NOW YOU SEE ME, NOW YOU DON'T: A CASE STUDY OF THE EFFECT OF THE SAMPLING METHOD ON THE PERCEIVED STRUCTURE OF ICHTHYOLOGICAL COMMUNITIES

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The fish community of a small rocky area near Ponta Delgada, Azores, was assessed using two methods: visual census and rotenone collections. The results obtained with each method are analysed and compared. A total of 46 species was recorded for this site. The visual census recorded more species than did the rotenone collections, but each method detected species that escaped the other. The total fish diversity was found to be similar to that reported in other localized studies of littoral rocky areas of the eastern Atlantic and the Mediterranean. Each method used revealed a different spatial structure and different trophic relationships of the ichthyological community. The visual census put in evidence the pelagic/demersal component, while the rotenone collections emphasized the benthic one. Both methods agree on the importance of the benthic primary production in the trophic food web. Visual census data further suggest that the relevance of the direct consumption of algal material by omnivores and herbivores is greater than could be guessed by the species diversity in this group. Strategies are discussed for combining visual and destructive sampling methods in order to achieve a more accurate representation of a given fish community.

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INTRODUCTION

Immediately after the advent of SCUBA diving, its potential for the scientific observation of the marine environment was realized. Researchers no longer needed to rely only on blind methods such as trawling or the use of traps but could actually see their object of study in its natural environment. Censusing methods used for terrestrial organisms were quickly adapted for underwater use, BROCK (1954) being probably the first to apply them to fishes. A wide variety of underwater visual census techniques was quickly developed and has been successfully applied to various aspects of fish biology and ecology (see HARMELIN-VIVIEN et al. 1985, for a revision). Those techniques are, however, subject to bias from a variety of sources, especially when applied to the complex field of community ecology. These biases stem from subjective factors such as the degree to which the observer is familiar with the local fauna but also include a whole range of factors such as the recording method used, the geomorphology of the place, and the peculiarities of the technique used. Because of this, and in spite of the numerous publications dedicated to comparative methodological studies (e.g. BROCK 1982; SALE & SHARP 1983; THRESHER & GUNN 1986; BORTONE et al. 1986, 1989, 1991; SANDERSON & SOLONSKY 1986; FOWLER 1987; DAVIS & ANDERSON 1989; GREENE & ALEVIZON 1989; JOHN et al. 1990), no standard technique exists for the visual qualitative and/or quantitative assessment of fish communities.

Diving also allowed the development of new capture techniques, among them the direct and selective capture of specimens using spears or

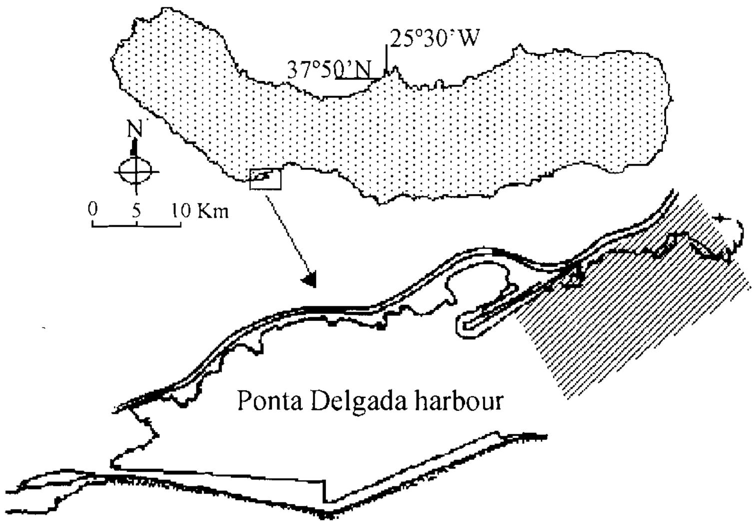

Fig. 1. São Miguel Island and location of the study area (stippled).

hand nets, or the less selective use of ichthyocides such as quinaldine or rotenone. Ichthyocides in particular have the advantage over visual census in being non-subjective (but the disadvantage of destructiveness).

The present results were obtained during a study whose main objective was to obtain quantitative data about the spatial and trophic structure of a fish community from a marine, rocky, shallow water area of the Azores (see AZEVEDO 1997). It was decided to combine a visual census technique with rotenone collections. The present paper documents and compares the results obtained with each method. The only other instance of such a mixed approach to the ecological study of fish communities known to the author is that of PARISH et al. (1985), although KULBICKI (1990) also discussed some of the methodological problems involved. A comparison of a visual census technique and another destructive sampling technique (trawling) was made by HARMELIN-VIVIEN & FRANCOUR (1991).

METHODS

Work was carried out in a small (approx. 100x300 m) and shallow marine area near the Ponta Delgada harbour, in the island of São Miguel, Azores (Fig. 1). The substrate is mostly very irregular rock, with some areas of boulders and pockets of sand. The algal cover is abundant. Depth is approximately uniform in all the area, from 3-5 m.

Fish collections were made monthly from December 1993 to November 1995 using rotenone, in the form of a 5% liquid emulsion. The sampling method was as follows. A circular area of about 100 m^2 was enclosed with a 1 cm mesh net, dropped from a rigid inflatable boat at the surface with the help of two divers in the water. The net was 4 m high by 36 m long, kept straight in the water by a string of buoys on the top and one of lead beads on the bottom. The circle was closed with velcro strips attached to the lateral extremities of the net. The whole netting operation generally took less than two minutes. Immediately after the closing of the net, one diver inside the sampling area would open a hole in a plastic bag containing 1.5 L of the rotenone emulsion, previously diluted in seawater, and proceed to spread it around, close to the bottom and as uniformly as possible. After the rotenone cloud dispersed, the bottom was carefully scanned and the fish collected with hand nets. A similar technique was used by NORRIS (1985) and KULBICKI (1990), however those authors used the net to enclose a small coral reef and not, as in the present case, to delimit part of an essentially continuous area. After the capture the fish were placed in buckets with seawater and transported to the laboratory, were identification and counting took place.

Visual census were made from September 1994 to December 1995 on an irregular monthly basis. The method used was an adaptation of the "Visual Fast Count" of KIMMEL (1985). In the original method, each census takes 50 minutes, divided in 5 intervals of 10 minutes each. The diver starts to swim randomly across the area to be sampled, identifying species and counting the respective number of individuals seen. In the present study, counts were recorded with pencil on sheets of polyester drafting film with a pre-printed species list, attached to a white acrylic board. In the following 10 minute intervals, the diver records and counts only the species not yet seen in that census. Preliminary essays with this method in the study area showed that almost all the species were sampled in the first 10 minutes, and that no species were seen in the last two or three intervals. Therefore, reducing the length of each census to 30 minutes resulted in greatly increased productivity without significantly affecting the results, either in number of species seen or in their relative abundances. It was also found that reducing the interval from 10 to 5 minutes made the counting process easier, because the diver had fewer species to look after simultaneously.

Abundance of each species is given as the number of fish counted times a coefficient related to the time interval when the species was seen. The coefficient is 1 for the first interval, 1/2 for the second, 1/3 for the third, and so on. Abundance indexes result, giving the number of fish seen per 5 minute interval. A total of 111 census was made in the area. The number of census per month ranged from 6 to 17, with an average of 11.

For the purposes of the present paper, the average number of individuals and the average biomass was computed for each species, over all the rotenone collections. The same was done for abundance indexes from the visual census. Biomass estimates were obtained from the visual census, using a Monte Carlo approach, as follows. For each observed species, an "abundance interval" and a "weight interval" was assigned. The 95% confidence interval of the mean abundance was used as the abundance interval. For the species in which enough individuals (>50) were collected, the weight interval was calculated as the 95% confidence interval of the mean weight; for the other species the interval was established in a variety of ways, including published length-weight relationships, weighing of specimens in reference collections and, in a few cases, reports from experienced fishermen. A small spreadsheet macro routine picked randomly abundance and weight values, for each species, from within the given intervals. Species were then grouped into the spatial and trophic categories defined below, and the biomass of each category was computed. This procedure was repeated 2000 times. The result was a frequency distribution of biomass values for each category, from which averages were calculated. Given the many sources of error associated with this approach, biomass estimates thus obtained are not meant to provide more than general indications.

The spatial and trophic structure of the community was analysed after grouping the species in functional categories (Table 1). Each species was assigned to one of the spatial categories defined by HARMELIN (1987): 1 - diurnal pelagic species, usually schooling (e.g. *Boops boops*); 2 - sedentary planktonivorous (e.g. *Chromis limbata*); 3 - demersal, with vertical movements of a few meter sand important lateral movements (e.g. *Diplodus*); 4 - nectobenthic, with marked substrate affinity but important lateral movements (e.g. *Mullus surmuletus*); 5 - sedentary nectobenthic species, with little vertical or lateral mobility (like most Labridae); 6 - benthic species (like most Gobiidae and Blenniidae). The trophic categories of Azevedo (1995) were adopted, with minor modifications on the assignment of species. Species were classified as herbivorous (H), omnivorous (O), benthic carnivorous (BC) and pelagic carnivorous (PC) (including planktivores and pelagic ichthyvorous predators).

RESULTS

SPECIES RICHNESS

The list of all the species observed or collected in the study area is given on Table 1, together with the average relative abundance of each species in each of the sampling methods. Both methods combined allowed the determination of a total of 46 species. The perceived species richness was greater with the visual counts than with the rotenone collections (41 *versus* 32 species). As expected, cryptic species (the cave-dwelling

Table 1

Species composition, classification into spatial (Spt) and trophic (Tro) categories, and relative abundance of the ichthyological community at the study site, as revealed by two sampling methods: rotenone collections and visual census (VFC). Values for biomass (B) and number of individuals (N) are relative (percentual) means from all the samples.

	Category		Rotenone		Visual
	Spt	Tro	B	N	N
Seen but not captured (14 spp.):					
Balistes carolinensis	1	CB	-	-	0.03
Belone sp.	1	CP	-	-	0.00
Bothus podas	4	CB	-	-	0.12
Canthigaster rostrata	5	O	-	-	0.00
Chelon labrosus	3	CB	-	-	9.8
Dasyatis pastinaca	4	O	-	-	0.01
Kyphosus sp.	3	H	-	-	0.03
Sarpa salpa	3	CB	-	-	2.55
Serranus atricauda	5	CP	-	-	0.03
Seriola sp.	1	CP	-	-	0.10
Sparisoma cretense	3	O	-	-	0.26
Sphyraena sp.	1	CP	-	-	0.00
Syngnathus acus	3	CB	-	-	0.00
Trachinotus ovatus	1	CP	-	-	0.02
Captured but not seen (5 spp.):					
Apogon imberbis	6	CB	1.62	0.49	-
Coryphoblennius galerita	6	O	0.05	0.16	-
Diplecogaster bimaculata	6	CB	0.02	0.85	-
Gaidropsarus guttatus	6	CB	1.47	0.66	-
Hippocampus ramulosus	6	CB	0.15	0.39	-
Seen and captured (27 spp.)					
Abudefduf luridus	6	CB	1.80	0.33	0.13
Atherina presbyter	1	CP	1.45	3.27	34.12
Boops boops	1	CP	5.38	3.67	7.51
Capros aper	3	CB	0.97	0.74	0.01
Centrolabrus caeruleus	5	CB	15.27	3.31	10.88
Chromis limbata	2	CP	4.16	0.99	0.50
Coris julis	5	CB	1.46	0.22	1.51
Diplodus sargus	3	O	1.33	0.16	9.37
Gobius paganellus	6	CB	14.32	11.45	0.66
Labrus bergylta	5	CB	3.02	0.49	0.04
Macroramphosus scolopax	3	CB	2.97	2.60	0.96
Mullus surmuletus	4	CB	1,21	0.41	2.25
Muraena helena	6	CB	1.42	0.25	0.03
Ophioblennius atlanticus	6	H	9.29	1.25	0.29

(Table 1 continued)

Pagellus bogaraveo	1	CP	1.37	1.97	10.45
Pagrus pagrus	3	CB	0.78	0.27	0.86
Parablennius incognitus	6	O	1.75	14.34	0.01
Parablennius ruber	6	O	6.59	10.90	0.48
Pseudocaranx dentex	1	CB	0.12	0.16	0.25
Scorpaena maderensis	6	CB	3.75	0.59	0.03
Scorpaena notata	6	CB	3.63	0.27	0.01
Sphoeroides marmoratus	4	CB	5.33	1.35	1.44
Symphodus mediterraneus	5	CB	0.60	0.29	1.54
Thalassoma pavo	5	CB	1.78	1.13	1.83
Thorogobius ephippiatus	6	CB	0.05	0.41	0.15
Trachurus picturatus	1	CP	0.70	0.33	0.36
Tripterygion delaisi	6	CB	6.09	35.73	1.19

Apogon imberbis and the nocturnal *Gaidropsarus guttatus*) were collected but not seen. Observers nevertheless failed to see species that live in the open but that are either small (like the gobiesocid *Diplecogaster* sp.) and/or well camouflaged (*Coryphoblennius galerita* and *Hippocampus ramulosus*). Most species that were seen but not captured were fast-moving, demersal or pelagic, and medium to large-sized. Among the most frequent were *Chelon labrosus*, *Sarpa salpa*, and *Sparisoma cretense*. One exception to this rule was the flatfish *Bothus podas*. This was a small and frequently seen species that was never captured, presumably because it could escape the net by swimming below it.

SPATIAL DISTRIBUTION

Fig. 2 shows the mean relative abundance of the most common species, as determined by each method. Clearly, the visual counts were biased towards the pelagic and/or more mobile species, while the rotenone collections were dominated by benthic species. These bias are reflected in the perceived spatial structure of the community, when species are grouped into spatial categories (Fig. 3). In the rotenone collections, category 6 (benthic, sedentary species) is always dominant, either in species richness, number of individuals or total biomass. The visual counts show a different organization. The various spatial categories have less disparate species richness, although the benthic category is still the most diverse. It is in terms of number of individuals and of total biomass that the two methods differ the most. No category is clearly dominant, but three have higher mean values: category 1 (pelagic species), predominantly the schooling *Atherina presbyter* and juveniles of *Pagellus* spp. and of *Boops boops*; category 3 (demersal), mainly *Chelon labrosus* and *Diplodus sargus*; and category 5 (nectobenthic), dominated by *Centrolabrus caeruleus*.

The visual census, therefore, reveal a spatially richer ichthyofauna than that shown by the rotenone collections. The pelagic and demersal components of the community, in particular, are seen to have an ecological importance (in both numbers and biomass) that could not be deduced from the destructive sampling or from the species lists.

TROPHIC STRUCTURE

Previous analysis of the Azorean littoral fish fauna showed that the benthic microcarnivores are the dominant trophic category, in terms of species richness (PATZNER & SANTOS 1993; AZEVEDO 1995). Most species, therefore, are dependent on the benthic primary production, which reaches them via the benthic invertebrates. A species list, however, is a poor indicator of ecological importance. To evaluate the relative dependence on a given energy pathway,

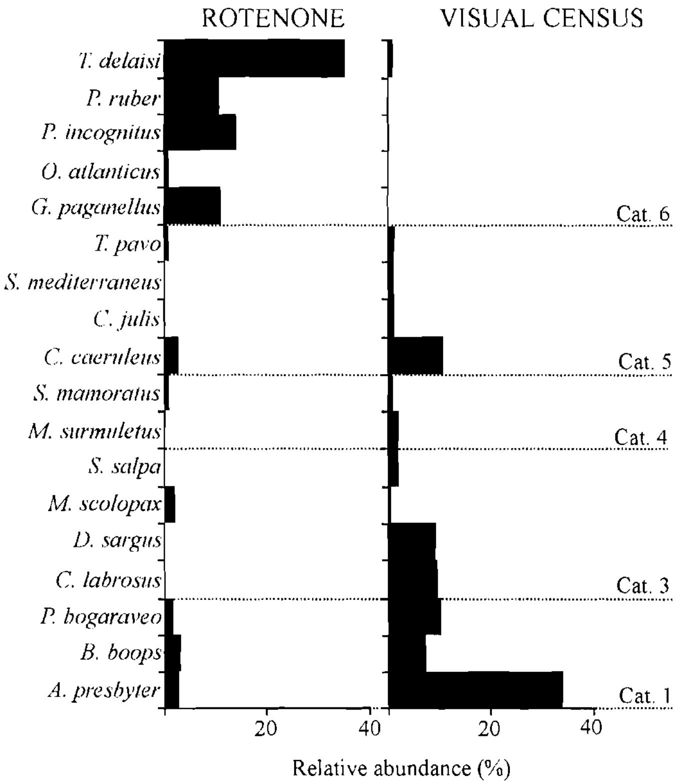

Fig. 2. Mean relative abundances (%) of the more common species, for each of the sampling methods. Species are listed by spatial category, in increasing (top to bottom) order of motility.

quantitative data are necessary. Preferably, biomass data should be used (as in PARISH et al. 1985 or POLUNIN & KLUMPP 1992).

Fig. 4 shows the distribution of the species richness, number of individuals and fish biomass by the 4 main trophic categories, as gathered from each sampling method. The dominance of the benthic carnivores in terms of number of species is confirmed by both methods. The fish community sampled by the rotenone is dominated in biomass also by benthic carnivores. Using only this method, therefore, one could conclude that the community picture in terms of species diversity translates directly into the ecological importance of the food web pathways. The biomass evaluation based on the visual census data, however, shows a dominance of the food web by omnivorous fish. This is mainly due to *Diplodus sargus* and *Chelon labrosus*. The results from this method also show that the herbivores (mainly *Sarpa salpa*) and the pelagic carnivores (*Atherina presbyter* and juveniles of *Pagellus* spp. and of *Boops boops*) are numerically important and have a non-negligible estimated biomass. This is an indication that two other energetic pathways are important to the studied fish community: benthic primary production via direct consumption of algal biomass and pelagic (planktonic) production.

DISCUSSION

The fish community perceived by the visual census was dominated in number and in biomass by mobile species, pelagic (category 1) and demersal (categories 3 and 5). On the other hand, the rotenone data show a community dominated by benthic species, with the sedentary demersal (category 5) increasing in relative importance in biomass terms. In addition, the visual census revealed a more diverse community although 2/5 of the species were invisible to one or the other methods.

These contradictions and omissions are a direct consequence of the characteristics and the limitations of the methods used. The effect of the rotenone on an individual fish varies with the concentration and the time that it is exposed to the product (GILDERHUS 1972). The reason for closing off the sampling area with a net was to keep the fish inside it until a lethal dosage was attained. It was however seen that the more mobile species escaped even while the net was being set. The rotenone collections therefore selectively collected the less mobile species or those whose instinct made them hide instead of escaping. Its excellence in sampling this group of species is demonstrated by the capture of species that were not recorded in the visual census and would otherwise be totally missed. Two additional factors should be kept in mind when using quantitative rotenone data, as was done in this paper. The first is the direct relationship between water temperature and rotenone efficiency (GILDERHUS 1972; MEADOWS 1973; SAMUELSEN et al. 1988; DAWSON et al. 1991): the number of fish collected is expected to be larger in summer than in winter, even if the density remains the same. The effect of the rotenone also varies across the phylogenetic scale. Different tolerances to this product between families and even species of marine fishes have in fact been documented (WINGARD & SWANSON 1992; M. LOCKETT pers. comm.), but few data exist and there is no explanation of this effect that has predictive value. Relative abundance results from rotenone collections may, then, be compounded by differences in sensitivity between the species sampled.

The visual census technique used in the present study sampled more efficiently the more visible species which, as a rule, are also the most mobile ones. Several schooling, abundant, species were consistently recorded with this method that were never captured with rotenone or were severely under represented. One of the more objectionable aspect of this technique is precisely a tendency of the observer to focus on moving objects. The relative abundance of immobile and cryptic species may thus be strongly under evaluated.

The present results establish that none of the techniques used gives a complete description of the ichthyological community, not even on qualitative terms. It is plausible to admit that a complete inventory of most ichthyological communities can only be achieved combining a variety of destructive and non-destructive sampling methods. If a quantitative description is necessary, several additional requirements must be met. Several visual census techniques produce absolute estimates of density (see revision in HARMELIN-VIVIEN et al. 1985; the distance sampling methods developed by BUCKLAND et al. 1993 are very promising in this context). It is even possible to accurately estimate the length of the fishes and, from it, their weight (as was done by, e.g., BELL et al. 1985, BELLWOOD & ALCALA 1988, JOHN et al. 1990, BORTONE et al. 1992 or MILLE & VAN TASSELL 1994). Given the multiple spatial niches occupied by fishes, the best strategy probably involves the simultaneous use of several such methods, each directed to a given species or group of species. The choice of the methods should be preceded by preliminary work to determine its relative efficiency in each case. The best visual estimates for each species could eventually be combined with quantitative destructive collections to provide an integrated view of the community.

The species richness recorded in the present study (S=46) is equal to that given by SANTOS (1992) for another Azorean site, the Monte da Guia, Faial Island, although the species are not all the same. This diversity is low if compared with similar studies in coral reefs: 143 species in the Great Barrier Reef (SALE & DOUGLAS 1984); 158 in Hawaii (NORRIS 1985); 280 species in Moorea, French Polynesia (GALZIN & LEGENDRE 1987). Contrary to expectations based on total faunistic richness, however, the Azorean sites show a species diversity similar to that of other temperate rocky coast communities of the Atlantic and the Mediterranean: HARMELIN (1987) recorded 47 species in Port-Cros, Corse; GARCÍA-RUBIES & ZABALA (1990) observed 51 species in the island of Medes, Spain and BORTONE et al. (1991) listed 47 species in the island of El Hierro, Canaries. This apparent contradiction may be explained by taking into account the scale factor. Faunal lists are compiled over a coastline of hundreds of kilometers and a depth of several hundreds of meters, encompassing necessarily different kinds of habitat. They will therefore contain many more species than those that can be found in any single location. Nevertheless, insular biogeography theory (MACARTHUR & WILSON 1967) predicts that even when sampling area size is the same, the Azores sites should still have a lower species diversity than the above mentioned ones. Further comparative work is needed before this discrepancy can be solved.

The perceived spatial distribution of the fish community is different according to the sampling method used, the visual census emphasizing the importance of the pelagic/demersal species, the rotenone collections that of the benthic one. Better methods have therefore to be developed,

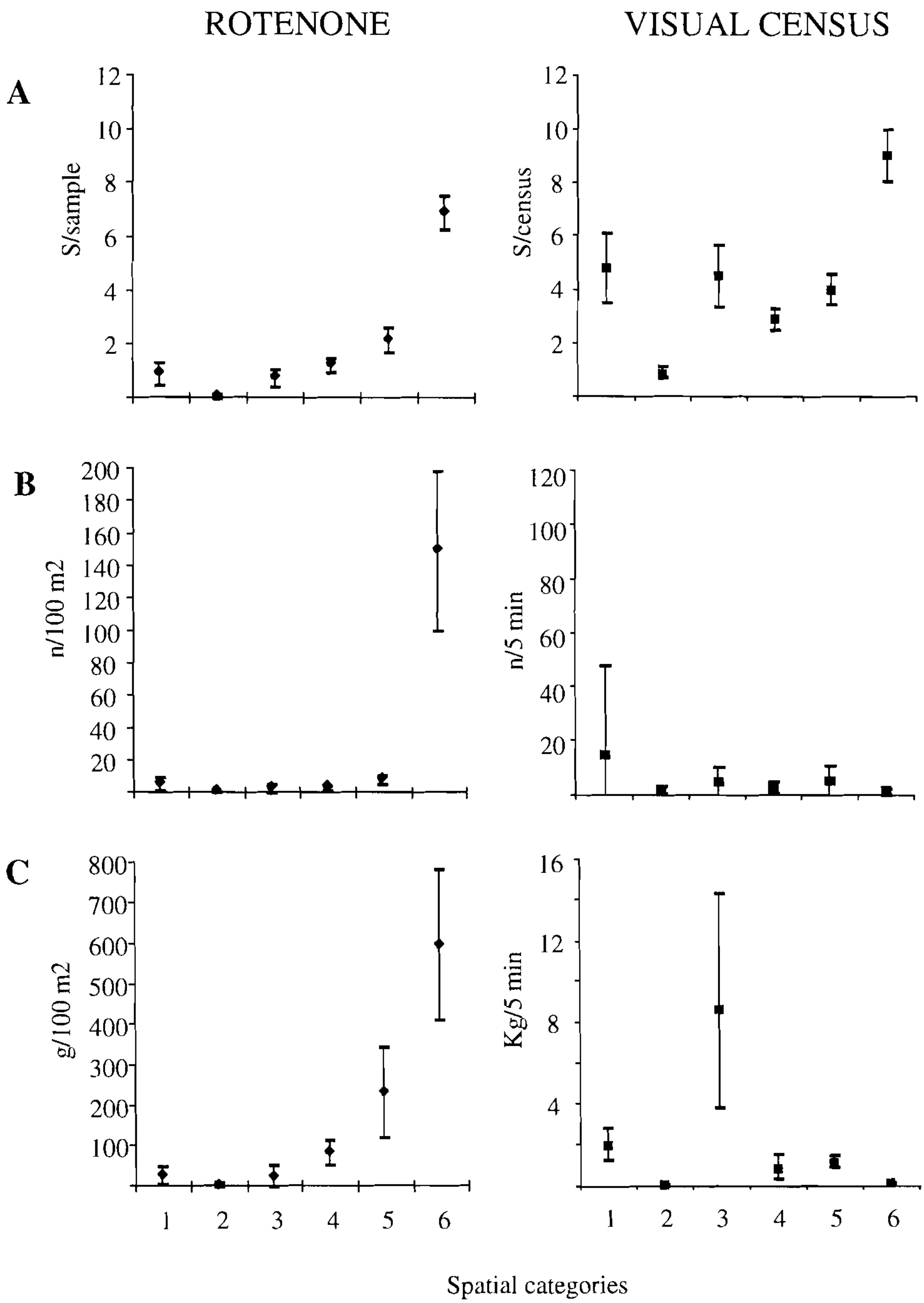

Fig. 3. Community structure: species richness, S (A), abundance (B) and biomass (C) of each spatial category, as given by the rotenone samples (left) and the visual census (right). Graphs show average ± 95% confidence interval, except for visual census biomass estimates, which show median ± 5/95 percentils.

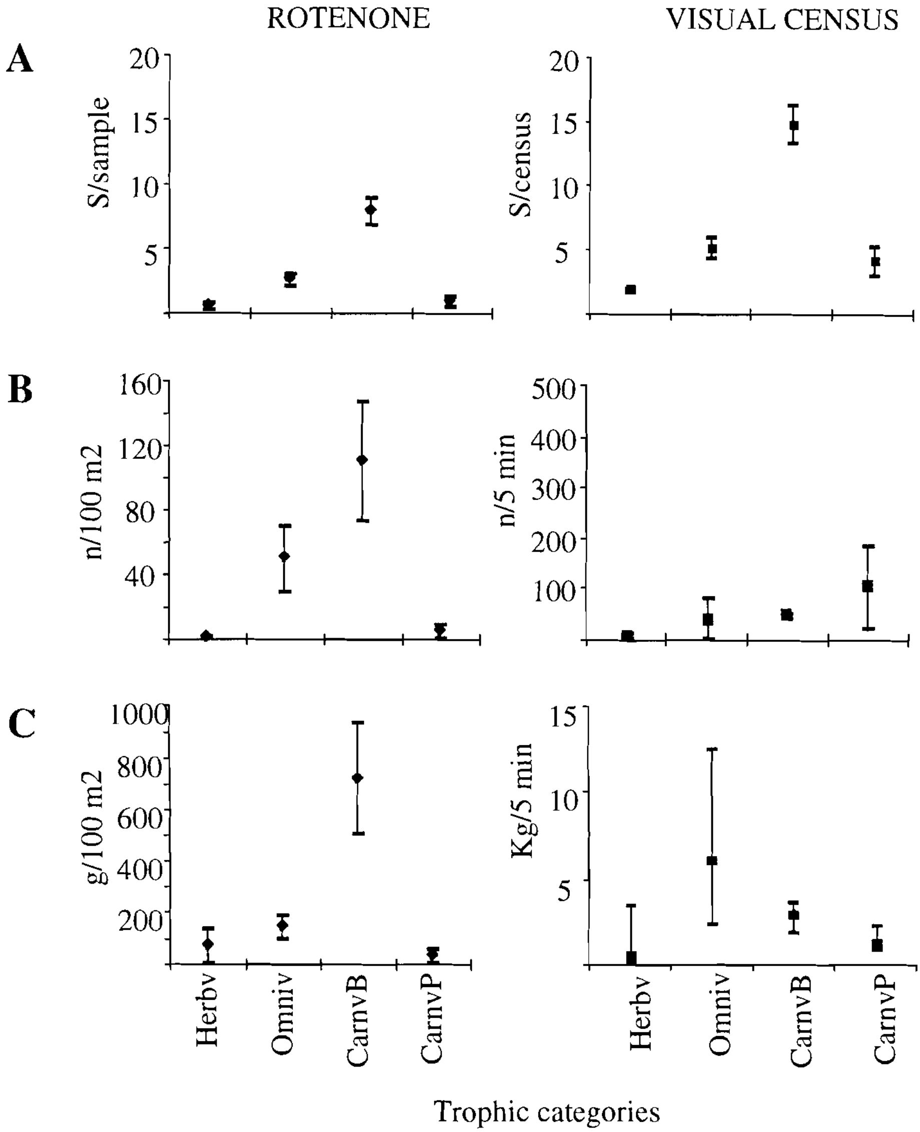

Fig. 4. Community structure: species richness, S (A), abundance (B) and biomass (C) of each trophic category, as given by the rotenone samples (left) and the visual census (right). Conventions as in Fig. 3.

along the lines discussed above, so that a more accurate description of the spatial structure of the Azorean littoral fish community can be attained. Attention should be given to the fact that spatial categories are likely to have different weight according to factors such as depth and type of substrate. Data consistent with this statement was obtained when geomorphologically and hydrodynamically distinct sites were compared by HARMELIN (1987) in Corse and by BORTONE et al. (1991) in the Canaries.

Little work has been done on the subject of quantification of trophic relationships within fish communities. Most studies limit themselves to express the relative importance of trophic categories in terms of species richness. This is the current state of the knowledge in the Azores, as reported by PATZNER & SANTOS (1993) and AZEVEDO (1995). These authors note that most species feed on benthic invertebrates. The quantitative estimates obtained in the present study using the rotenone collections also show the benthic carnivores as dominant in terms of biomass and hence of ecological importance. Nevertheless, with all their associated bias, the visual census data suggest that, in this particular site, algal biomass is also an important energy pathway in the fish community. Overall, it is the benthic primary production that emerges as the main energy source of the studied community. Further work is needed to confirm these results and to verify its applicability on different geomorphological and depth settings.

The clarification and quantification of the fish trophic web has important applied aspects, as illustrated by the work of POLUNIN & KLUMPP (1992).These authors developed a trophodynamic model applied to an intensively studied area, the Davies Reef on the Great Barrier Reef, Australia. In the model the trophic chains that link the benthic and planktonic primary productions to the fish community were delineated. Data from many sources were then used to estimate the energetic input and the efficiency of transmission along the food chains. The resulting model was finally used to generate data relevant for fisheries management. This integrated approach could also be useful in the context of the littoral fisheries of the Azores which are, as in tropical areas, mainly pluriespecific.

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REFERENCES

AZEVEDO, J. M. N. 1995. Food web of the Azorean shallow water marine ichthyological communities: a guild approach. *Boletim do Museu Municipal do Funchal* Suplemento 4: 29-53.

AZEVEDO, J. M. N. 1997. *Estrutura de uma comunidade ictiológica do litoral da ilha de São Miguel (Açores): caracterização e variações espaço-temporais*. Ph.D. thesis, Universidade dos Açores, Ponta Delgada. 178 pp.

BELL, J. D., G. J. S. CRAIK, D. A. POLLARD & B. C. RUSSELL 1985. Estimating length frequency distributions of large reef fish underwater. *Coral Reefs* 4: 41-44.

BELLWOOD, D. R. & A. C. ALCALA 1988. The effect of a minimum length specification on visual estimates of density and biomass of coral reef fishes. *Coral Reefs* 7: 23-27.

BORTONE, S. A., R. W. HASTINGS & J. L. OGLESBY 1986. Quantification of reef fish assemblages: a comparison of several *in situ* methods. *Northeast Gulf Science* 8(1): 1-22.

BORTONE, S. A., J. J. KIMMEL & C. M. BUNDRICK 1989. A comparison of three methods for visually assessing reef fish communities: time and area compensated. *Northeast Gulf Science* 10(2): 85-96.

BORTONE, S. A., T. MARTIN & C. M. BUNDRICK 1991. Visual census of reef fish assemblages: A comparison of slate, audio, and video recording devices. *Northeast Gulf Science* 12(1): 17-23.

BORTONE, S.A., J. VAN TASSELL, A. BRITO, J.M. FALCON & C.M. BUNDRICK 1991. A visual assessment of the inshore fishes and fishery resources off El Hierro, Canary Islands: A baseline survey. *Scientia Marina* 55(3): 529-541.

BORTONE, S. A., J. VAN TASSELL, A. BRITO, J. M. FALCON & C. M. BUNDRICK 1992. Visual census as a means to estimate standing biomass, length, and growth in fishes. *Diving for Science* 1992: 13-21.

BROCK, R. E. 1982. A critique of the visual census method for assessing coral reef fish populations. *Bulletin of Marine Science* 32(1): 269-276.

BROCK, V. E. 1954. A preliminary report on a method of estimating reef fish populations. *Journal of Wildlife Management* 18: 289-308.

BUCKLAND, S. T., D. R. ANDERSON, K. P. BURNHAM & J. L. LAAKE 1993. *Distance Sampling: Estimating Abundance of Biological Populations*. Chapman & Hall, London. 446 pp.

DAVIS, G. E. & T. W. ANDERSON 1989. Population estimates of four kelp forest fishes and an evaluation of three *in situ* assessment techniques. *Bulletin of Marine Science* 44 (3): 1138-1151.

DAWSON, V. K., W. H. GINGERICH, R. A. DAVIS & P. A. GILDERHUS 1991. Rotenone persistence in freshwater ponds: effects of temperature and sediment adsorption. *North American Journal of*

Fisheries Management 11: 226-231.
FOWLER, A. J. 1987. The development of sampling strategies for population studies of coral reef fishes. A case study. *Coral Reefs* 6: 49-58.
GALZIN, R. & P. LEGENDRE 1987. The fish communities of a coral reef transect. *Pacific Science* 41: 1-4.
GARCÍA-RUBIES, A. & M. ZABALA 1990. Effects of total fishing prohibition on the rocky fish assemblages of Medes Islands marine reserve (NW Mediterranean). *Scientia Marina* 54(4): 317-328.
GILDERHUS, P. A. 1972. Exposure times necessary for antimycin and rotenone to eliminate certain freshwater fish. *Journal of the Fisheries Research Board of Canada* 29(2): 199-202.
GREENE, L. E. & W. S. ALEVIZON 1989. Comparative accuracies of visual assessment methods for coral reef fishes. *Bulletin of Marine Science* 44(2): 899-912.
HARMELIN, J. G. 1987. Structure et variabilité de l'ichtyofaune d'une zone rocheuse protégée en Méditerranée (Parc national de Port-Cros, France). *P. S. Z. N. I: Marine Ecology* 8(3): 263-284.
HARMELIN-VIVIEN, M. L. & P. FRANCOUR 1991. Trawling or visual censuses? Methodological bias in the assessment of fish populations in seagrass beds. *Marine Ecology Progress Series* 13(1): 41-51.
HARMELIN-VIVIEN, M. L., J. G. HARMELIN, C. CHAUVET, C. DUVAL, R. GALZIN, et al. 1985. Evaluation visuelle des peuplements et populations de poissons: methodes et problèmes. *Revue d'Ecologie (Terre Vie)* 40: 467-539.
JOHN, J. S., G. R. RUSS & W. GLADSTONE 1990. Accuracy and bias of visual estimates of numbers, size structure and biomass of a coral reef fish. *Marine Ecology Progress Series* 64: 253-262.
KIMMEL, J. J. 1985. A new species-time method for visual assessment of fishes and its comparison with established methods. *Environmental Biology of Fishes* 12(1): 23-32.
KULBICKI, M. 1990. Comparaisons entre empoisonnements à la roténone et comptages en plongee pour l'estimation de la densité et la biomasse de peuplements de poissons coralliens. *Proceedings ISRS, Nouméa*: 105-112.
MACARTHUR, R. H. & E. O. WILSON 1967. *The theory of island biogeography*. Princeton University Press, Princeton, New Jersey.
MEADOWS, B. S. 1973. Toxicity of rotenone to some species of coarse fish and invertebrates. *Journal of Fish Biology* 5: 155-163.
MILLE, K.J. & J. L. VAN TASSELL 1994. Diver accuracy in estimating length of models of the parrotfish, *Sparisoma cretense*, in situ. *Northeast Gulf Science* 13(2): 149-155.
NORRIS, J. E. 1985. *Trophic relationships of piscivorous coral reef fishes from the Northwestern Hawaiian islands*. Master of Science Thesis, University of Hawaii. 71 pp.
PARISH, J. D., M. W. CALLAHAN & J. E. NORRIS 1985. Fish trophic relationships that structure reef communities. *Proceedings of the Fifth International Coral Reef Congress, Tahiti* 4:73-78.
PATZNER, R. A. & R. S. SANTOS 1993. Ecology of rocky littoral fishes of the Azores. *Courier Forschungsinstitut Senckenberg* 159:423-427.
POLUNIN, N. V. C. & D. W. KLUMPP 1992. A trophodynamic model of fish production on a winward reef tract. In D. M. John, S. J. Hawkins & J. H. Price (Eds). *Plant-Animal Interactions in the Marine Benthos*, pp: 213-233. Systematics Association Special Volume, 46. Clarendon Press, Oxford.
SALE, P. F. & W. A. DOUGLAS 1984. Temporal variability in the community structure of fish on coral patch reefs and the relation of community structure to reef structure. *Ecology* 65 (2):409-422.
SALE, P. F. & B. J. SHARP 1983. Correction for bias in visual transect census of coral reef fishes. *Coral Reefs* 2:37-42.
SAMUELSEN, O. B., E. SOLHEIM, H. OTERRA & J. P. PEDEREN 1988. The toxicity, adsorption and excretion of rotenone in Oysters (*Ostrea edulis*), and its degradation in seawater at temperatures near 0° C. *Aquaculture* 70: 355-363.
SANDERSON, S. L. & A. C. SOLONSKY 1986. Comparison of a rapid visual and a strip transect technique for censuring reef fish assemblages. *Bulletin of Marine Science* 39 (1): 119-129.
SANTOS, R. S. 1992. *Behavioural ecology, phenology and ethology of an intertidal blenny, Parablennius sanguinolentus parvicornis (Valenciennes in Cuvier & Valenciennes, 1836) (Pisces: Bleniidae), from the Azores*. PhD Thesis. Port Erin Marine Laboratory, University of Liverpool. x + 293 pp
THRESHER R.E. & J. S. GUNN 1986. Comparative analysis of visul census techniques for highly mobile, reef associated piscivores (Carangidae). *Environmental Biology of Fishes* 17(2):93-116.
WINGARD, C. J. & C. J. SWANSON 1992. Ventilatory responses of four marine teleosts to acute rotenone exposure. *Journal of Applied Ichthyology* 8:132-142.

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