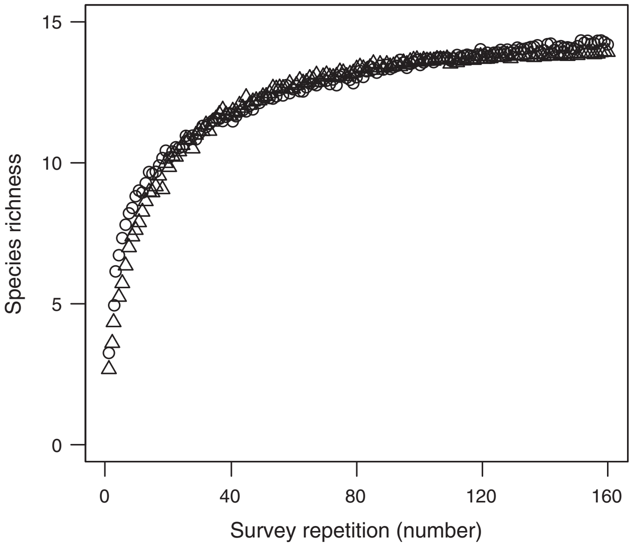

Fig. 2. Randomised species richness per survey intensity (999 randomisations) for UVC (circles) and UWC (triangles).

Table 2
PERMANOVA and PERMDISP based on a Bray–Curtis similarity matrix of square-root transformed fish density (factors ST for "site" and PD for "presence of diver").

	PERMANOVA						PERMDISP	
Source	df	SS	MS	Pseudo-F	p-Value	Unique perms	F	p-Value
ST	3	37,245	9311.3	7.6205	0.001	999	11,536	0.001
PD (ST)	4	33,086	6617.1	5.4155	0.001	998	57.89	0.001
Residuals	188	2.30E + 05	1221.9					
Total	197	3.01E + 05						

shaded background, while when the visibility was high the camera's video sensors smeared the edges of details (also reported by Shortis et al., 1993), producing low contrasted imagery, and thereby making the detection of fish silhouettes less precise. This source of inconsistency not only was responsible for fewer counts, but also made it impossible to identify specimens in about 3% of the occurrences (similar value to Pelletier et al., 2011).

Another factor that may have contributed to fewer counts with the UWC was the duration of surveys. Even under an instantaneous approach, the UVC surveys took more time than the UWC records (which were exactly 10 s) because the diver needed to identify, count and record fish, making him spend time looking at the slate instead of the aggregations (also noted by Pelletier et al., 2011). This might have allowed fish to enter or leave the survey area without being detected by the diver (Bortone et al., 1991). This distraction may have increased the probability of counting the same fish twice or recording more species per survey. Considering this, the accurate measurement of the camera's true loss of resolution becomes a puzzling exercise. Nevertheless, even with the implicit loss of resolution, the differences found between methods were barely separable and the survey's variability differed in less than 1%, suggesting that these methods have the same power and consistency in data records (Watson et al., 2005).

The differences found between methods were less important than those introduced by the presence of a SCUBA diver. In our simulations, the effect of the diver resulted in changes in fish assemblages, from the moment he entered the survey area until the end of the counts. In addition, the assemblages were more similar between surveys when the diver was present then on his absence. This consistency in data can be explained by a systematic responsive behaviour from species towards the diver. Our results showed that species that form large schools with no commercial value (*C. julis* and *S. salpa*) were attracted to the diver and produced higher abundances. All the other species, which are known to be targeted by spearfishers in this region (with exception for *Centrolabrus exoletus*; see Veiga et al., 2010), and consequently deterred by the human presence (Bozec et al., 2011), avoided the diver, yielding lower abundances. Other studies demonstrated the same systematic behaviour of targeted and non-targeted fish towards divers (e.g. Edgar et al., 2004; Watson et al., 2005; Willis et al., 2000). With the stand-alone camera we found higher variability in data between surveys, i.e., without such responsive behaviour, it was more likely to record different patterns of fish assemblages. Conditioned behaviour can occur with various species, for instance, when outside an MPA fish avoid divers as a learned response to the presence of spearfishers (Jouvenel and Pollard, 2001), or within an MPA when they are attracted to divers, due to curiosity or in response to hand-feeding (Cole, 1994; Willis et al., 2000). In either situation, alternatives to visual census like the UWC should be considered in order to reduce bias when evaluating the effectiveness of fisheries management.

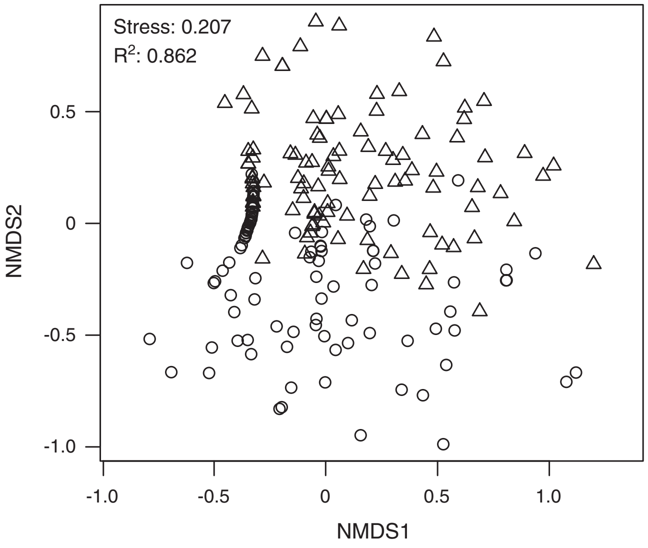

Fig. 3. nMDS of the Bray–Curtis square-root transformed data matrix of UWC density records in the presence (circles) and absence (triangles) of a diver.

The higher variability found in data when the diver was absent from surveys may also explain the differences between methods in terms of field effort. The UWC gathered less species per survey, yet it achieved total species richness with less field effort than UVC. Since fish were expected to have no responsive behaviour towards the UWC alone, there was an increased probability of sighting more different species, even with lower richness per survey. It has been postulated that for most aims methods that produce the greatest amount of information in the least amount of time are the most effective (Bortone and Mille, 1999) and thus should be used for field surveys.

Techniques like the UWC have even further inherent advantages. There is no variability between observers recording the data, which has been demonstrated by several authors (most notably Thompson and Mapstone, 1997) to systematically bias the UVC-based data driven from different divers. There is also a lower risk of counting the same fish more than once. Furthermore, the reduction in field effort can be largely improved if one considers the deployment of multiple UWC systems at different depths and habitats (e.g. Watson et al., 2005). Also, divers' experience, census time, maximum depth and exposure restrictions are not concerns with the underwater video. Records can be made from far greater depths and over longer periods of time. Such reduced field effort also implies lower field costs, which generally are higher than the laboratory costs (Francour et al., 1999; Pelletier et al., 2011). Furthermore, divers that perform UVC need to be trained to identify and count fish species underwater, which carries even more substantial cost. This can be either in terms of additional field expenses and salaries, or, more usually, by reducing replication during data gathering, which reduces the power of statistical tests (Edgar et al., 2004). With minimal training, technicians and volunteers can assist with the analysis of imagery.

Underwater video can also be used with different objectives than initially considered (e.g. fish behaviour, benthic invertebrate surveys, and groundtruthing for other remote sensing techniques) reducing the need for conducting additional expensive field surveys. Unlike a diver who has to make immediate decisions and records underwater, in the laboratory, video observers can review the images later and

Table 3
Pairwise PERMANOVA and PERMDISP analysis based on a Bray–Curtis similarity matrix of square-root transformed fish density (D.E. − 1 = 1 min before the diver got into the survey site; D.E.0 = on the exact moment the diver entered the site; D.E. + 1 = 1 min after his entrance).

	PERMANOVA								PERMDISP	
	Site 1		Site 2		Site 3		Site 4			
Source	t	p-Value	t	p-Value	t	p-Value	t	p-Value	F	p-Value
D.E. − 1. D.E.0	2.088	0.006	1.7287	0.029	1.988	0.016	1.7159	0.036	4.6984	0.001
D.E. − 1. D.E. + 1	1.7062	0.019	1.5275	0.047	1.8062	0.021	2.012	0.008	2.7634	0.02
D.E.0. D.E. + 1	1.032	0.369	0.29236	0.913	0.66425	0.729	0.71677	0.694	1.5621	0.187

repeatedly for more than one objective (Harvey et al., 2001). This can also be of use to update species identification after taxonomical revisions, which result in nomenclatural changes. These advantages, coupled with future advances in video sensors, will surely improve the statistical power of fisheries management and biological surveys.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jembe.2013.04.007.

References

Aguzzi, J., Mànuel, A., Condal, F., Guillén, J., Nogueras, M., del Rio, J., Costa, C., Menesatti, P., Puig, P., Sardà, F., Toma, D., Palanques, A., 2011. The new seafloor observatory (OBSEA) for remote and long-term coastal ecosystem monitoring. Sensors 11, 5850–5872.

Anderson, M.J., 2001. A new method for non-parametric multivariate analysis of variance. Aust. Ecol. 26, 32–46.

Anderson, M.J., 2004. PERMDISP: A FORTRAN Computer Program for Permutation Analysis of Multivariate Dispersions (for any two-factor ANOVA design) using Permutation Tests. Department of Statistics, University of Auckland, New Zealand.

Anderson, M.J., Millar, R.B., 2004. Spatial variation and effects of habitat on temperate reef fish assemblages in northeastern New Zealand. J. Exp. Mar. Biol. Ecol. 305, 191–221.

Baddeley, A.D., 1971. Diver performance. In: Woods, J.D., Lythgoe, J.N. (Eds.), Underwater Science. Oxford Univ. Press, London, pp. 33–67.

Bailey, D.M., Priede, I.G., 2002. Predicting fish behaviour in response to abyssal food falls. Mar. Biol. 141, 831–840.

Barrett, N., Buxton, C.D., 2002. Examining underwater visual census techniques for the assessment of population structure and biodiversity in temperate coastal marine protected areas. Tasman. Aquac. Fish. Inst. Tech. Rep. Ser. 11, 1–114.

Bennett, R.H., Gotz, A., Sauer, W.H.H., Cowley, P.D., Palmer, R.M., 2009. Optimisation of underwater visual census and controlled angling methods for monitoring subtidal temperate reef fish communities. Afr. J. Mar. Sci. 31 (3), 277–287.

Bortone, S.A., Mille, K.J., 1999. Data needs for assessing marine reserves with an emphasis on estimating fish size in situ. Naturalista Sicil. 23, 13–31.

Bortone, S.A., Hastings, H.W., Oglesby, J.L., 1986. Quantification of reef fish assemblages: a comparison of several in situ methods. Northeast Gulf Sci. 8, 1–22.

Bortone, S.A., Martin, T., Bundrick, C.M., 1991. Visual census of reef fish assemblages: a comparison of slate, audio and video recording devices. Northeast Gulf Sci. 12, 17–23.

Bortone, S.A., Samoilys, M.A., Francour, P., 2000. Fish and macroinvertebrate evaluation. In: Seaman Jr., W. (Ed.), Artificial Reef Evaluation with Application to Natural Marine Habitats. CRC Press, Boca Raton, pp. 127–164.

Bozec, Y.M., Kulbicki, M., Mou-Tham, G., Gascuel, D., 2011. Factors affecting the detection distances of reef fish: implications for visual counts. Mar. Biol. 5, 969–981.

Bunn, S.E., Abal, E.G., Smith, M.J., Choy, S.C., Fellows, C.S., Harch, B.D., Kennard, M.J., Sheldon, F., 2010. Integration of science and monitoring of river ecosystem health to guide investments in catchment protection and rehabilitation. Freshw. Biol. 55, 223–240.

Cappo, M., Harvey, E., Malcolm, H., Speare, P., 2003. Advantages and applications of novel “video-fishing” techniques to design and monitor Marine Protected Areas. In: Beumer, J.P., Grant, A., Smith, D.C. (Eds.), Aquatic Protected Areas — What Works Best and How Do We Know? : Proceedings of the World Congress on Aquatic Protected Areas, pp. 455–464 (Cairns, Australia).

Cappo, M., Speare, P., De'ath, G., 2004. Comparison of baited remote underwater video stations (BRUVS) and prawn trawls for assessments of fish biodiversity in inter-reefal areas of the Great Barrier Reef Marine Park. J. Exp. Mar. Biol. Ecol. 302, 123–152.

Clapham, M., 2011. Ordination methods and the evaluation of Ediacaran communities. In: Laflamme, M., Schiffbauer, J.D., Dornbos, S.Q. (Eds.), Quantifying the Evolution of Early life: Topics in Geobiology, 36, pp. 3–22.

Clarke, K.R., 1993. Non-parametric multivariate analyses of changes in community structure. Aust. J. Ecol. 18, 117–143.

Clarke, K.R., Gorley, R.N., 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.

Cole, R.G., 1994. Abundance, size structure, and diver-oriented behaviour of three large benthic carnivorous fishes in a marine reserve in northeastern New Zealand. Biol. Conserv. 70, 93–99.

Collins, M.A., Yau, C., Guilfoyle, F., Bagley, P., Everson, I., Priede, I.G., Agnew, D., 2002. Assessment of stone crab (Lithodidae) density on the South Georgia slope using baited video cameras. ICES J. Mar. Sci. 59, 370–379.

De Girolamo, M., Mazzoldi, C., 2001. The application of visual census on Mediterranean rocky habitats. Mar. Environ. Res. 51, 1–16.

Edgar, G.J., Barrett, N.S., Morton, A.J., 2004. Biases associated with the use of underwater visual census techniques to quantify the density and size-structure of fish populations. J. Exp. Mar. Biol. Ecol. 308, 269–290.

Francour, P., Liret, C., Harvey, E., 1999. Comparison of fish abundance estimates made by remote underwater video and visual census. Nat. Sicil. 23, 155–168.

Harmelin-Vivien, M.L., Harmelin, J.G., Chauvet, C., Duval, C., Galzin, R., Lejeune, P., Barnabe, G., Blanc, F., Chevalier, R., Duclerc, J., Lassere, G., 1985. Evaluation visuelle des peuplements et populations de poissons: methodes et problemes. Rev. Ecol. Terre Vie 40, 467–539.

Harvey, E., Fletcher, D., Shortis, M., 2001. A comparison of the precision and accuracy of estimates of reef-fish lengths determined visually by divers with estimates produced by a stereo-video system. Fish. Bull. 99, 63–71.

Harvey, E., Fletcher, D., Shortis, M.R., Kendrick, G.A., 2004. A comparison of underwater visual distance estimates made by SCUBA divers and a stereo-video system: implications for underwater visual census of reef fish abundance. Mar. Freshw. Res. 55, 573–580.

Hiscock, K., 1987. Subtidal rock and shallow sediments using diving. In: Baker, J.M., Wolff, W.J. (Eds.), Biological Surveys of Estuaries and Coasts. Cambridge University Press, Cambridge, pp. 198–237.

Hyndes, G.A., Platell, M.E., Potter, I.C., Lenanton, R.C.J., 1999. Does the composition of the demersal fish assemblages in temperate coastal waters change with depth and undergo consistent seasonal changes? Mar. Biol. 134, 335–352.

Jouvenel, J.Y., Pollard, D.A., 2001. Some effects of marine reserve protection on the population structure of two spearfishing target-fish species, *Dicentrarchus labrax* (Moronidae) and *Sparus aurata* (Sparidae), in shallow inshore waters, along a rocky coast in the northwestern Mediterranean Sea. Aquat. Conserv. Mar. Freshw. Ecosyst. 11, 1–9.

Kingsford, M., Battershill, C., 1998. Studying Temperate Marine Environments: A Handbook for Ecologists. Canterbury University Press, Christchurch 335.

Kulbicki, M., 1998. How the acquired behaviour of commercial reef fishes may influence the results obtained from visual censuses. J. Exp. Mar. Biol. Ecol. 222, 11–30.

Langlois, T., Harvey, E., Fitzpatrick, B., Meeuwig, J., Shedrawi, G., Watson, D., 2010. Cost-efficient sampling of fish assemblages: comparison of baited video stations and diver video transects. Aquat. Biol. 9 (2), 155–168.

Lincoln-Smith, M.P., 1989. Improving multispecies rocky reef fish censuses by counting different groups of species using different procedures. Environ. Biol. Fishes 26, 29–37.

Lines, J.A., Tillett, R.D., Ross, L.G., Chan, D., Hockaday, S., McFarlane, N.J.B., 2001. An automatic image-based system for estimating the mass of free-swimming fish. Comput. Electron. Agric. 31, 151–168.

Lipej, L., Bonaca, M.O., Sisko, M., 2003. Coastal fish diversity in three marine protected areas and one unprotected area in the Gulf of Trieste (Northern Adriatic). Mar. Ecol. 24, 259–273.

Lowry, M., Folpp, H., Gregson, M., Suthers, I., 2012. Comparison of baited remote underwater video (BRUV) and underwater visual census (UVC) for assessment of artificial reefs in estuaries. J. Exp. Mar. Biol. Ecol. 417, 243–253.

Mapstone, B.D., Ayling, A.M., 1998. An investigation of optimum methods and unit sizes for the visual estimation of abundances of some coral reef organisms. Great Barrier Reef Marine Park Authority Res Pub Ser 47, Townsville, Queensland.

Pease, A.A., Taylor, J.M., Winemiller, K.O., King, R.S., 2011. Multiscale environmental influences on fish assemblage structure in central Texas streams. Trans. Am. Fish. Soc. 140 (5), 1409–1427.

Pelletier, D., Leleu, K., Mou-Tham, G., Guillemot, N., Chabanet, P., 2011. Comparison of visual census and high definition video transects for monitoring coral reef fish assemblages. Fish. Res. 107 (1–3), 84–93.

Richards, L.J., Schnute, J.T., 1986. An experimental and statistical approach to the question: is CPUE and index of abundance? Can. J. Fish. Aquat. Sci. 43, 1214–1227.

Rossi, J.P., 2011. Rich: species richness. Diversity 3 (1), 112–120.

Sainte-Marie, B., Hargrave, B.T., 1987. Estimation of scavenger abundance and distance of attraction to bait. Mar. Biol. 94, 431–433.

Sale, P.F., Sharp, B.J., 1983. Correction for bias in visual transect censuses of coral reef fish. Coral Reefs 2, 37–42.

Samoilys, M.A., Carlos, G., 2000. Determining methods of underwater visual census for estimating the abundance of coral reef fishes. Environ. Biol. Fishes 57, 289–304.

Shortis, M.R., Snow, W.L., Childers, B.A., Goad, W.K., 1993. The influence of storage media on the accuracy and repeatability of photogrammetric measurements using CCD cameras. Videometrics II, 2067. SPIE (International Society for Optical Engineering), pp. 80–92.

Smale, D.A., Kendrick, G.A., Waddington, K.I., Van Niel, K.P., Meeuwig, J.J., Harvey, E.S., 2010. Benthic assemblage composition on subtidal reefs along a latitudinal gradient in Western Australia. Estuarine Coastal Shelf Sci. 86 (1), 83–92.

Tessier, E., Chabanet, P., Othin, K., Soria, M., Lasserre, G., 2005. Visual censuses of tropical fish aggregations on artificial reefs: slate versus video recording techniques. J. Exp. Mar. Biol. Ecol. 315, 17–30.

Thompson, A.A., Mapstone, B.D., 1997. Observer effects and training in underwater visual surveys of reef fishes. Mar. Ecol. Prog. Ser. 154, 53–63.

Thresher, R.E., Gunn, J.S., 1986. Comparative analysis of visual census techniques for highly mobile, reef-associated piscivores (Carangidae). Environ. Biol. Fishes 17 (2), 93–116.

Trenkel, M.A., Francis, R.I.C., Lorance, A., Mahévas, S., Rochet, M., Tracey, D., 2004. Availability of deep-water fish to trawling and visual observation from a remotely operated vehicle (ROV). Mar. Ecol. Prog. Ser. 284, 293–303.

Tuya, F., Boyra, A., Sanchez-Jerez, P., Haroun, R.J., 2005. Multivariate analysis of the bentho-demersal ichthyofauna along soft bottoms of the Eastern Atlantic: comparison between unvegetated substrates, seagrass meadows and sandy bottoms beneath sea-cage fish farms. Mar. Biol. 147 (5), 1229–1237.

Veiga, P., Ribeiro, J., Gonçalves, J.M.S., Erzini, K., 2010. Quantifying recreational shore angling catch and harvest in the south of Portugal (north-east Atlantic Ocean): implications for conservation and integrated fisheries management. J. Fish Biol. 76, 2216–2237.

Ward-Paige, C., Mills Flemming, J., Lotze, H.K., 2010. Overestimating fish counts by non-instantaneous visual censuses: consequences for population and community descriptions. PLoS One 5 (7), e11722.

Watson, D.L., Harvey, E.S., 2007. Behaviour of temperate and sub-tropical reef fishes towards a stationary SCUBA diver. Mar. Freshw. Behav. Physiol. 40, 85–103.

Watson, R.A., Quinn, T.J., 1997. Performance of transect and point count underwater visual census methods. Ecol. Model. 104, 103–112.

Watson, D.L., Harvey, E.S., Anderson, M.J., Kendrick, G.A., 2005. A comparison of temperate reef fish assemblages recorded by three underwater stereo-video techniques. Mar. Biol. 148, 415–425.

Westera, M., Lavery, P., Hyndes, P., 2003. Differences in recreationally targeted fishes between protected and fished areas of a coral reef marine park. J. Exp. Mar. Biol. Ecol. 294, 145–168.

Williams, I.D., Walsh, W.J., Tissot, B.N., Hallacher, L.E., 2006. Impact of observers' experience level on counts of fishes in underwater visual surveys. Mar. Ecol. Prog. Ser. 310, 185–191.

Willis, T.J., Babcock, R.C., 2000. A baited underwater video system for the detection of relative density of carnivorous reef fish. Mar. Freshw. Res. 51, 755–763.

Willis, T.J., Millar, R.B., Babcock, R.C., 2000. Detection of spatial variability in relative density of fishes: comparison of visual census, angling, and baited underwater video. Mar. Ecol. Prog. Ser. 198, 249–260 **[SS]**.