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Video transects as a complement to underwater visual census to study reserve effect on fish assemblages

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ABSTRACT: The present study focuses on the use of diver-operated video (DOV) as a tool to evaluate the impact of a marine reserve on a fish assemblage, in comparison to underwater visual census (UVC). Samplings were conducted in the vicinity of the marine protected area (MPA) Cerbère-Banyuls (northwestern Mediterranean Sea). Four sites, with different levels of protection, were sampled 4 times, at depths of 5 and 10 m, to study abundance, species richness, structure of fish assemblages and fish aggregation. Results obtained by DOV and UVC provided evidence of significant effects of protection on abundance, species richness and fish assemblages. However, detection of weaker reserve effects using DOV may be limited. Furthermore, certain species are difficult to identify by video (e.g. *Symphodus* spp.), but DOV may be useful when studying a target and/or easily identifiable species. Contrary to UVC, DOV data can be archived and used for further study. Results concerning fish aggregation within fish assemblages showed specific patterns. Sites outside the MPA were mainly characterized by the absence of fish or few fish aggregations, and sites inside were characterized by high fish density (i.e. dispersed or patched aggregations). Thus, the fish aggregation parameter measured using DOV is an interesting metric to quantify reserve effect. Consequently, although this technique is time-consuming to produce results, DOV presents great potential for estimating MPA effectiveness while allowing simultaneous work on several sites to limit temporal bias.

KEY WORDS: MPA · Marine protected area · Reserve effect · Underwater video · Visual census · Mediterranean Sea · Fish

INTRODUCTION

Marine protected areas (MPAs) are an effective management tool to preserve marine biodiversity or resources and to prevent environmental degradation (e.g. Gell & Roberts 2003, Guidetti & Sala 2007, Himes 2007, Fenberg et al. 2012). The evaluation of their performance can be reviewed through (1) monitoring of the density and biomass of the targeted species (e.g. Côté et al. 2001, Ferraris et al. 2005, Claudet et al. 2011) or (2) biodiversity indicators, such as environmental health and the functioning of ecosystems (Bianchi & Morri 2000, Hilty & Merenlende 2000).

MPA creation may lead to a reserve effect induced by the effect of protection. A reserve effect reveals itself through an increase in (1) global species richness, (2) density, particularly that of species targeted by fishing (professional and recreational), and (3) frequency of large individuals compared to outside of the reserve (e.g. Alcala & Russ 1990, Francour 1994,

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Harmelin et al. 1995, Vacchi et al. 1998, Mosquera et al. 2000, García-Charton et al. 2004, Hussein et al. 2011, Sahyoun et al. 2013).

Other phenomena, such as spillover or propagule effects, may be observed in the adjacent areas. This may be due to an exportation of eggs, larvae, juveniles or adult individuals (Sabatés et al. 2003, Di Franco et al. 2012) and may contribute to the recolonization and increased catches of target species (Sabatés et al. 2003, Guidetti 2007, Harmelin-Vivien et al. 2008).

The study of reserve effect and performance effectiveness of MPAs requires data on fish assemblages. Such data can be sampled through destructive methods: angling, trawling, fixed nets or spearfishing (Willis et al. 2000, Cappo et al. 2004). In contrast, non-destructive methods, like underwater visual census (UVC: strip transect, point count or fish assemblage survey techniques), are also available (e.g. Harmelin-Vivien et al. 1985, Seytre & Francour 2009). UVC is generally preferred in MPAs and for the study of particular species (e.g. species with IUCN protection status).

Despite the worldwide use of UVC, numerous biases exist and are well documented. Biases are linked to the observer but also to factors that are intrinsic to the species observed (e.g. Harmelin-Vivien et al. 1985, Harvey et al. 2004, Cole et al. 2007). Furthermore, several parameters can limit the amount of scientific data collected on fish assemblages, such as dive time, depth, climatic conditions and sea temperature (Francour et al. 1999, Colton & Swearer 2010).

To reduce biases and limiting parameters, scientists have increasingly resorted to using video survey systems, such as baited (or unbaited) remote underwater video (BRUV) during the day or night (Francour et al. 1999, Denny et al. 2004, Harvey et al. 2007, 2012, Colton & Swearer 2010). These video methods are used to avoid some biases due to UVC (e.g. presence of the diver) but also to overcome limiting dive constraints (dive time, depth and sampling at dusk and dawn, facilitated by the high light-sensitivity of video; Francour et al. 1999). The use of video has the further advantage of enabling simultaneous studies to be carried out in different sites because it does not require a person able to identify the species in the field since identification is done in the laboratory. Thus, studies comparing UVC to video are becoming more frequent. They compare mainly UVC to BRUV (Willis & Babcock 2000, Willis et al. 2000, Stobart et al. 2007, Colton & Swearer 2010), omitting other methods of sampling using video.

The present study focuses on diver-operated video (DOV). Underwater video transects have been used sporadically for studies of fish (Boland & Lewbel. 1986, Michalopoulos et al. 1992, Tessier et al. 2005, Pelletier et al. 2011), in contrast to benthos (e.g. algae or corals). DOV, like other video methods, is less cost-efficient than UVC. In fact, the data acquisition time is greater for video because those data are acquired through analysis of videotapes in the laboratory (Francour et al. 1999), while in UVC, data are acquired directly in the field during the dive. Thus, with video, there is the time in the field and the time in the laboratory to visualize the video clip. Furthermore, DOV is less cost-efficient than other video methods. Like UVC, it requires divers and a similar amount of diving time, but it entails the additional cost needed for post-treatment in the laboratory. However, it may allow access to the aggregation of fish along a transect, which is not possible in UVC or methods using a fixed camera. A strong relationship between fishes and habitat has now been proven (e.g. Letourneur et al. 2003, García-Charton et al. 2004). As species richness is high in MPAs, it seems that information about spatial fish distribution and the presence of fish aggregation (with several species) could provide a new indicator for evaluating the effectiveness of MPAs.

However, it is obvious that like other methods (e.g. UVC and BRUV), this method will present biases (Colton & Swearer 2010), but DOV could be complementary to UVC to study fish assemblages and to detect a marine reserve effect. With the reserve effect, the number of fish often increases inside the reserve; thus, there is a greater possibility of inter- or intra-species aggregation of fish. As individual abundance increases in a given space, the aggregation of individuals also increases. This can be due to a lack of space, to grouping behaviour to escape predators or to finding food or shelter (Landeau & Terborgh 1986, Ward & Hart 2005). In fact, with the reserve effect, the food chain is more complex; thus, interactions between species are more varied, and a species has potentially more predators (Pauly et al. 1998, Guidetti & Sala 2007).

The purpose of the present paper is twofold. The first aim was to determine if DOV, like UVC, can indicate marine reserve effect. Fish assemblage abundance and the species richness stemming from both methods were compared regarding the reserve effect. The present study was carried out at the Cerbère-Banyuls marine reserve (France, Mediterranean Sea), which is known to have an effective reserve effect (Bell 1983, Dufour et al. 1995, Harmelin-

Vivien et al. 2008, Claudet et al. 2011). To compare UVC to DOV, a cost-benefit analysis was carried out for each method. The second objective of the present paper was to determine if a metric related to fish aggregation and assessed by DOV could provides additional information about marine reserve effect on ichthyofauna.

MATERIALS AND METHODS

Study area

The study site is located in the south of France in the Mediterranean Sea (Fig. 1) in the vicinity of the Cerbère-Banyuls MPA. It is oriented north–south, and includes bays and capes. Underwater slopes can be steep, and fish habitats are diverse, including *Posidonia* meadows, coralligenous rocks, rocks and sand. Four sites with similar habitats but with different levels of protection and fishing pressure were selected: Cape Rédéris in the no-take area (NO); Cape Abeille in the partially protected, regulated part of the reserve (R); Cape Canadell, south of the reserve, unprotected with moderate fishing pressure (OR-S); Cape Oullestrell, north of the reserve, with high fishing pressure (OR-N) (Table 1), All sites had similar exposure to wind and waves, including an uneven rocky area colonised by *Posidonia* meadows, algae and white gorgonians *Eunicella singularis* (Esper, 1794).

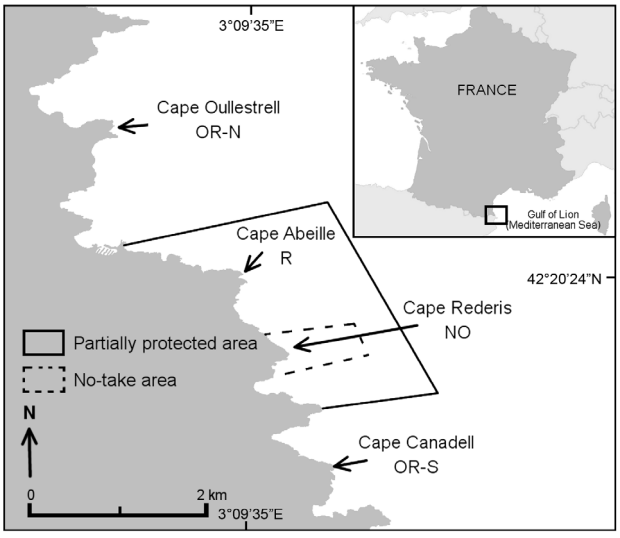

Fig. 1. Sampling locations along the French Catalan coast in SW France. OR-N/S: outside reserve north/south; R: reserve; NO: no-take area

Sampling methods

To limit any efects caused by changes in environmental conditions, sampling was conducted over 4 d during the summer of 2008 (between 21 and 28 August). Two visual census techniques (UVC and DOV) were used at each site at 5 m and 10 m depths. The sampling protocol consisted of 4 replicates (chosen randomly) per site, per depth and per method, yielding 63 samples (1 DOV sample was not available due to technical error).

The UVC method consisted of a transect belt of 5 × 50 m (250 m^2). The distance of 50 m was measured using a pentameter (Harmelin-Vivien et al. 1985). An experienced scientific diver swam at constant speed along the transect and noted the species observed on a slate. The same diver conducted all UVC counts to avoid biases due to the observer.

DOV surveys were carried out with a colour video camera placed in an underwater housing. All DOVs were made by the same video operator swimming

Table 1. Characteristics of sampling sites. OR-N: outside reserve north; OR-S: outside reserve south; R: reserve; NO: no-take area

Code	Sites	Location	Distance to		Protection status	Fishing pressure
			No-take area	Partially protected area		
OR-N	Cape Oullestrell	42° 30′ N, 3° 08′ E	4 km	3 km	Unprotected area: artisanal and recreational fishing are not regulated	High
R	Cape Abeille	42° 29′ N, 3° 09′ E	1 km	–	Partially protected area: artisanal and recreational fishing are regulated	Controlled
NO	Cape Rédéris	42° 28′ N, 3° 10′ E	–	1 km	No-take area: all human activities are prohibited	No pressure
OR-S	Cape Canadell	42° 27′ N, 3° 10′ E	2 km	3 km	Unprotected area: artisanal and recreational fishing are not regulated	Moderate

alongside the diver who performed the UVC and were made at the same speed. The camera operator swam 1.5 m above the bottom and, keeping the video camera steady and perpendicular to the bottom, recorded in front of himself. The area sampled in DOV is lower than in UVC (the camera's field of view angle is smaller than the human eye), and this area has not been estimated. However, the sampling area of the DOV transects is standard because the camera was always 1.5 m from the bottom and kept in the same position. Furthermore, the conditions of visibility were identical (10 m) during the sampling period (between 21 and 28 August). In the laboratory, the videos were analysed on a computer. A single viewer watched all of the video recordings to avoid a multiple-observer bias. The individuals observed were identified to species level or, in some cases, to genus level. To improve the viewer's ability to identify fish (Colton & Swearer 2010), each video was examined twice: a first reading to become familiar with the species and a second one to determine them. The number of individuals observed was also estimated, using freeze-frame when the number of specimens in movement was too high.

To determine whether fish aggregation was suitable as a reserve effect metric, the present study was carried out only on videos recorded at a depth of 10 m. Fifteen freeze-frames were taken randomly on each video transect, and a code of fish aggregation was attributed to each. After a preliminary study, 15 freeze-frames appeared to be the minimum number necessary to be representative of fish aggregation for a video of ~7 min. The fish aggregation code was applied without considering the species, only individuals. Five codes of fish aggregation were defined (Fig. 2): 'No fish' when no individual was observed in the freeze-frame, 'Isolated' if 1 to 3 fish were visible, 'Scattered' when fish were not observed in clusters, 'Fragmented' when fish were grouped in a cluster but with a certain distance between them (more than twice the individual length of fish) and 'Patch' if fish were in schools with a short distance between individuals (less than twice the individual length of fish).

Data analysis

Chromis chromis (Linnaeus, 1758) and *Coris julis* (Linnaeus, 1758) were not considered for the analysis of abundance and structure of fish assemblages because their high abundance at all of the studied sites increased the variance and limited statistical comparison (Francour 1997). *C. chromis* and *C. julis* also have gregarious behaviour that can mask the protection effect (García-Charton et al. 2004, Forcada et al. 2008).

Analyses were performed using the R 2.9.0 software (R Development Core Team 2008) and the Primer v6 multivariate statistics package (Clarke & Gorley 2006).

Univariate analyses were carried out to compare fish abundance and species richness among sites with both methods. Appropriate tests were used after validation of the conditions of application. The effect of protection status and depth on abundance and species richness was tested using a Scheirer-Ray-Hare's test (a non-parametric 2-way ANOVA; Sokal & Rohlf 1995). An *a posteriori* test (Mann-Whitney) was performed when the 2-way ANOVA detected a significant difference. This test was used to identify the modalities of the factor associated with the variation in the response variable. In order to compromise between a large overall Type I error and a large overall Type II error (with the application of a Bonferroni correction), a p-value of 0.01 was used in each separate *a posteriori* test.

To study the structure of fish assemblage analysis according to the method, sites and depths, we examined non-metric multi-dimensional scaling plots (nMDS) based on Bray-Curtis similarity coefficients. Hierarchical clusters based on group-average linkages of Bray-Curtis similarity coefficients were combined on the nMDS plots (Forcada et al. 2008). A permutational multivariate ANOVA (PERMANOVA; 9999 permutations) on Bray-Curtis similarity coefficients was made to identify significant differences in the proportion of each species in relation to a given factor using NPMANOVA software (Anderson 2000). An *a posteriori* test (Student's *t*-test with 9999 permutations) was used when a PERMANOVA indicated a significant difference.

The time required to collect and analyse data was used to conduct a cost-benefit analysis. Time cost was calculated on both a 'working hour' and a 'total day' basis for the involvement of 1 diver who performed daily 1 h dives and 1 person working 6 h d^{-1} in the laboratory (Francour et al. 1999).

To assess the suitability of DOV (through the 'fish aggregation' variable) for studying reserve effect, we performed chi-squared tests to analyse inter- and intra-site distribution concerning fish aggregation.

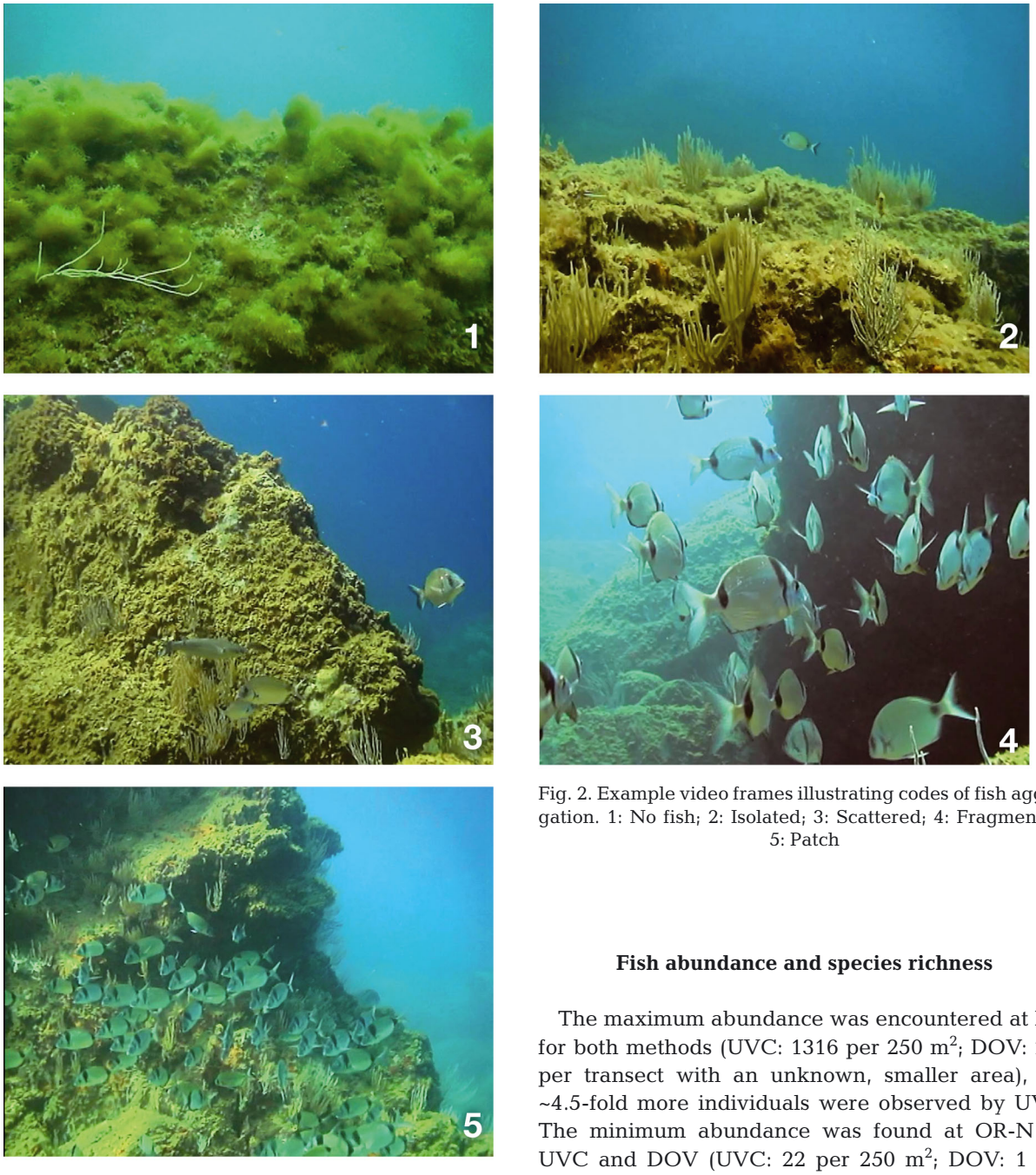

Fig. 2. Example video frames illustrating codes of fish aggregation. 1: No fish; 2: Isolated; 3: Scattered; 4: Fragmented; 5: Patch

RESULTS

A total of 24 species belonging to 8 families were recorded using DOVs at all of the sites combined, and 30 species belonging to 9 families were recorded using UVC. Six species were observed only by UVC. All species observed by DOV were viewed by UVC. A total of 11 439 fish were counted: 8890 in UVC and 2549 in DOV, i.e. ~3.5-fold more individuals were counted by UVC.

Fish abundance and species richness

The maximum abundance was encountered at NO for both methods (UVC: 1316 per 250 m^2; DOV: 297 per transect with an unknown, smaller area), i.e. ~4.5-fold more individuals were observed by UVC. The minimum abundance was found at OR-N by UVC and DOV (UVC: 22 per 250 m^2; DOV: 1 per transect; 22-fold more individuals observed by UVC). For both methods, mean abundance differed significantly among sites (UVC: $p < 0.001$; DOV: $p < 0.001$; Table 2) and mean abundance was significantly smaller at OR-N than at NO (UVC: 74.12 vs. 566.25, $p < 0.001$; DOV: 15.37 vs. 178.25, $p < 0.0005$; Fig. 3). For UVC, a significantly lower mean abundance was detected at OR-N than at OR-S (Mann-Whitney test, UVC: 74.12 vs. 298.87, $p < 0.005$; Fig. 4).

Both methods identified maximum species richness at NO (UVC: 15 per 250 m^2, DOV: 12 per transect),

Table 2. Comparison of 2 methods used to measure abundance and species richness in 4 sampling areas. UVC: underwater visual census; DOV: diver-operated video; OR-N: outside reserve north; OR-S: outside reserve south; R: reserve; NO: no-take area; n: number of replicates

Variable	Method	OR-N			R			NO			OR-S			*F*	p
		Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n		
Abund.	UVC	74.12	73.78	4	172.00	157.09	4	566.25	416.35	4	298.87	163.10	4	9.825	0.0002
	DOV	15.37	12.05	4	77.12	69.44	4	178.25	89.45	4	54.71	42.56	3	10.329	0.000016
Species richness	UVC	11.25	2.12	4	12.62	1.77	4	13.37	1.60	4	9.12	1.81	4	8.306	0.0005
	DOV	5.50	1.95	4	8.50	1.95	4	8.37	1.92	4	7.00	1.73	3	5.769	0.004

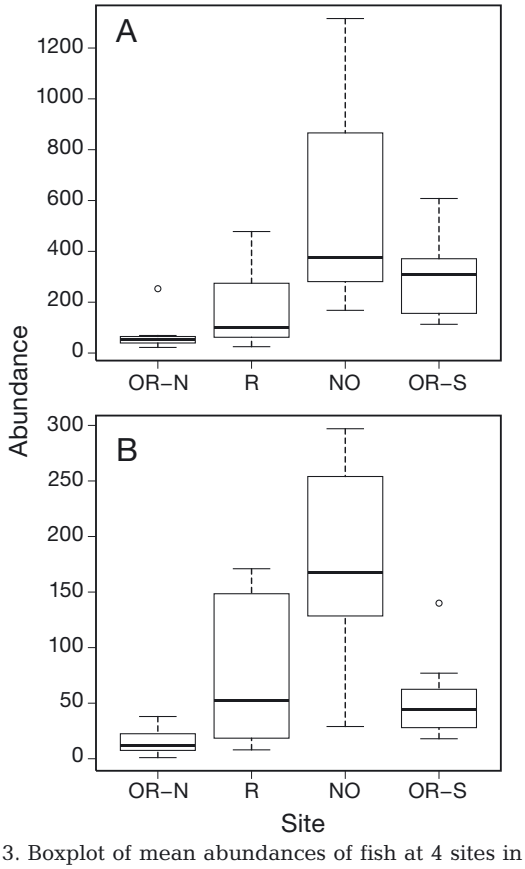

Fig. 3. Boxplot of mean abundances of fish at 4 sites in and near the marine protected area, comparing 2 methods. (A) UVC. Mean abundance at OR-N is significantly different from that at NO ($p < 0.01$) and OR-S ($p < 0.05$). (B) DOV. Mean abundance at OR-N is significantly different from that at NO ($p < 0.0005$). See Table 2 for abbreviations

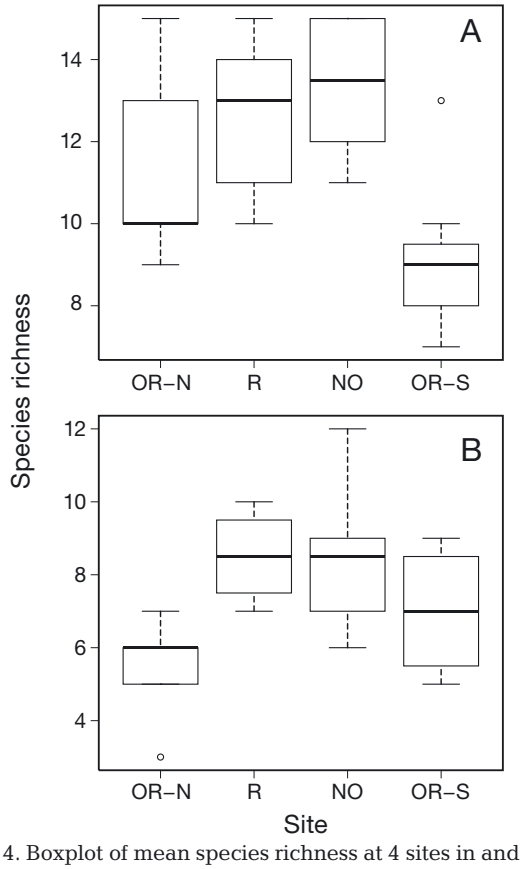

Fig. 4. Boxplot of mean species richness at 4 sites in and near the marine protected area, comparing 2 methods. (A) UVC. Mean species richness at OR-N is significantly different from that at OR-S ($p < 0.005$) and NO ($p < 0.0005$). (B) DOV. Mean species richness at OR-N is significantly different from that at R ($p < 0.005$) and NO ($p < 0.0005$). See Table 2 for abbreviations

however minimum species richness was identified at different sites (UVC: 7 species at OR-S ; DOV 3 species at OR-N). Mean species richness differed significantly among sites independent of method (UVC: $p < 0.001$; DOV: $p < 0.005$; Table 2) and was significantly lower at the OR sites than at NO and R. However, the OR site with the lowest measured richness depended on the method. OR-S presented lower species richness for UVC (Mann-Whitney test, OR-S vs. NO: 9.12 vs. 13.37, $p < 0.005$; OR-S vs. R: 9.12 vs. 12.62, $p < 0.005$; Fig. 4). In contrast, the lowest species richness was at OR-N for DOV (OR-N vs. NO: 5.62 vs. 8.37, $p < 0.005$ and OR-N vs. R: 5.62 vs. 8.62, $p < 0.005$; Fig. 4).

All of the species observed by DOV were also observed by UVC (Table 3), whereas 6 species were

Table 3. List of the 31 fish species recorded in the survey with corresponding frequencies (%) for each site and method (–: zero frequency). See Table 2 for abbreviations. Schooling behavior (B): solitary (so), facultative schooler (f.sc) or schooler (sc). Territoriality (T; daily movement range): not territorial (no.t; capacity of movement > 100 m) or territorial (t; capacity of movement < 100 m). Fishing (F): fished species (f) or non-fished species or without real value for recreational or professional fishermen (no.f). Complementary information (I): evasive (e), cryptic (c), problem of identification (pb.i), nothing of note (–)

Family	Species	B	T	F	I	OR-N (%)		R (%)		NO (%)		OR-S (%)	
						UVC	DOV	UVC	DOV	UVC	DOV	UVC	DOV
Centracanthidae	*Spicara maena* (Linnaeus, 1758)	sc	no.t	no.f	e	–	–	25	–	–	–	–	–
Labridae	*Coris julis* (Linnaeus, 1758)	sc	t	no.f	–	100	100	100	100	100	100	100	100
Labridae	*Ctenolabrus rupestris* (Linnaeus, 1758)	so	t	no.f	c	37.5	–	12.5	–	–	–	–	–
Labridae	*Labrus merula* Linnaeus, 1758	so	t	f	c	37.5	12.5	37.5	12.5	50	12.5	25	28.58
Labridae	*Labrus viridis* Linnaeus, 1758	so	t	f	–	12.5	–	–	–	12.5	–	–	–
Labridae	*Symphodus mediterraneus* (Linnaeus, 1758)	so	no.t	no.f	pb.i	75	12.5	12.5	–	25	–	25	–
Labridae	*Symphodus melanocercus* (Risso, 1810)	so	no.t	no.f	–	62.5	25	100	75	25	25	25	14.28
Labridae	*Symphodus roissali* (Risso, 1810)	so	no.t	no.f	pb.i	12.5	–	12.5	–	–	–	–	–
Labridae	*Symphodus tinca* (Linnaeus, 1758)	so	no.t	no.f	c	100	87.5	62.5	37.5	25	12.5	50	57.14
Moronidae	*Dicentrarchus labrax* (Linnaeus, 1758)	so	no.t	f	e	–	–	25	–	50	12.5	–	–
Mugilidae	*Liza aurata* (Risso, 1810)	f.sc	no.t	f	e	25	–	25	12.5	37.5	25	12.5	–
Mugilidae	*Mugil cephalus* Linnaeus, 1758	so	no.t	f	c	–	–	12.5	12.5	25	12.5	–	–
Mullidae	*Mullus surmuletus* Linnaeus, 1758	f.sc	no.t	f	e	50	–	–	–	25	12.5	–	–
Pomacentridae	*Chromis chromis* (Linnaeus, 1758)	f.sc	no.t	no.f	–	100	100	100	100	100	100	100	100
Sciaenidae	*Sciaena umbra* Linnaeus, 1758	f.sc	t	f	–	–	–	50	50	50	37.5	–	–
Serranidae	*Epinephelus marginatus* (Lowe, 1834)	so	t	f	–	–	–	37.5	25	62.5	37.5	–	–
Serranidae	*Serranus cabrilla* (Linnaeus, 1758)	so	t	f	–	100	25	100	50	75	25	100	42.85
Serranidae	*Serranus scriba* (Linnaeus, 1758)	so	t	f	c	62.5	–	12.5	–	25	12.5	50	28.58
Sparidae	*Boops boops* (Linnaeus, 1758)	sc	no.t	no.f	e	–	–	–	–	–	–	12.5	–
Sparidae	*Dentex dentex* (Linnaeus, 1758)	f.sc	no.t	f	e	12.5	–	37.5	12.5	25	–	25	–
Sparidae	*Diplodus annularis* (Rafinesque, 1810)	f.sc	no.t	f	–	37.5	12.5	–	–	–	–	–	–
Sparidae	*Diplodus cervinus* (Lowe, 1838)	f.sc	no.t	f	–	–	–	37.5	12.5	100	25	12.5	–
Sparidae	*Diplodus puntazzo* (Walbaum 1792)	f.sc	no.t	f	pb.i	–	–	62.5	25	75	–	–	–
Sparidae	*Diplodus sargus* (Linnaeus, 1758)	f.sc	no.t	f	–	100	87.5	100	100	100	100	100	100
Sparidae	*Diplodus vulgaris* (Geoffroy St-Hilaire, 1817)	f.sc	no.t	f	–	100	62.5	100	100	100	100	100	100
Sparidae	*Lithognathus mormyrus* (Linnaeus, 1758)	f.sc	no.t	f	–	–	–	–	–	–	–	12.5	–
Sparidae	*Oblada melanura* (Linnaeus, 1758)	sc	no.t	f	–	25	12.5	62.5	37.5	100	100	87.5	71.42
Sparidae	*Sarpa salpa* (Linnaeus, 1758)	sc	no.t	f	–	12.5	12.5	62.5	50	87.5	62.5	62.5	28.58
Sparidae	*Sparus aurata* Linnaeus, 1758	f.sc	no.t	f	e	–	–	50	37.5	37.5	–	25	–
Sparidae	*Spondyliosoma cantharus* (Linnaeus, 1758)	f.sc	no.t	f	pb.i	12.5	–	25	–	12.5	12.5	–	–

counted by UVC only (*Boops boops*, *Ctenolabrus rupestris*, *Labrus viridis*, *Lithognathus mormyrus*, *Spicara maena* and *Symphodus roissali*). *Chromis chromis* and *Coris julis*, gregarious and non-evasive species, presented the same frequencies in the different sites for both methods. Twelve species showed a similar trend in frequencies using both methods, but with slightly lower frequencies for DOV. These 12 species are for the most part territorial, non-gregarious and non-evasive. A total of 10 species out of 30 showed a different pattern between the methods. Of these 10 species, 6 were always detected by both methods at NO but were not detected by DOV when these species were recorded by UVC at sites outside NO. These 6 species are evasive or cryptic and did not form schools.

Structure of fish assemblage analysis

The nMDS plot suggests there is no marked difference between the detection structure of fish assemblage with UVC and DOV or depth (Fig. 5). However, the nMDS plot clearly separates the sites into 2 groups (NO, R and OR-S vs. OR-N), with a similarity of 40% within the assemblage observed in the grouped sampling sites (Fig. 5). The PERMANOVA test also indicates a difference in assemblage among sites ($p = 0.0001$) and an interaction between sites and methods ($p < 0.05$). A significant difference regarding the detection of the structure of fish assemblages between the UVC and DOV methods ($p < 0.0005$) and among depths ($p < 0.05$) was also observed. The post hoc test reveals that for UVC, all sites showed differences among themselves, except for NO and OR-S. The results are similar for DOV, except that the assemblage at R and OR-S can be considered as the same (Table 4).

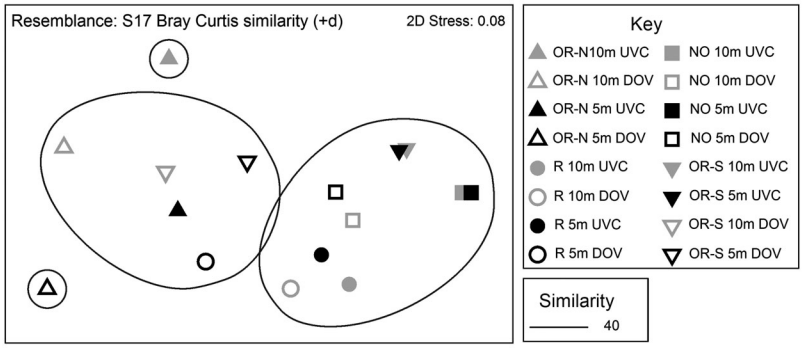

Fig. 5. Two-dimensional non-metric multi-dimensional scaling ordination of species abundance observed at each site, depth and method in and near the marine protected area. Cluster grouping with similarity level of 40%. See Table 2 for abbreviations

Table 4. Student's *t*-test with 999 permutations comparing the difference in structures of fish assemblages by sampling method. See Table 2 for abbreviations

Method	Site		*t*	p
UVC	OR-N	R	1.66	0.0185
		NO	3.26	0.0002
		OR-S	2.494	0.0002
	R	NO	2.075	0.00047
		OR-S	1.896	0.00023
	NO	OR-S	1.341	0.118
DOV	OR-N	R	1.558	0.0322
		NO	2.504	0.0007
		OR-S	1.553	0.00097
	R	NO	1.881	0.0185
		OR-S	1.241	0.148
	NO	OR-S	1.885	0.00077

Cost-benefit analysis

The cost-benefit analysis suggests that DOV is less cost-effective than UVC on an hourly or daily basis (Table 5). The time needed to generate data per station is similar for both methods (4 h). The time used for data extraction is greater for DOV (2 d) than for UVC (0.25 d).

DOV contribution to study reserve effect

Chi-squared tests carried out for each sampling site show that fish aggregation codes were not present in the same proportion at a given site (OR-N: $\chi^2 = 98.67$, $p < 0.05$; R: $\chi^2 = 27.67$, $p < 0.05$; NO: $\chi^2 = 23.33$, $p < 0.05$; and OR-S: $\chi^2 = 45$, $p < 0.05$). Concerning the set of sites, fish aggregation codes were not the same among sites ($\chi^2 = 99.30$, $p < 0.0001$). Fig. 6 shows that the 'No fish', 'Isolated' and 'Scattered' classes dominated at all sites (> 60%). The 'No fish' code was more common at OR-N than at the other sites (70%). All fish aggregation codes were present at each sampling site, except the 'Patch' code. The 'Patch' class was found only at sites located within the marine reserve (R and NO). Moreover, the codes corresponding to high densities were more frequent with increasing protection status and varied inversely with the codes describing low density.

Table 5. Cost-benefit per station for both sampling strategies: UVC (underwater visual census) and DOV (diver-operated video). The 2 parts of the study, field sampling and data analysis, were considered. The daily dive time for a diver takes into account the time of transport and of sampling at the study site

	UVC		DOV	
Work on an hourly basis				
Sampling per site	(A) Number of transects	8	(a) Number of transects	8
	(B) Transect sampled h^{-1}	2	(b) Transect sampled h^{-1}	2
	(C) Work hours (A/B)	4	(c) Work hours (a/b)	4
Analysis per site	(D) Data processing	1	(d) Visualization of tape	1.5
	(E) Analysis, data acquisition	0.5	(e) Tape processing	0.5
	(F) Work hours (D + E)	1.5	(f) Work hours [(a × d) + e]	12.5
Total	C + F	5.5	c + f	16.5
Work on a daily basis				
Sampling per station	1 diver d^{-1} and 1 h $dive^{-1}$	1	1 diver d^{-1} and 1 h $dive^{-1}$	1
Analysis per station	1 worker and 6 h d^{-1}	0.25	1 worker and 6 h d^{-1}	2
Total		1.25		3

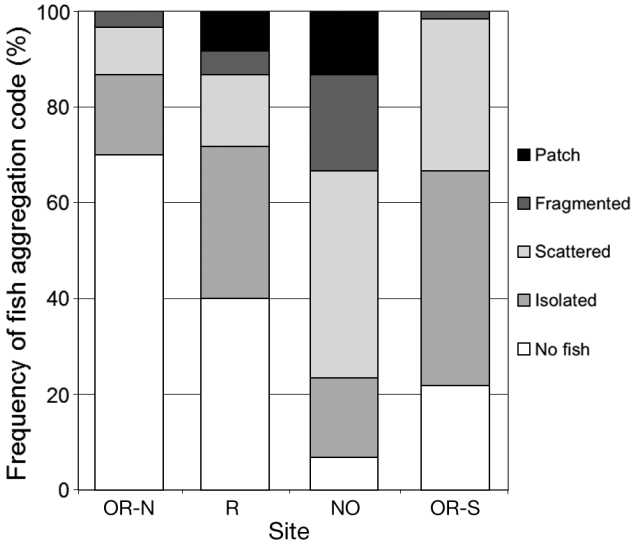

Fig. 6. Frequency of 'fish aggregation code' in percentage by site. See Table 2 for abbreviations

DISCUSSION

Suitability of DOV for studying reserve effect

The differences in abundance and species richness among sites detected by UVC in the present study are similar to those reported in previous studies for Cerbère-Banyuls MPA (Bell 1983, Dufour et al. 1995, Harmelin-Vivien et al. 2008). Abundance was lower at OR-N than at NO due to artisanal and recreational fishing pressures at OR-N, in contrast to NO where they are prohibited (Bell 1983, Dufour et al. 1995). The difference between OR-N and OR-S could be due to the fact that these activities are more important in the north of the marine reserve than in the south (Goñi et al. 2008). Furthermore, this difference could also be due to a spillover effect. The mean spillover distance is <2 km around the no-take area for the Cerbère-Banyuls MPA (Harmelin-Vivien et al. 2008). OR-N, 4 km from NO, cannot benefit from spillover, in contrast to OR-S, located at 2 km. The greater species richness inside the Cerbère-Banyuls MPA (NO and R) than at OR-N is due to the presence of certain species like (*Epinephelus marginatus, Sciaena umbra* and *Diplodus cervinus*) that were encountered exclusively inside the marine reserve. This exclusivity is due to their high sensitivity to artisanal or recreational fishing pressure and their low production/biomass ratio (Francour et al. 2001, Lenfant et al. 2003).

In the present study, abundance and species richness were always less when measured using DOV than with UVC. This difference is a phenomenon widely encountered in other studies (Tessier et al. 2005, Stobart et al. 2007, Colton & Swearer 2010, Pelletier et al. 2011) and could be due to the fact that the sampling area differs slightly between the 2 methods. The angle of the camera field of view can generate this difference. The angle of view of a diver is ca. 80° (Lam et al. 2006), and a diver is able to turn his or her head to census fish outside his or her field of view. This is not possible with the fixed angle of view of DOV. In addition, the behaviour of shy and evasive species is clearly influenced by the noise generated by the diver operating a DOV census (Francour et al. 1999, Cole et al. 2007). Consequently, these shy spe-

cies were probably not sampled along the DOV transect, yielding lower abundance and lower species richness. Only fixed video recorders, without divers around, are able to record shy species (Francour et al. 1999). In contrast, a diver performing UVC can detect these shy species at the limit of the transect belt (Harmelin-Vivien et al. 1985). Therefore, DOV is not asuitable substitute for UVC in cases where an observer wants to characterize fish assemblages, even if its bias (underestimation of cryptic, mobile and nocturnal fishes) is well known (Harmelin-Vivien et al. 1985, Harmelin-Vivien & Francour 1992).

Concerning abundance, DOV did not detect the difference between OR-N and OR-S, probably due to the lower values calculated in comparison to UVC (smaller sampling area; see above). A minimum transect surface is recommended to study ichthyofauna (Harmelin-Vivien et al. 1985), and a smaller one can prevent the detection of difference among sites. Consequently, no significant difference was detected between OR-N and OR-S, but a difference was detected between OR-N and NO.

DOV, like UVC, indicated lower species richness outside the MPA, but for different sites: OR-N and OR-S, respectively, for DOV and UVC. This difference is probably linked to the low resolution (number of pixels) of the video or computer monitor, which limited the accurate identification of fish at species level. For example, tiny details allow the underwater identification of some species, such as *Symphodus* spp. Their identification on a computer is more complicated because its resolution is less than that of the human eye. Some anatomic details or characteristic colours, already difficult to discern in UVC, are even less recognizable in DOV. Poor video identification of species of the genus *Symphodus* could probably explain the difference between the 2 methods or among sites.

However, despite these biases, DOV can detect a reserve effect like UVC did, but DOV is less powerful. DOV may be appropriate to sample a part of the fish assemblage: the non-shy, non-cryptic and easily identifiable species, such as most of the target species. The cost-benefit analysis showed a much longer data collection time per transect via DOV than with UVC. This time can be reduced by the analysis of a few selected species. Some studies using underwater video, essentially employing stationary cameras, came to the same conclusion (Francour et al. 1999, Stobart et al. 2007, Pelletier et al. 2011).

As mentioned before, using the UVC method on multiple sites induces temporal bias in the case of a unique diving observer. Multiple observers, diving simultaneously, remove this effect but introduce an observer bias. The use of the DOV method can reduce temporal and observer variability.

DOV would allow the study of more parameters than UVC. In the field, an observer cannot simultaneously record the size, number, species, fish aggregation along transect, type of substrate or cover and their percentage, for example. With too much information to write at the same time, the risk of information loss (by forgetting to note or by missing a fish that crosses the transect) increases, even if there is more than one observer. However, this expanded data collection is possible with video. DOV also allows data archiving. This would enable the use of the video for another study or the comparison of the evolution of substrates over time.

However, DOV is not suitable for measuring fish sizes. This is only possible using stereo-video (Harvey et al. 2002, Dunbrack 2006, Watson et al. 2010), which requires more sophisticated material, making it more costly and less easy to implement in the field. Thus, DOV cannot be used by all organisations conducting fish monitoring, unlike UVC. This is especially true for simultaneous multi-site studies.

Contribution of DOV in studying reserve effect

Of the few studies that have used DOV (also stereo-video) to study ichthyofauna (Tessier et al. 2005, Langlois et al. 2010, Watson et al. 2010), none have focused on finding an additional metric in this regard. Yet, DOV provides access to the spatial component of a transect through the use of aggregation metrics. Therefore, it appeared interesting to see if access to this component could provide a complement to UVC for fish fauna studies.

The analysis of fish aggregation showed an unequal inter- and intra-site distribution of fish aggregation codes. 'No fish' was the fish aggregation code that dominated at OR-N. This could be explained by the generally low fish abundance found in this site outside the MPA. In contrast, the 'Patch' code — translating the greatest abundance — was found only at sites located inside the MPA. It appeared also that the higher the protection status of a site, the higher the frequency of the codes describing important groupings of fish. The 2 types of fish schools observed (patchy and fragmented) were principally composed of species targeted by fishing, such as *Diplodus vulgaris*, *D. sargus* and *Sciaena umbra*. The variation of the frequency of the codes could be the result of protection status but could also be the result

of a variation of habitat among sites. Some studies have shown the impact of habitat complexity on fish density (Claudet et al. 2011). It is possible that this is the same for the species cited previously. However, this hypothesis can be rejected because our observation during the sampling and a fine mapping of the study area show a very similar habitat complexity among all of the sampling sites. Furthermore, this parameter is a less-determinant factor for the difference of abundance or species richness among sites than the protection status in shallow water (≤10 m) (Claudet et al. 2011). As habitat complexity probably does not play a role here, the variation of the frequency of the codes detected in the present study could be the result of the protection status. Due to the high abundance in the sites inside the MPA, the lack of space could drive an aggregation of fish (Ward & Hart 2005), which can also be linked to a mechanism of density dependence. Indeed, an increase in the number of individuals increases the encounters with other members of the species and thus promotes the formation of a school. Furthermore, an increase in the number of schools could increase their probability of meeting and their amalgamation. This phenomenon has been observed for terrestrial species (Pépin & Gerard 2008). In the present study, the ecological roles of aggregation have not been considered, such as reproduction, nutrition and strategies to escape predators. The last hypothesis should be explored because the main result of a reserve effect is to increase the presence of large predators (Francour et al. 2010). DOV data, at a species level, have to be linked to aggregation phenomena to understand ecological patterns. Nevertheless, in the context of our work, fish aggregation is a variable that can be used to study the reserve effect with DOV technique.

CONCLUSION

The present study shows that DOV can detect a reserve effect when the impact is significant. It is difficult for DOV to detect this effect when it is weak, but it may be of use when studying a targeted species or an easily identifiable species, in this case *Epinephelus marginatus*, *Diplodus cervinus*, *D. vulgaris*, *D. sargus* or *Sciaena umbra*. The present work also shows that the analysis of fish aggregation along transects can help to detect a reserve effect for some species. This is an interesting metric that has not been used to date. This raises the question of how protection status may affect the behaviour of schooling for some species. DOV appears to be a promising method that can be very useful for MPA managers, notably to monitor target fishes. However, a multisite study to verify whether this method is valid for sites other than the Cerbère-Banyuls marine reserve is necessary.

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