Visual censuses of tropical fish aggregations on artificial reefs: slate versus video recording techniques

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Abstract

Artificial coastal reefs were initially installed off Reunion Island (SW Indian Ocean) in order to attract and catch small pelagic fish of economic importance for the local fishery. These artificial reefs also attract a high density of juvenile coral reef fish, especially after recruitment. Because of high species richness and density, a suitable method of evaluating diversity and abundance in such assemblages is needed. An experiment was conducted in situ for 1 year in order to test which of the two visual techniques, slate or video recording, would be the most suitable for sampling artificial reefs. For the quantitative study, a rope framework (four belt transects each measuring 24×3 m) was used to ease the movement of the divers. To avoid bias due to time variations, the study was conducted under limited time in situ. The advantages and disadvantages of the two techniques regarding the accuracy of qualitative and quantitative results are discussed. The qualitative study results show that the slate technique is the most accurate one for determining species richness. In the quantitative study, factors such as species characteristics (ecological type), attractiveness (relationship between fish and diver) and abundance of fish communities around the artificial reefs appear to influence our results on the comparison of the two techniques. Of 13 'permanent' (observed in more than 75% of dives) species, 6 returned a similar frequency of detection by slate and video (*Lutjanus kasmira*, *Lutjanus bengalensis*, *Priacanthus hamrur*, *Chaetodon kleinii*, *Heniochus diphreutes*, *Mulloides vanicolensis*); these were then selected for comparison of the techniques using quantitative data. The correlation between video and slate census results is high, but, in comparison with the slate census, the video census underestimates abundance, especially for low values. A corrected index is

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proposed to remedy this underestimation; it could be used for video surveys conducted on species responding well to video detection (as below).

1. Introduction

Artisanal fish harvesting is the oldest and most geographically widespread use of artificial reefs. Its overall goal is food production and sometimes, at least partly, the economic sustenance of individuals, families and communities in coastal areas (Seaman and Jensen, 2000). In Reunion Island (SW Indian Ocean), fishers have installed self-made artificial reefs in order to attract and catch small pelagic fish, mainly Carangidae. As the artificial reefs attract and concentrate most of the small coastal pelagic fish during the harvest season, they are very useful for monitoring the state of the resource and could help provide better stock assessments. As in other cases (Pickering and Whitmarsh, 1997; Wantiez and Thollot, 2000), fish densities were higher around the artificial reefs than in the neighbouring natural zones, potentially reaching some 10 individuals/m^3. Because of high species richness and density, an accurate method to evaluate the diversity and abundance of such aggregations is necessary. In Reunion Island, the methodological problem is accentuated by the fact that the artificial reef represents a relatively small surface area (around 250 m^3), which attracts a very high density of juveniles, especially just after the colonisation phase. Methodological reviews have summarised the advantages and disadvantages of the various underwater visual census techniques (Harmelin-Vivien et al., 1985; Samoilys, 1997; Bortone et al., 2000) used in natural (Bortone et al., 1986, 1991; Francour et al., 1999) or controlled environments (Bortone et al., 1991; Greene and Alevizon, 1989). But no studies have compared in situ methods on tropical artificial reefs characterised by high species richness and high abundance variations. Non-destructive assessment methods, which include acoustic and underwater visual censuses (slate, audio and video records), are the most common techniques used to characterise fish aggregations and their evolution (Barans and Bortone, 1983; Bohnsack, 1996; Bortone and Kimmel, 1991; Bortone et al., 2000; Harmelin-Vivien et al., 1985; Tresher and Gunn, 1986; Samoilys, 1997). They are generally preferred because they do not disturb the habitat, are minimally disruptive to the marine organisms (Harmelin-Vivien et al., 1985; Bortone and Kimmel, 1991), are less selective when compared to most other sampling methods (Brock, 1954) and can be repeated in the same place with brief intervals between samplings (Bortone et al., 2000). These methods, originally designed for natural biotopes, could also be used for artificial reef sampling (Bortone and Bohnsack, 1991; Bortone et al., 2000; Charbonnel et al., 1995). In the last 10 years, with the advent of digital devices, video recording has become an appropriate tool for fish surveys (Michalopoulos et al., 1992; Potts et al., 1987; Tipping, 1994).

In Reunion Island, an in situ experiment was conducted for 1 year in order to test which visual technique (slate or video recording), could best be used to sample the artificial reef built there. The two methods were tested for qualitative (species richness) and quantitative (number of individuals by species) assessments. We test how species-related factors (ecological type, total abundance, contrast between fish and background) and their relationships with divers (attractiveness) may influence the results of quantitative evaluation between the two recording methods. An index calculation was performed to express video abundance as related to slate abundance for permanent species. The advantages and disadvantages of the two techniques in relation to the accuracy of qualitative and quantitative results are discussed, along with diving time requirements. The results herein should aid researchers and managers in their choice of recording techniques for future studies.

2. Materials and methods

2.1. Study area and artificial reef structure

The study was carried out on high tropical volcanic Reunion Island, located in the western Indian Ocean (21°07 S, 55°32 E). The total shoreline of the island is about 215 km long. The major coastal marine environments are fringing coral reefs ($\approx$ 25 km long), rocky coasts ($\approx$ 100 km long), and coasts characterised by a sandy bottom mixed with small basalt blocks ($\approx$ 90 km in length). The study took place in the sandy bay of St-Paul, located in the western part of the island. Artificial reefs made with modules of identical size (around 250 m^2 each) were installed at a depth of 15 m, 400-m offshore, and the average distance between the various modules was about 1 mile. The central part of each module (6 m^3) was made with plastic containers, tires and plastic strips to simulate crevices and seagrass beds. The total height of the structure was about 1 m. Plastic strips were attached to the mooring ropes between the module and the surface at each corner and in the center of the module in order to attract pelagic fish. The modules were moored to the seabed with concrete blocks.

2.2. Sampling methods

Fish aggregations were surveyed by two visual census techniques in order to evaluate species richness (qualitative study) and abundance by species (quanti-tative study). Data were recorded on a plastic slate and by a video recorder. During this 1-year study (March 2001 to February 2002), we monitored three artificial reefs installed in February 2001 at least once monthly (40 censuses in all). Data were collected during sunny days, between 9 and 12 AM, when visibility was sufficiently high (>5 m), on the same days for all the artificial reefs to reduce bias due to natural variation of fish aggregations (Harmelin-Vivien et al., 1985). All dives were performed by three divers (slate, video, security), with video recordings being processed just before slate recording. We used a digital video camera with a wide-angle lens. In order to obtain the best image quality, which gives the highest definition on the screen, the filming was done in 'progressive-scan' mode.

2.2.1. Qualitative study

The qualitative study was carried out by means of two circuits around the reef in order to locate the different species (Bombace et al., 2000; Charbonnel et al., 1995) and to determine the proportion of each species in multi-specific groups. The first was conducted 6–12 m from the reef centre and the second 1-m from the center (Fig. 1).

2.2.2. Quantitative study

When the data were adjusted for a given area and limited survey time (see below), it was determined by Bortone et al. (1989) that divers were most efficient in sampling the number of individuals in tropical areas when using the transect method. This method may
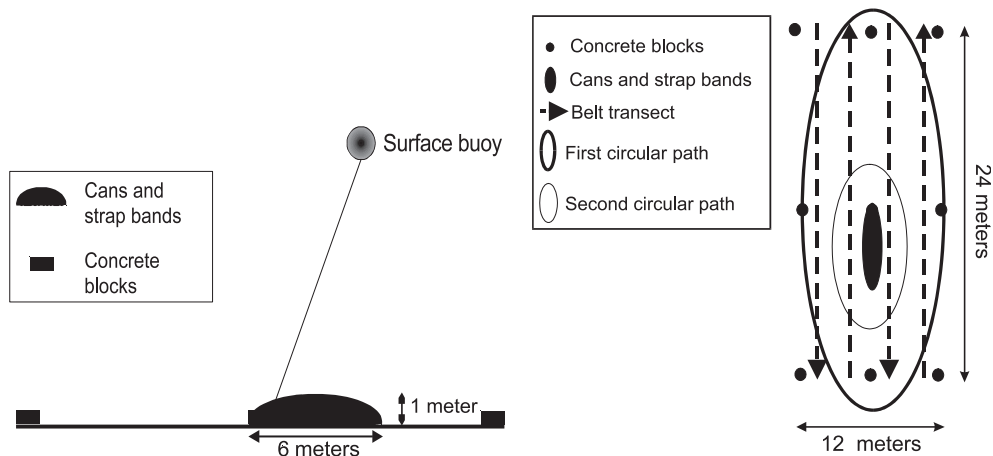

Fig. 1. Artificial reef structure (A: lateral view, B: top view) and sampling technique.

avoid also the risk of duplicate counts of schooling species occurring with point-count methods (Gledhill et al., 1996; Francour et al., 1999). Furthermore, a framework could be used to facilitate the movement of the divers on the artificial reefs (Buckley and Hueckel, 1989), and to obtain a known surface area for video analysis (Auster et al., 1989; Michalopoulos et al., 1992). Therefore, during our study, a rope framework was installed on the seabed to demarcate four belt transects (24 m long by 3 m wide). The diver successively followed each belt transect in applying slate and video techniques (Fig. 1).

In the slate census, when a monospecific group containing more than 50 individuals was observed, sets of individuals were used by the diver, who formed a visual image of what forms a group of 20 fish and then multiplied these figures in order to estimate the entire population size (Bortone et al., 2000; Harmelin-Vivien et al., 1985). For schools of mixed species, a number was estimated for the entire school and then an approximation was made of the proportion of each species composing the school (Bortone and Kimmel, 1991; Bortone et al., 2000).

For the video census, a protocol using digital video recording and image processing was developed. Each belt transect (3×24 m) was divided into eight grid units corresponding to the camera's breadth of field (3×3 m). The total framework included 32 such units, each measuring 3×3 m. The cameraman followed the belt transect at a height of 3 m, a distance presumed to minimize the bias resulting from positive and/or negative attractions of fish species to SCUBA divers. To characterise fish abundance with minimal data processing, the optimum swimming speed was calculated in a preliminary study (Lacour et al., 2001). This study has shown that with a swimming speed of 0.3 m/s, there was no significant difference of fish numbers by grid unit over five consecutive seconds, this result being calculated from different fish densities (27, 45, 55, 88, 200 and 540 individuals/9 m^2). Therefore, this swimming speed yielded two images per unit every 10 s. The videotape was then analysed on a large computer screen using the framework through standard image processing software. Every 5 s, the tape was stopped and the fish were counted in order to calculate the total number of individuals present. Species was determined for individuals whenever possible. As video recording was performed in 'progressive-scan'

mode, the quality of the images was improved when necessary (increase of contrast, negative images).

2.2.3. Time of survey

As determined by many authors (e.g. Bortone et al., 1986, 1989), survey time is one of the most important parameters affecting fish community assessment. In order to avoid bias due to time variations, the study was conduced under limited time. In situ, the total survey took 25 min for the slate census (5 min for qualitative study, 20 min for quantitative study), and 10 min for the video census (5 min for qualitative study and 5 min for quantitative study).

2.3. Data analysis

The number of species (qualitative study) and the number of individuals (quantitative study) were determined for each transect. These parameters were also calculated in relation to their vertical distribution inside the water column and their position relative to the reef (Nakamura, 1985), which characteristics are collectively defined hereafter as "ecological groups" The first group (type A) included species that tend to have direct contact with the reef structure itself, and often occupy crevices, holes or gaps within the reef species (Apogonidae, Serranidae, Scorpaenidae, Aulostomidae, Plotosidae). The second group (type B) included species found in the immediate vicinity, but not coming into direct contact with the reef (Lutjanidae, Priacanthidae, Mullidae). The third, (type C), included species found above the reef in the mid-water and pelagic zones (Carangidae, Caesionidae).

2.3.1. Qualitative study

The percentage occurrence of each species was obtained using the scale proposed by Charbonnel et al. (1995): permanent species (>75%), frequent species (50–74.9%), scarce species (25–49.9%), and rare species (<25%). Species occurrences obtained by the two methods were compared in order to determine which species have similar underwater detection rates with slate and video techniques. Sørensen's index (S) (Legendre and Legendre, 1998) was used to compare the two sets of data (x1, x2) obtained with video and slate techniques:

$$S(\text{x1}, \text{x2}) = 2a/(2a + b + c)$$

where a: number of similar species between the two techniques; b: number of species missing from the first list; and c: number of species missing from the second list.

2.3.2. Quantitative study

2.3.2.1. Species characteristics and similarity. To determine the similarities between slate and video estimations for each species, we also need to consider which factors could influence our results. Harmelin-Vivien et al. (1985) identified fish mobility and diver attractiveness as belonging to these major factors. As mobility is related to fish behaviour, we categorised this factor with reference to the Nakamura classification in relation to the ecological group (types A, B, C). Attractiveness between fish and diver was categorised as positive, neutral or negative, depending on precedent observations and on our general knowledge of the ecology and behaviour of coral reef fishes. Authors have taking account of this parameter to gather visual data using strip transects, counting first the evasive species and after less moving species (Galzin, 1985; Chabanet, 1994). Furthermore, fish detectability, which depends on the contrast between the specimen and the background, could also be a factor influencing our results, particularly during video analyses. On the black volcanic sand of St-Paul Bay, the contrast is maximum for species with red or yellow as their main colour and for striped species. Additionally, as each transect is characterised by a total number of individuals, the two recording methods were compared using this variable classified in a log scale (0–10; 10–100; 100–1000, >1000 individuals). Species were thus characterised using the following variables: "ecological group" (types A, B, C), "attractiveness" (positive, neutral, negative), "contrast" on the sea floor (high or low) and "class abundance" (0–10 to >1000 individuals).

To determine the similarities between slate and video estimations for each species, we use the Gower similarity quotient (Si) (Legendre and Legendre, 1998):

$$Si = 1 - [\mathrm{abs}(y_{i1} - y_{i2})/R_i]$$

where $\mathrm{abs}(y_{i1}-y_{i2})$ is the absolute value of abundance difference estimated by slate (1) and video (2) for

species i, and R_i is the maximum difference observed in all samples.

When the species was not observed in the census by both methods (slate and video), the sample was not taken in account in the Si calculation. In order to perform a multiparameter ANOVA, these indices were transformed by arcsinus (to be normally distributed). Similarity was studied regarding to fish characteristics (ecological group, contrast between fish and background, attractiveness, class abundance) to test the null hypothesis (H0: there is no effect of fish characteristics on Si values). Then a post hoc Tukey HSD test (Honest significant difference) is performed to identify parameter values that differ from others. A unilateral Dunnett test is complete to determine the type of difference.

2.3.2.2. Index calculation. In order to reduce any bias in the data obtained by video census, a quantitative video index was calculated from slate abundance data. To do so, a linear relationship between video and slate sets of Ln transformed data (Ln+1 to avoid null data) was formed. The correlation between slate and video abundance was analysed using Pearson's index (Bortone et al., 1989). After logarithmic conversion, linear adjustments of the video and slate abundance versus rank of video abundance classified in ascending order were plotted. A covariance analysis was then performed to compare the slope of the two linear models obtained. In order to reduce the counting time under

Table 1

Number of species by category of occurrence and by ecological type and mean number of species by ecological type (A, B, C)

	Slate census				Video census			
	A	B	C	$\sum$	A	B	C	$\sum$
>75%	2	11	1	14	–	4	–	4
50–74.9	3	3	1	7	3	6	1	10
25–49.9	3	11	1	15	5	6	2	13
<25%	14	31	2	47	11	28	3	42
$\sum$ species number	22	56	5	83	19	44	6	69
Mean number of species	5.7	18.0	1.9	25.6	4.3	12.2	1.4	17.9
S.D.	(2.6)	(4.2)	(0.9)	(6.4)	(2.9)	(3.9)	(0.9)	(7.8)

A: species with direct contact with reef, B: species found closely around the reef, C: species found in mid-water, $\sum$: sum of species. Category of occurrence: >75%=permanent sp., 50–74.9%=frequent sp., 25–49.9%=scarce sp., <25%: rare sp.

Table 2
Species occurrence calculated with the two methods (slate and video)

Similarity index	Species	Ecological type	Attractiveness	Contrast/ seafloor	Slate			Video		
					Mean abundance	Standard deviation	Frequency	Mean abundance	Standard deviation	Frequency
0.95	*Priacanthus hamrur*	b	Nu	H	511.00	1238.05	0.88	1060.93	3697.69	0.78
0.88	*Caranx* sp.	c	Po	L	27.65	97.14	0.78	19.28	75.37	0.53
0.86	*Sargocentron diadema*	a	Ne	L	2.13	9.38	0.23	0.10	0.50	0.05
0.86	*Upeneus vittatus*	b	Ne	L	86.08	157.98	0.58	47.83	115.43	0.35
0.85	*Dascyllus trimaculatus*	b	Nu	H	1.98	2.43	0.68	1.60	1.45	0.68
0.85	*Carangoides*	c	Ne	L	5.40	31.59	0.18	0.35	1.48	0.08
0.82	*Plotosus lineatus*	a	Nu	H	58.23	77.86	0.68	46.80	68.21	0.58
0.82	*Chaetodon klenii*	b	Nu	H	19.48	17.16	0.95	8.35	6.28	0.95
0.82	*Lutjanus notatus*	b	Po	H	12.85	43.59	0.33	5.13	20.16	0.15
0.81	*Apogon apogonides*	a	Nu	L	13.68	24.87	0.50	7.53	14.02	0.45
0.80	*Fistularia* sp.	b	Ne	L	2.15	5.66	0.40	0.10	0.44	0.05
0.80	*Pterocaesio tile*	a	Nu	H	13.13	56.22	0.15	10.13	44.12	0.10
0.80	*Pseudobalistes fuscus*	b	Ne	H	0.33	0.86	0.23	0.10	0.30	0.10
0.80	*Pseudanthias cooperi*	b	Nu	H	21.45	43.34	0.45	14.08	44.16	0.38
0.79	*Pseudocaranx dentex*	c	Po	H	18.43	64.61	0.40	14.25	54.04	0.38
0.79	*Lutjanus bengalensis*	b	Po	H	98.88	144.53	0.80	101.98	154.65	0.70
0.79	*Chaetodon blakburni*	b	Nu	L	3.30	2.22	1.00	0.98	1.17	0.55
0.79	*Mulloides vanicolensis*	b	Nu	H	81.88	96.03	0.83	56.95	72.24	0.70
0.78	*Heniochus diphreutes*	b	Po	H	114.78	122.32	0.95	113.23	153.27	0.95
0.77	*Chaetodon dolosus*	b	Nu	L	1.83	4.09	0.35	0.40	0.98	0.18
0.76	*Selar crumenophtalmus*	c	Ne	L	509.38	999.65	0.53	200.60	514.30	0.38
0.74	*Pterois miles*	a	Nu	H	2.33	2.04	0.80	1.50	1.72	0.60
0.73	*Lutjanus gibbus*	b	Po	L	0.30	0.61	0.23	0.25	1.13	0.10
0.73	*Upeneus tragula*	b	Nu	H	11.85	25.05	0.30	9.25	20.38	0.38
0.72	*Parupeneus rubescens*	b	Nu	L	5.95	16.49	0.20	3.03	9.35	0.20
0.72	*Canthigaster smithae*	a	Ne	L	0.45	1.41	0.18	0.05	0.22	0.05
0.71	*Lutjanus kasmira*	b	Po	H	131.53	101.70	1.00	106.40	96.34	0.88
0.70	*Aulostomus chinensis*	b	Nu	L	5.93	4.23	1.00	1.55	1.89	0.63
0.69	*Apogon cooki*	a	Nu	L	3.55	8.54	0.25	1.28	4.92	0.28
0.68	*Naso unicornis*	b	Ne	L	5.78	7.14	0.55	1.05	3.61	0.28
0.68	*Epinephelus longispinis*	a	Nu	L	1.50	1.20	0.78	0.78	0.97	0.55
0.68	*Myripristis* sp.	a	Ne	L	14.20	21.68	0.48	6.30	11.84	0.35
0.68	*Parupeneus macronema*	b	Nu	L	8.93	14.15	0.48	2.93	6.26	0.33
0.66	*Mulloides flavolineatus*	b	Ne	L	22.05	20.72	0.80	0.30	1.14	0.08
0.66	*Canthigaster* sp.	a	Ne	L	0.28	0.88	0.15	0.03	0.16	0.03
0.65	*Caranx melampygus*	c	Po	L	2.70	16.75	0.05	1.80	8.77	0.08
0.65	*Acanthurus mata*	b	Po	H	7.70	6.60	0.85	3.55	4.72	0.60
0.65	*Epinephelus chlorostigma*	a	Nu	H	0.18	0.55	0.13	0.33	1.05	0.13
0.65	*Gnathodentex aurolineatus*	b	Po	H	8.13	26.41	0.30	5.93	21.59	0.30
0.65	*Epinephelus multinotatus*	a	Ne	H	0.60	0.84	0.40	0.33	0.73	0.23
0.63	*Pomacentrus caerulus*	b	Nu	L	0.15	0.36	0.15	0.23	0.48	0.20
0.63	*Diodon histrix*	b	Ne	H	0.20	0.46	0.18	0.10	0.30	0.10
0.62	*Cyprinocirrhites polyactis*	b	Nu	L	1.18	2.31	0.25	0.30	0.79	0.15
0.62	*Cantherines pardali*	b	Ne	H	0.45	1.32	0.15	0.05	0.22	0.05

Table 2 (*continued*)

Similarity index	Species	Ecological type	Attractiveness	Contrast/ seafloor	Slate			Video		
					Mean abundance	Standard deviation	Frequency	Mean abundance	Standard deviation	Frequency
0.62	*Odonus niger*	b	Nu	H	0.40	1.17	0.18	0.00	0.00	0.00
0.61	*Balistoides conspicillum*	b	Ne	H	0.20	0.97	0.08	0.03	0.16	0.03
0.58	*Coris caudimaculata*	b	Po	L	0.28	0.68	0.18	0.08	0.27	0.08
0.58	*Epinephelus fasciatus*	a	Ne	H	1.45	1.75	0.58	0.70	1.16	0.38
0.56	*Aprion virescens*	b	Po	L	0.55	1.91	0.13	0.00	0.00	0.00
0.54	*Acanthurus nigrofuscus*	b	Po	H	0.48	2.05	0.08	0.08	0.47	0.03
0.54	*Parupeneus pleurostigma*	b	Nu	L	5.93	9.63	0.38	2.05	6.21	0.23
0.54	*Ctenochaetus*	b	Ne	H	0.38	0.63	0.30	0.20	0.46	0.18
0.53	*Chaetodon madagascariensis*	b	Nu	L	0.18	0.81	0.08	0.00	0.00	0.00
0.53	*Dactyloptena orientalis*	a	Nu	L	0.33	0.76	0.18	0.25	0.59	0.18
0.50	*Zebrazoma gemmatum*	b	Nu	H	0.28	0.68	0.15	0.13	0.40	0.10
0.50	*Arothron hispidus*	b	Nu	H	0.05	0.22	0.05	0.03	0.16	0.03
0.50	*Abalistes stellatus*	b	Ne	L	0.13	0.65	0.05	0.05	0.22	0.05
0.50	*Echeneis naucrates*	b	Po	H	0.03	0.16	0.03	0.05	0.22	0.05
0.49	*Cantherines fronticintus*	b	Ne	H	1.53	2.36	0.45	0.15	0.48	0.10
0.43	*Naso hexacanthus*	b	Po	H	0.28	1.22	0.05	0.28	1.20	0.08
0.38	*Pseudanthias squammipinis*	b	Nu	L	0.13	0.65	0.05	0.00	0.00	0.00
0.37	*Naso brevirostris*	b	Ne	L	7.95	16.31	0.23	0.00	0.00	0.00
0.33	*Variola louti*	a	Po	H	0.08	0.27	0.08	0.03	0.16	0.03
0.33	*Arothron stellatus*	b	Ne	H	0.08	0.27	0.08	0.03	0.16	0.03
0.32	*Torpedo fuscomaculatus*	a	Nu	H	0.13	0.56	0.05	0.40	0.78	0.25
0.27	*Diodon liturosus*	b	Nu	H	0.18	0.38	0.18	0.18	0.38	0.18
0.25	*Labroides dimidiatus*	b	Po	L	0.03	0.16	0.03	0.10	0.30	0.10
0.25	*Synodus variegatus*	a	Nu	L	0.13	0.33	0.13	0.13	0.33	0.13
0.25	*Saurida gracilis*	a	Nu	L	0.00	0.00	0.00	0.08	0.35	0.05
0.11	*Canthigaster valentini*	a	Ne	L	0.23	0.83	0.08	0.03	0.16	0.03
0.00	*Gymnothorax* sp.	a	Nu	H	0.03	0.16	0.03	0.00	0.00	0.00
0.00	*Epinephelus rivulatus*	a	Nu	L	0.05	0.22	0.05	0.00	0.00	0.00
0.00	*Lut Janus bohar*	b	Po	L	0.03	0.16	0.03	0.00	0.00	0.00
0.00	*Gymnocranius* sp.	b	Ne	L	0.03	0.16	0.03	0.00	0.00	0.00
0.00	*Decapterus* sp.	c	Ne	L	0.00	0.00	0.00	0.25	1.58	0.03
0.00	*Xyrichtys* sp.	b	Ne	L	0.03	0.16	0.03	0.00	0.00	0.00
0.00	*Forcipiger* sp.	b	Nu	L	0.05	0.22	0.05	0.00	0.00	0.00
0.00	*Acanthurus thompsoni*	b	Po	H	0.03	0.16	0.03	0.05	0.22	0.05
0.00	*Zebrazoma scopas*	b	Nu	H	0.05	0.22	0.05	0.00	0.00	0.00
0.00	*Pervagor janthinosoma*	a	Ne	H	0.10	0.63	0.03	0.00	0.00	0.00
0.00	*Aluterus monoceros*	b	Po	H	0.05	0.22	0.05	0.05	0.22	0.05
0.00	*Ostracion cubitus*	a	Nu	H	0.03	0.16	0.03	0.00	0.00	0.00
0.00	*Lactoria cornuta*	b	Po	H	0.00	0.00	0.00	0.05	0.22	0.05
0.00	*Sphyraena barracuda*	b	Ne	L	0.03	0.16	0.03	0.00	0.00	0.00
0.00	*Sufflamen bursa*	b	Ne	L	0.03	0.16	0.03	0.00	0.00	0.00
0.00	*Siganus* sp.	b	Ne	L	0.03	0.16	0.03	0.00	0.00	0.00

Species are classified according to their ecological type (A: species with direct contact with reef, B: species found closely around the reef, C: species found in mid-water), their attractiveness (Po: positive, Nu: null, Ne: negative); high (H) or low (L) contrast on the sea floor. For each technique and each species is indicated the mean abundance with standard deviation and frequency of observations.

water, time being a limiting factor in diving, species were selected using the criterion of their continual presence on the artificial reefs using the slate method (permanent species) during the whole sampling period.

3. Results

3.1. Qualitative study

Eighty-six species belonging to 29 families were observed during the study. The majority of the species belonged to types A (26.7%) and B (66.3%); only 7.0% belonged to type C (mostly carangids and caesionids). The total number of species recorded by the slate method was higher than by video. Seventeen species were only observed by slate census and they were rare species (Table 1). Three species were only observed by video but they were also rare species [*Decapterus* sp. and *Lactoria cornuta* (Linnaeus, 1758) and *Saurida gracilis* (Quoy and Gaimard, 1824)]. Differences in the mean number of species are significant for types A, B and C (M-W test, $p > 0.0001$). With rare species, the similarity index probably indicated that the species was never seen simultaneously by the two techniques. This indicates the low probability of detection of these species.

Of the 66 species recorded, 47 have a greater occurrence by slate census, 8 by video, and 11 have exactly the same occurrence by the two methods. Differences in occurrence may be major not only for rare species (Table 2). For the 13 permanent species observed by the slate method, 6 showed a similar occurrence [*Lutjanus kasmira* (Forsskål, 1775); *Lutjanus bengalensis* (Bloch, 1790); *Priacanthus hamrur* (Forsskål, 1775); *Chaetodon kleinii* (Bloch, 1790); *Heniochus diphreutes* (Jordan, 1903); *Mulloidichthys vanicolensis* (Valenciennes, 1831)].

The mean value of Sørensen's index is 0.72 (± 0.07) which indicates a good global association of species detected by the two methods. But averages are similar for groups B and C species (0.73 ± 0.09 and 0.74 ± 0.31) and different for group A species (0.62 ± 0.22) (K-W, $p = 0.041$). This result shows that detected differences in aggregations between the two methods are related to the ecological group to which the fishes belong.

3.2. Quantitative study

3.2.1. Species characteristics and similarity

Similarity was significantly affected by all variables except for the contrast variable (Table 3). This is in accordance with the lack of significant difference which occurred between the S index obtained for contrasted species and uncontrasted species (0.91; 0.86). The interaction between contrast and attractiveness is also significant. «Contrast» is a factor increasing similarity for neutral species and decreasing similarity for evasive species (Table 3). Class abundance is the main factor affecting similarity (represented by the mean arcsine S index in Table 4). The higher the overall abundance the lower the similarity. The difference is significant for the highest abundance class (>1000) where similarity between techniques is low (0.46). This difference could be related to ecological type and to attractiveness (significant interactions). For the ecological group, the similarity increases with the fishes' position around the artificial reef. The S index increases with the distance between the fish position and the reef structure. The S index is significantly higher for type C fishes, which are found in mid-water and pelagic zones, than for B species, which are found close to the reef, and C species, which tend to have a direct contact with the reef structure itself (S=1.08, 0.89, 0.83, respectively, Table 4). Furthermore, similarity is also affected by attractiveness as evasive species

Table 3

Analysis of variance (ANOVA) of Gower similarity index (Si) transformed into arcsine

Effect	df	F	P
Attractiveness	2	7.102	0.001
Abundance class	3	13.209	<0.001
Ecological type	2	4.704	<0.001
Contrast	1	.917	0.338
Attractiveness*abundance class	4	3.945	0.003
Attractiveness*ecological type	3	1.483	0.217
Attractiveness*contrast	2	10.237	<0.001
Abundance class*ecological type	4	3.144	0.014
Abundance class*contrast	2	1.109	0.330
Ecological type*contrast	2	1.333	0.264

Influence of attractiveness (positive, neutral, negative), abundance class (0–10 to >1000), ecological type (A, B, C), contrast (high or low) and their interactions on Si. Ecological type (A: species with direct contact with reef, B: species found closely around the reef, C: species found in mid-water).

Table 4
Gower similarity index (Si) for attractiveness (positive, neutral, negative), abundance class (0–10 to >1000), ecological type (A, B, C), contrast (yes or no)

Effect	Class	Mean arcsine Si
Abundance class	0–10	0.92
	10–100	0.86
	100–1000	0.82
	>1000	0.46*
Ecological type	A	0.84
	B	0.89
	C	1.08*
Attractiveness	Positive	0.89
	Null	0.92
	Negative	0.83*
Contrast	High	0.91
	Low	0.86

Differences between groups are calculated with Tukey test.
  * Indicates significance at 0.05 level.

(negative attraction) have a significantly lower S index than attracted (positive attraction) and unattracted ones (null attraction) (0.83, 0.90, 0.92, respectively, Table 4).

3.2.2. Index calculation

The 13 species observed in all censuses by the slate method were selected to calculate the correlation between video and slate census techniques. As *L. kasmira* and *L. bengalensis* are morphologically similar (shape and colour) and included within the same fish school, their proportion was determined using the two methods. Slate and video censuses give similar results (W., Z=−1.346; p=0.178). For the two methods, abundance of each species was obtained by (total number of individuals in the shoal×proportion of each species in the shoal).

Correlation coefficients on Ln converted abundance data reveal a high relationship (Pearson, Kandall and Spearman coefficients) between slate and video for nine species (Table 5), which will be selected for the linear adjustment model. For the remaining species, there is no correlation [*Epinephelus longispinis* (Kner, 1864) and *Mulloides flavolineatus* (Lacépède, 1801)], or the correlation is significant (Pearson coefficient), but not for all the selected coefficients [*Chaetodon blackburnii* (Desjardins, 1836) and *Acanthurus mata* (Cuvier, 1829)— Table 5]. A linear adjustment of the video abundance classified in ascending order and slate abundance

versus rank of video abundance was conducted on log-converted data of the nine selected species. As the linear adjustments were weak (R^2=0.33 for video and R^2=0.15 for slate census), the species responsible for these low R^2 were eliminated step by step [*Aulostomus chinensis* (Linnaeus, 1766), *Pterois miles* (Bennett, 1828) and *Caranx* sp.]. For the six remaining species (*P. hamrur*, *L. bengalensis*, *L. kasmira*, *C. kleinii*, *Heniochus diphreustes*, *Mulloides vanicolensis*), the linear adjustments were good (R^2=0.98 for video and R^2=0.83 for slate census, Fig. 2). Using the Kolmogorov and Smirnov test, the normality of the distribution for the two sets of data is confirmed. Then, covariance analysis shows no difference on the slope of the two linear models (p<0.001). An a posteriori Levene test confirms the homogeneity of variance between the two data sets. The expression of Ln(slate abundance+1) from Ln(video abundance+1) for the six permanent species is a linear model:

$$\text{Ln visual} = 0.827 * \text{Ln video} + 1.017 \qquad (R^2 = 0.86) \qquad (1)$$

The residual analysis between observed data and predictive values obtained by the linear model (1) do not show any trend. This result confirms a good

Table 5
Pearson's index (R), Kandall index (B), Spearman rank (Rho) per species between slate and video techniques for permanent species

Species	R	B	Rho	Fq
Priacanthus hamrur	0.939*	0.777**	0.900**	0.88
Chaetodon blackburnii	0.346*	0.241	0.296	1.00
Lutjanus kasmira	0.67*	0.487**	0.642**	1.00
Aulostomus chinensis	0.507*	0.392**	0.502**	1.00
Chaetodon kleini	0.598*	0.404**	0.604**	0.95
Heniochus diphreutes	0.943*	0.760**	0.922**	0.95
Acanthurus mata	0.352*	0.247	0.35*	0.88
Mulloidichthys vanicolensis	0.788*	0.734**	0.853**	0.88
Lutjanus bengalensis	0.783*	0.665**	0.826**	0.80
Pterois miles	0.485*	0.432**	0.508**	0.83
Mulloidichthys flavolineatus	−0.1	−0.144	−0.179	0.80
Caranx sp.	0.629*	0.404**	0.517**	0.78
Epinephelus longispinis	−0.048	0.015	0.019	0.80

Fq: frequency of observations on 40 samples.
  * Indicates significance beyond the 0.05 level.
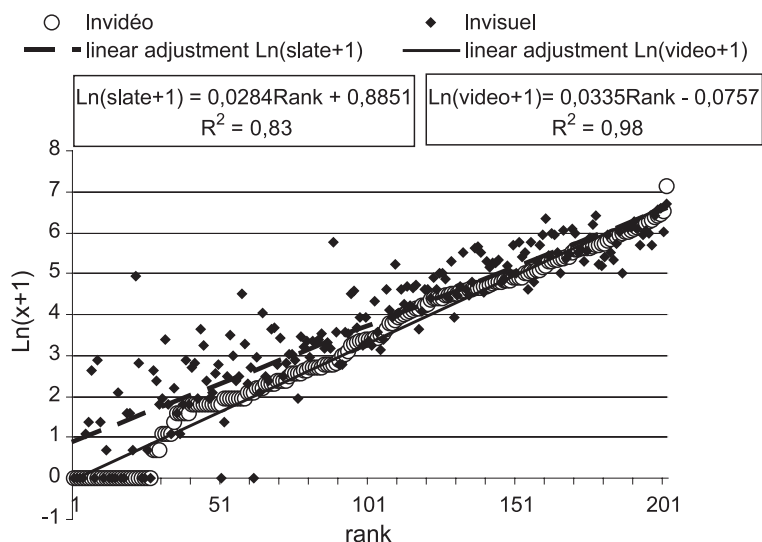 ** Indicates significance beyond the 0.01 level.

Fig. 2. Values (circles) of Ln(video+1) ranged in ascending order and corresponding Ln(slate+1) values (rhomb). Linear adjustment for Ln(video+1) (full line) and linear adjustment for Ln(visual+1) (dotted line).

match between the observed data and the predictive model.

4. Discussion

4.1. Number of species

The underwater visual census method has long been used to estimate the size of reef fish aggregations (Brock, 1954), but this method is limited to non-cryptic and diurnally active fishes (e.g. Brock, 1982; Harmelin-Vivien et al., 1985; Sale and Douglas, 1981). It is likely that the number of type A species that tend to have direct contact with the reef structure itself, and often occupy crevices, holes, or spaces within the reef, is underestimated by underwater visual census techniques, as compared to destructive methods such as rotenone (Letourneur, 1992; Willis, 2001). For type B species, we found that video detects less species than slate methods do, as suggested by other authors either in a natural or in a controlled environment (Bortone et al., 1991; Francour et al., 1999). This result can be explained by the fact that the field of view of a video recording device is much more limited than the human eye, even though one's vision is partially reduced when using a diving mask. This limited field of view can reduce the probability

of detecting an individual when using a video recorder (Bortone et al., 2000), especially with rare species (Table 1). Another reason is the time of observation, as the time spent underwater is shorter using video recording than in a visual census. Many authors have shown that the number of species detected was determined by the duration of the observations (Harmelin-Vivien et al., 1985), and consequently, the amount of time per survey is an important aspect of any method (Bortone et al., 1986, 1989, 2000). In addition, of the 13 permanent species, the 6 species selected for quantitative study (*L. kasmira*, *L. bengalensis*, *P. hamrur*, *M. vanicolensis*, *C. kleinii* and *H. diphreutes*) showed a very similar occurrence with either slate or video census techniques. For the other permanent species, their behaviours make them difficult to detect by video because they are shy (*E. longispinis*, *P. miles*), evasive (*A. mata*), indistinguishable from the background ropes (*A. chinensis*) or offer a low contrast against the black basalt sand (*M. flavolineatus*). Fortunately, of the six species that could be sampled using one of the two underwater visual census techniques (and then selected for quantitative study), four of them (*L. kasmira*, *L. bengalensis*, *P. hamrur* and *M. vanicolensis*) offer the greatest potential for fisheries here (high abundance and high commercial value). Only *M. flavolineatus*, which is also of value for local fisheries, could not be

included in a survey using the video method because of its insufficient contrast against the black basalt sand.

4.2. Abundance

The behaviour of fishes, including attractiveness, ecological type and overall abundance by species are the main factors affecting similarity between the video and slate methods. Even if contrast is not a significant factor on its own, it interacts with attractiveness and makes evaluation of abundances difficult for neutral species We found that the similarity between video and visual recording decreases with high abundances (>1000 individuals). Regarding ecological type, it appears that mean abundances are higher with video for B species (mainly *P. hamrur*) but in contrast, abundance is higher with slate recording for C species (mainly *Selar crumenophtalmus*). For contrasted static species concentrated around the reef, such as *P. hamrur*, video is of real value in allowing the evaluation of high abundance. But for the pelagic species, movement distances and schools size decrease the probability of detection within the 5 min allowed for the video census. By slate, due to the swimming speed of the fishes, it is possible to count the same group of fish several times, which can induce an overestimation of abundance. For these species, a better evaluation could be afforded by acoustic methods. Regarding ecological type, similarity is higher for type C species with a significant interaction with abundance class. In this category small schools of carangids (*Caranx* sp. and *Pseudocaranx dentex*) attracted by the divers permit good detection by the two methods. In contrast, large shoals of evasive species give less similarity.

On the six permanent species during the quantitative study (*P. hamrur*, *L. bengalensis*, *L. kasmira*, *C. kleinii*, *H. diphreustes*, *M. vanicolensis*) overall, on all values recorded, the slate census reveals higher abundance than the video one (Table 2). This fact is confirmed by some authors who have recommended the use of the slate method to estimate the abundance of fishes (Bohnsack, 1996; Bortone et al., 1991). When the annual mean abundance per species is considered, differences between slate and video techniques are low, except for very high abundances (*P. hamrur*, Table 2). However, a linear relation

between the abundance obtained by the two visual census methods permits the calculation of a visual abundance index. Consequently, the predictive model allows us to use either slate or video methods during monitoring. Even if this relation was demonstrated for only six species, these species are permanent and the most abundant on the artificial structures, their abundance being related to their aggregating behaviour (except for *C. kleinii*). Furthermore, in mobile plurispecific schools with morphologically identical individuals, such as *L. kasmira* and *L. bengalensis*, the study shows similar data obtained with either slate or video methods. On the other hand, the species with similar shape and colour (i.e., genus *Haemulon*) are cited to be responsible for differences in density recorded by slate or video methods (Bortone et al., 1991). In this last study, a survey was conducted using point-counts that may have been less suitable than transects for differentiating between such species. On artificial reefs, belt transects can be recommended when the survey takes place under limited time and on large adjusted areas with aligned modules (Bortone et al., 2000), as is the case here. However, the influence of fish behaviour on the abundance evaluations by video is real, especially for evasive schooling species and for low abundance shy species. The characterisation of the diversity of the aggregations may be biased by the technique used. In our case, the Shannon diversity index is significantly different with the two methods (Z W=−4.54**).

4.3. Methodological cost–benefit analysis

Given that conventional scientific diving is expensive and constrained by depth–duration relationships, it is extremely important to develop techniques for in situ visual assessments, which produce the greatest amount of information within a limited time (Bortone et al., 1999). As dive time is a limiting factor below a depth of 10 m, a cost–benefit analysis of the slate and video census techniques was conducted regarding this factor (Table 6). Time comparison between the two techniques shows that, for the qualitative study, the sampling time is similar, but as seen before, the visual census gives better results. For the quantitative study, the time spent for each path (3×24 m, four times) is about 5 min in a visual census and 1.25 min with a video census. Several sampling methods could be

combined to obtain a better understanding of fish aggregations (Bortone et al., 1991; Francour et al., 1999). Furthermore, the methods that produce the greatest amount of information in the least amount of time would be the most effective (Bortone et al., 1999). In our case, the slate census turned out to be the more accurate technique to determine the total number of species (sampling time=5 min) and the abundance of lower-density species, which are cryptic, evasive, difficult to distinguish with a rope background or offer low contrast against the black sand. In order to sample these low-abundance species, 5 min are necessary for an ichthyologist using the slate method. For the estimation of permanent species present in high densities, especially those which tend to school, video saves dive time, in particular during recruitment (sampling time=5 min). Combining the advantages of slate and video methods, sampling will last 15 min, which represents a time gain of 10 min (40%) over a survey using only the slate method (Table 6).

Obviously, the video method reduces the time spent under water, allowing more surveys. During slate censuses, the timelag between making an observation and recording the results increases the probability of error because considerable time is spent looking at the slate instead of the aggregation (Bortone et al., 1991). Audio census techniques could be superior to slate recording devices, as suggested by some authors (Greene and Alevizon, 1989; Bortone et al., 1991), but require more sophisticated technology especially if the experiment is conducted in situ In contrast to a controlled environment (Greene and Alevizon, 1989), the in situ method has to be easy to perform under natural conditions. Even if audiotape could be the most appropriate tool for recording estimations of fish abundance (Greene and Alevizon, 1989), it was not chosen because of difficulties of communication between the diver and the boat at the working depths. Greene and Alevizon (1989) have also demonstrated in an aquarium that there were no apparent differences in the productivity of video and slate methods. But in our case, the study was realised in magnitude of abundance, between 1 and 311 individuals for 44 species of coral reef fishes and, in the case of high abundance, video techniques are of real value (Tessier and Chabanet, 2004). Furthermore, a video census allows a rapid recording of many data items, and videotapes produce a reasonably permanent record that can be re-examined to verify an observation. The disadvantage of this system is that all data must be transcribed from the film. Transcription time is usually greater than the time required to make the recording, and greater for video than for slate (Francour et al., 1999). The limited field of vision of video recorders may preclude accurate species identification. Nevertheless, the resolution of video recording is today increasing with digital imagery, which is especially helpful for murky or poorly lit waters, visibility being one of the main factors limiting visual census techniques (Bortone et al., 1986; Bortone and Mille, 1999; Harmelin-Vivien et al., 1985).

5. Conclusion

There are numerous circumstances and objectives that may dictate the methods that can be used; the specific methods employed often define the limitations of the data (Bortone et al., 2000). The collection of basic data (e.g. number of individuals per species) using visual census techniques is essential for comparing artificial reef structures and following their colonisation process through space and time. It is obvious that underwater human observation is indispensable to assess fish aggregations; only with direct involvement in the natural environment can a wide range of information be gathered, for various reasons, including the human capacity of stereoscopic vision. But visual sampling, including slate and audio census techniques, is limited by the human capacity to intercept visual cues and by depth constraints. In the aggregation versus production debate about artificial reefs (Jensen, 1997; Pickering and Whitmarsh, 1997), variation in mortality rates, whether correlated with or

Table 6
Dive time by type of study and by technique

	Slate census	Video recording	Mixed method
Qualitative study	5 min	5 min	5 min (visual)
Quantitative study	20 min	5 min	10 min (visual+video)
Total time	25 min	10 min	15 min

independent from density, is likely to be of major importance to any study on the structure and dynamics of fish populations (Sale, 1991). To follow fish populations just after massive recruitment, the accuracy of data is fundamental to estimate the mortality rates of the recruits and, in this case, the use of video census technique proves to be of real interest. As suggested before, several sampling methods could be used jointly to obtain a better understanding of fish aggregations. In our study, the slate census is the more accurate technique to determine species richness, in particular for species difficult to detect by video because of their behaviour. Nevertheless, video census can be valuable in particular conditions (in case of strong recruitment or high abundance) and during regular monitoring for key species (described as permanent, abundant and targeted by fisheries). In this case, we recommend using a visual abundance index that will correct the underestimation due to the video in comparison with the slate method. Additionally, the video census, which could also be handled by a non-fish specialist, would permit a larger data set in space and time, almost without constraints, except those influenced by data processing that could be also computerized in the future.

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