Fish assemblages of Cais do Carvão Bay (Madeira Island) determined by the visual census technique

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Fish assemblages in Cais do Carvão Bay, Madeira Island, a proposed marine protected area (MPA), were determined from a diver visual census. A total of 32 transect counts were performed. Habitats sampled included sandy bottom, rocky boulders, vertical walls and rocky outcrops. Species richness, diversity, density, trophic structure, size and spatial organization were documented for the fish assemblages. Forty-four species from 23 families were encountered; 32% belonged to Sparidae (10) and Labridae (four). The greatest species richness (25) was observed in rocky boulder habitat at 10–15 m depth, while the lowest (five) occurred over a deeper sand habitat. The greatest density (760·5 individuals per 100 m^2) was recorded over rocky outcropping (20–25 m deep), and the lowest of 11·6 individuals per 100 m^2 was over a sand bottom at 10–15 m depth. *Thalassoma pavo*, *Abudefduf luridus* and *Chromis limbata* had higher densities on hard bottoms, while *Heteroconger longissimus* was the most abundant species in sand bottom habitats. No significant differences were detected for all indices calculated among depth intervals for sand and rocky boulder stations. Sand and rock boulder substratum, however, differed significantly for the 10–15 m depth stratum.   © 2005 The Fisheries Society of the British Isles

Key words: fish community; marine protected areas; temperate reefs.

INTRODUCTION

Fish assemblages, especially those composing commercial and recreational fishery species, have been widely studied. Many descriptions of marine fish assemblages have concentrated on reef-fish assemblages, including coral (Colton & Alevizon, 1981; Brock, 1982; Bohnsack & Bannerot, 1986) and temperate reefs (Bell, 1983; Jessee *et al.*, 1985; Lindquist *et al.*, 1985; Harmelin, 1987, 1999; Harmelin *et al.*, 1995). *In situ* data on reef fish assemblages can be used to evaluate community responses to natural and artificial changes in the biotope (Bortone *et al.*, 1991*a*; Bythell *et al.*, 1993). Non-destructive techniques, such as underwater visual observation (scuba and a submersible-based camera), have

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frequently been used to characterize reef fish communities (Bohnsack & Bannerot, 1986; Clarke, 1986). Visual techniques have commonly been used to quantitatively measure relative abundances and community structure of coral reef fishes for 50 years (Brock, 1954; Alevizon & Brooks, 1975; Brock, 1979, 1982; Colton & Alevizon, 1981) and more recent studies have begun to address temperate reef fish assemblages at rock-reef outcroppings in North America (Jessee *et al.*, 1985; Bodkin, 1986; Lindquist *et al.*, 1989) and also in Europe, *e.g.* Portugal (Andrade & Albuquerque, 1995; Almeida, 1996; Santos *et al.*, 1996), Canary Islands (Bortone *et al.*, 1991*a, b*; Falcón *et al.*, 1993), and in the Mediterranean Sea (Bell & Harmelin-Vivien, 1983; Harmelin, 1987, 1990).

A wide variety of *in situ* visual assessment methods have been developed to study reef fishes, including point counts (Slobodkin & Fishelson, 1974; Bohnsack, 1982), rapid visual count (RVC) (Jones & Thompson, 1978), visual fast count (VFC) (Kimmel, 1985), spot mapping (Thresher & Gunn, 1986) and random counts (Bohnsack & Bannerot, 1986). Accuracy and precision of counts of reef fish assemblages using these methods are difficult to achieve because of the diversity and mobility of the fauna encountered and the variety of micro-habitats that exist within complex reef substrata (Russell *et al.*, 1978). Although each of them offers advantages and disadvantages relative to the others, no single method is best suited for all circumstances. Each is designed to examine a specific, but incomplete portion of the fish assemblages, and thus each yields a relative rather than absolute characterization of those assemblages (Clarke, 1986).

The primary objective of the present study was to describe and document reef fish assemblages of Cais do Carvão Bay on Madeira Island using a visual census technique to provide a baseline data-set for use in future. The second objective was to evaluate the importance of abiotic factors such as water depth, and habitat and substratum type on the community structure of the reef fish assem-blages. The third objective was to provide data on fish assemblages, prior to designation of the study area as a no-take marine reserve (marine protected area, MPA).

MATERIALS AND METHODS

The study was performed in Cais do Carvão Bay, a small bay located on the south coast of Madeira Island, east of Ponta da Cruz (Fig. 1). This bay is located in a proposed MPA, pending approval by the Regional Government of Madeira. Cais do Carvão Bay lies south-west to north-east and is bordered by coastline characterized by steep, irregular sea cliffs. The sea floor consists primarily of hard bottom habitat (*i.e.* basalt rocks covered with sessile biota, including a variety of algae, sponges, sea urchins, sea ane-mones and sea cucumbers). Several streams located along the island coast flow directly to beaches, which are comprised of small boulders (<1 m). Underwater visibility in Cais do Carvão Bay is typically 5–25 m at water depths <20 m, *c.* 0·5 km offshore (Anon, 1979).

VISUAL CENSUS SURVEYS

Visual census site selection was based on depth strata (0–5, 10–15 and 20–25 m) and substratum type, including rocky boulders, vertical walls, sand and rocky outcropping. The fish assemblages were described using visual census surveys at six sites (Table I) between November 1997 and August 1998. A widely-accepted transect method was
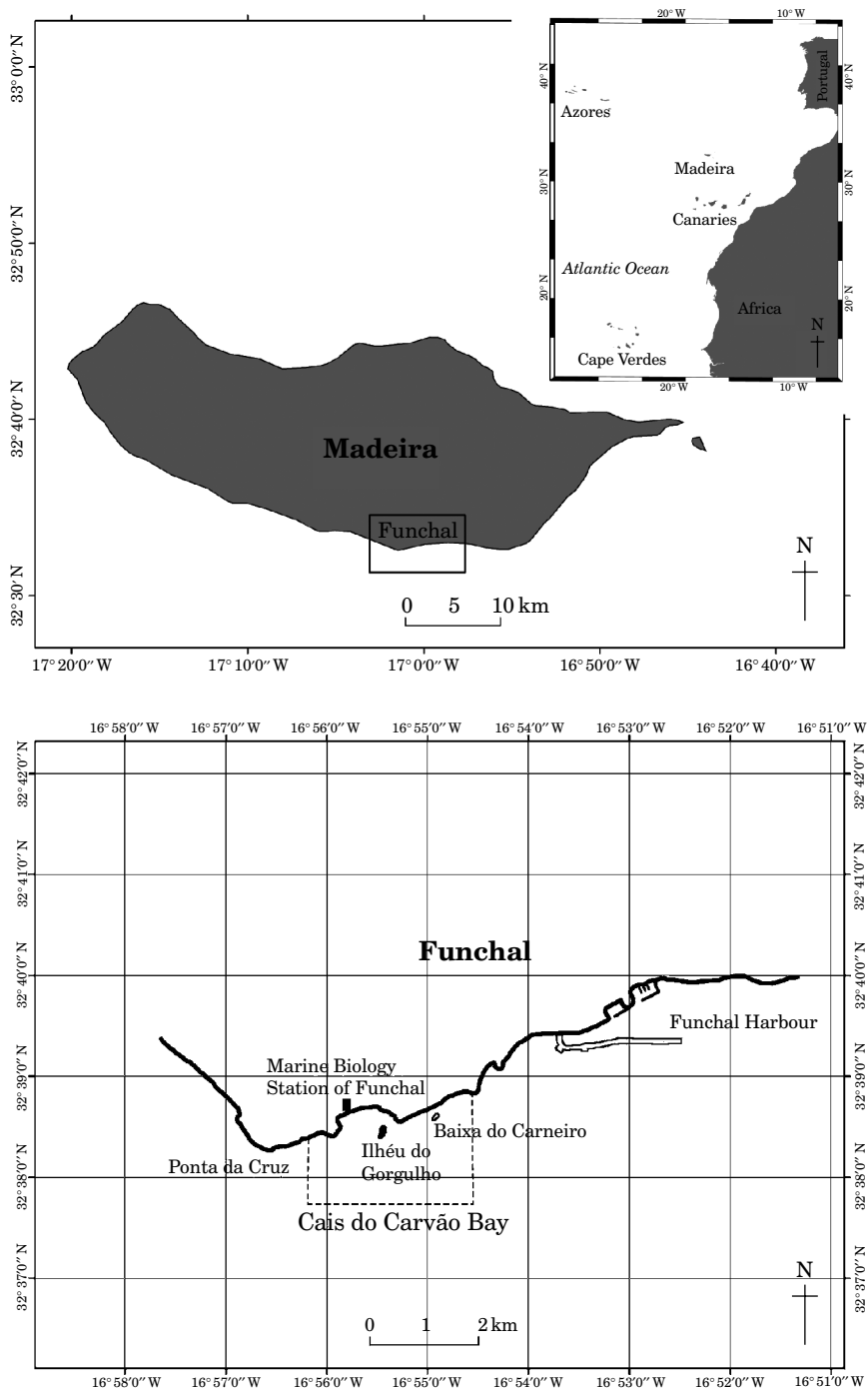
FIG. 1. Map of the study area and position of Madeira Island in the north-eastern Atlantic Ocean.

TABLE I. Sampled sites at Cais do Carvão Bay

Depth range (m)	Site designation	Habitat description
0–5	0–5 mRb	Rocky boulders: rock substratum typified by frequent occurrence of the sea anemone *Anemonia sulcata* and the polychaete *Hermodice carunculata*. Other invertebrates include the polychaete, *Nereis* sp., the sea cucumber, *Holothuria forskali*, sea urchins (*Arbacia lixula* and *Sphaerechinus granularis*) and limpets (*Patella aspera, Patella candei* and *Patella piperata*)
	0–5 mVw	Vertical walls: small, vertical wall with ≤10 m relief, typified by the occurrence of the sponge, *Clatria* sp. and the sea urchin, *Arbacia lixula*
10–15	10–15 mRb	Rocky boulders: rock substratum typified by the occurrence of the sea urchin, *Diadema antillarum*
	10–15 mS	Sand: fine volcanic or basaltic sand bottom, characteristic of Madeira Island littoral zone
20–25	20–25 mS	Deeper sand site, seaward of Ilheu do Lido, typified by the occurrence of *Heteroconger longissimus* colonies
	20–25 mRo	Rocky outcrop: 'baixa das moreias', western side of the bay

selected for the visual census (Brock, 1982; Kimmel, 1985; Bortone *et al.*, 1986; Sanderson & Solonsky, 1986; Davis & Anderson, 1989) with some modifications. At each site a marker buoy was deployed at the start of transect and its length was determined using a 50 m cable attached to the buoy anchor. As the divers swam away from the anchor, the cable was 'spooled' out. The two observers swam abreast, on each side of the line as it was paid out, and each recorded fishes seen within 2·5 m of the line and 1–1·5 m above the substratum. Hence at each site a 250 m^2 area was surveyed. Additionally, species seen outside transect area were recorded to evaluate simple diversity (number of species). Fish counts were made using procedures adopted by Brock (1954) and Bodkin (1986). Species with high probability of occurrence were pre-listed (name and size class categories) on an acrylic slate. Abundance data were recorded for four pre-defined size classes (juvenile, small, medium and large) used by Harmelin-Vivien & Harmelin (1975) and Harmelin (1987). All surveys were completed between 1000 and 1600 hours local time to take advantage of maximum light levels and to avoid crepuscular periods when fishes may become more or less active, thus altering their visibility along the transects. Prior to this study observers (always the two same observers performed the surveys) had a 2 month training period to acquaint the divers with the topographic layout of reef structure and fish fauna at each site as recommended by previous investigators (Christensen & Winterbottom, 1981; Kimmel, 1985; Sanderson & Solonsky, 1986; McCormick & Choat, 1987).

DATA ANALYSIS

Fish counts from the two divers were compared for species composition and abundance and no significant differences were found between diver observations at any of the

sites or sampling times, since both divers had similar experience in fish identification and because both were sampling the same spot (swimming side by side) at the same time. Therefore, counts recorded by both divers were pooled and averaged for each of the 32 transects. For each species, densities (mean ± S.D. number of individuals per 100 m²) were calculated for all transects. Additional calculations were made to determine species richness (S), diversity (Shannon–Weaver diversity index, H'), distribution of individuals among species (evenness component, E, $E = H' H'_{max}{}^{-1}$), and species frequency (Magurran, 1991).

Trophic classification of fishes (herbivores, omnivores or carnivores) was described from available data on feeding habits (Bell & Harmelin-Vivien, 1983). Spatial organization of fish assemblages in Cais do Carvão Bay was characterized as one of six types (Table II) based on a classification system proposed by Harmelin (1987). To determine if adequate sampling was conducted, a curve of cumulative species *v.* number of surveys was plotted. As visual count data typically do not follow a normal distribution (Clavijo *et al.*, 1989), non-parametric tests were performed to compare mean values for all variables calculated. To determine if significant differences existed between stations, a non-parametric, Mann–Whitney *U*-test pair-wise comparison procedure (Zar, 1984) was used. Cluster analysis using group average was done on the data from species composition and abundance. Similarities among stations were compared with the Bray–Curtis index, either for qualitative data (presence or absence) and abundance data (square root transformed). The Bray–Curtis index was computed using the group average method in the PRIMER® 5.0 package.

RESULTS

FISH ABUNDANCE AND DIVERSITY

Cumulative species curves (Fig. 2) indicated that the sampling effort at the rocky outcropping and deep sand site (20–25 m) was probably insufficient to qualitatively characterize fish assemblages on these substrata. Unfortunately only two surveys were performed in these sites, because both were located too far offshore to be routinely visited by the shore-based diving operations. Cumulative species curves on the remaining sites showed that the number of species reached an asymptote after about seven surveys.

A total of 32 transects were conducted at the six sites. Altogether, 44 fish species belonging to 23 families were observed in the study area (Table II). Two families, Sparidae and Labridae, were the most diverse, with 10 and four species, respectively, followed by Carangidae with three species, Blenniidae, Gobiidae, Muraenidae, Pomacentridae, Scorpaenidae, Serranidae and Tetraodontidae all with two species. The 13 remaining families were represented by a single species. In addition to being represented by the highest number of species, the sparids were most abundant numerically ($n = 3409$), followed by Pomacentridae, Congridae and Labridae. Species richness (S) was not equally distributed among sites (Fig. 3). Greatest mean S was found at the rocky boulder habitat (10–15 m depth) followed by the deepest rocky outcropping and the shallowest rocky boulder stations whilst the lowest mean S was observed over sand bottom (10–15 and 20–25 mS). Nevertheless, significant differences were only observed between rocky boulder and sand substratum stations at 10–15 m depth (Mann–Whitney *U*-test, $P < 0.05$). Likewise H' indicated variation among sites with the greatest diversity observed at hard bottom sites and the lowest at sand bottom sites. Statistical differences in H' were registered between rocky boulder and sand

TABLE II. List of species at Cais do Carvão Bay, with trophic category, spatial organization, mean ± s.d. density (D) (number of individuals per 100 m^2) and frequency of occurrence (F) of each species by site

Family	Species	Trophic category	Spatial category	0–5 mRb D	F	0–5 mVW D	F	10–15 mRb D	F	10–15 mS D	F	20–25 mS D	F	20–25 mRo D	F
Apogonidae	Apogon imberbis (L.)	Carnivore	6	—	—	—	—	—	—	—	—	—	—	—	—
Balistidae	Balistes capriscus Gmelin	Carnivore	1	—	—	—	—	—	—	—	—	—	—	9·50 ± 12·87	100
Blenniidae	Ophioblennius atlanticus (Valenciennes)	Carnivore	6	—	—	0·43 ± 0·37	83	—	—	—	—	—	—	—	—
	Parablennius ruber (Valenciennes)	Carnivore	6	—	—	—	—	—	—	—	—	—	—	—	—
Carangidae	Pseudocaranx dentex (Bloch & Schneider)	Omnivore	1	—	—	—	—	0·31 ± 0·54	29	—	—	0·30 ± 0·42	50	—	—
	Seriola sp. (Risso)	Carnivore	1	1·50 ± 4·24	13	—	—	0·06 ± 0·15	14	—	—	—	—	1·80 ± 2·55	50
	Trachurus picturatus (Bowdich)	Carnivore	1	—	—	—	—	—	—	—	—	—	—	—	—
Congridae	Heteroconger longissimus Gunther	Carnivore	6	—	—	—	—	—	—	9·51 ± 25·17	14	274·00 ± 387·49	50	—	—
Gadidae	Phycis phycis (L.)	Carnivore	6	—	—	—	—	—	—	—	—	—	—	0·20 ± 0·28	50
Gobiesocidae	Lepadogaster candollei (Risso)	Carnivore	6	—	—	—	—	—	—	—	—	—	—	—	—
Gobiidae	Mauligobius maderensis (Valenciennes)	Carnivore	6	—	—	—	—	—	—	—	—	—	—	—	—
	Gobius paganellus L.	Carnivore	6	—	—	—	—	—	—	—	—	—	—	—	—
Haemulidae	Pomadasys incisus (Bowdich)	Carnivore	4	—	—	—	—	—	—	—	—	0·30 ± 0·42	50	65·00 ± 91·92	50
Labridae	Centrolabrus trutta (Lowe)	Omnivore	5	0·48 ± 0·45	75	0·47 ± 0·30	83	0·09 ± 0·16	29	—	—	—	—	—	—
	Coris julis (L.)	Carnivore	5	0·18 ± 0·20	50	0·13 ± 0·24	33	0·77 ± 1·06	57	—	—	—	—	—	—
	Thalassoma pavo (L.)	Carnivore	5	18·20 ± 8·78	100	31·5 ± 13·00	100	8·31 ± 6·47	100	0·11 ± 0·30	14	—	—	23·10 ± 15·13	100
	Xyrichthys novacula (L.)	Carnivore	5	—	—	—	—	0·03 ± 0·08	14	0·37 ± 0·24	86	—	—	—	—
Labrisomidae	Labrisomus nuchipinnis (Quoy & Gaimard)	Carnivore	6	—	—	—	—	—	—	—	—	—	—	—	—
Mullidae	Mullus surmuletus L.	Carnivore	4	0·03 ± 0·07	13	—	—	0·51 ± 0·91	43	—	—	—	—	—	—
Muraenidae	Gymnothorax unicolor (Delaroche)	Carnivore	6	—	—	—	—	0·06 ± 0·15	14	—	—	—	—	—	—
Priacanthidae	Heteropriacanthus cruentatus Lacepède	Carnivore	6	—	—	—	—	0·03 ± 0·08	14	—	—	—	—	0·10 ± 0·14	50
Pomacentridae	Abudefduf luridus (Cuvier)	Omnivore	5	10·30 ± 5·84	100	5·37 ± 2·55	100	9·29 ± 3·57	100	0·11 ± 0·30	14	—	—	15·10 ± 6·93	100

TABLE II. Continued

Family	Species	Trophic category	Spatial category	0–5 mRb D	F	0–5 mVW D	F	10–15 mRb D	F	10–15 mS D	F	20–25 mS D	F	20–25 mRo D	F
	Chromis limbata (Valenciennes)	Carnivore	2	4·05 ± 3·42	75	1·30 ± 1·45	67	40·31 ± 36·86	100	0·51 ± 1·11	43	—	—	357·50 ± 385·37	100
Scaridae	*Sparisoma cretense* (L.)	Omnivore	5	3·30 ± 5·40	63	3·20 ± 2·64	67	0·80 ± 1·11	43	—	—	—	—	0·10 ± 0·14	50
Scorpaenidae	*Scorpaena maderensis* Valenciennes	Carnivore	6	—	—	0·03 ± 0·08	17	—	—	—	—	—	—	—	—
	Scorpaena porcus L.	Carnivore	6	—	—	—	—	—	—	—	—	—	—	—	—
Serranidae	*Mycteroperca fusca* (Lowe)	Carnivore	5	0·15 ± 0·18	50	0·07 ± 01·6	17	0·03 ± 0·08	14	—	—	—	—	0·20 ± 0·28	50
	Serranus atricauda Gunther	Carnivore	5	—	—	0·27 ± 0·65	17	0·34 ± 0·34	71	—	—	—	—	0·60 ± 0·28	100
Sparidae	*Boops boops* (L.)	Omnivore	1	30·40 ± 81·50	38	—	—	10·97 ± 12·42	71	—	—	—	—	272·50 ± 180·31	100
	Dentex gibbosus (Rafinesque)	Carnivore	3	0·03 ± 0·07	13	0·07 ± 0·16	17	0·03 ± 0·08	14	0·17 ± 0·45	14	—	—	—	—
	Diplodus cervinus (Lowe)	Omnivore	3	1·13 ± 1·40	63	0·17 ± 0·32	33	—	—	—	—	—	—	—	—
	Diplodus sargus (L.)	Carnivore	3	4·13 ± 4·38	75	0·43 ± 0·37	67	0·91 ± 1·84	43	—	—	—	—	—	—
	Diplodus vulgaris (Geoffroy Saint-Hillaire)	Carnivore	3	16·9 ± 24·21	63	0·07 ± 0·16	17	3·80 ± 4·53	100	0·06 ± 0·15	14	—	—	6·50 ± 2·12	100
	Oblada melanura (L.)	Omnivore	1	—	—	0·07 ± 0·16	17	22·91 ± 25·94	71	—	—	—	—	—	—
	Pagrus pagrus (L.)	Carnivore	3	0·05 ± 0·14	13	0·03 ± 0·08	17	0·34 ± 0·53	43	—	—	—	—	—	—
	Pagellus erythrinus (L.)	Carnivore	3	—	—	—	—	0·09 ± 0·23	14	—	—	—	—	—	—
	Sarpa salpa (L.)	Herbivore	3	7·75 ± 13·99	38	2·90 ± 6·53	33	—	—	—	—	—	—	—	—
	Spondyliosoma cantharus (L.)	Omnivore	3	0·05 ± 0·14	13	0·03 ± 0·08	17	0·09 ± 0·23	14	—	—	—	—	8 ± 11·31	50
Synodontidae	*Synodus* sp. L.	Carnivore	4	—	—	0·07 ± 0·16	17	0·06 ± 0·15	14	—	—	—	—	—	—
Spyraenidae	*Sphyraena viridensis* Cuvier	Carnivore	1	—	—	—	—	—	—	—	—	—	—	0·30 ± 0·42	50
Tetraodontidae	*Canthigaster capistratus* (Lowe)	Omnivore	4	0·48 ± 0·45	75	0·67 ± 0·53	83	1·60 ± 0·89	100	0·34 ± 0·46	57	0·50 ± 0·71	50	—	—
	Sphoeroides marmoratus (Lowe)	Omnivore	4	0·45 ± 0·38	88	0·33 ± 0·27	83	0·43 ± 0·71	43	0·46 ± 0·64	57	0·10 ± 0·14	50	—	—
Trypterigydae	*Tripterygion delaisi* Cadenat & Blanche	Carnivore	6	—	—	—	—	—	—	—	—	—	—	—	—
	Total			99·53 ± 83·72	—	47·53 ± 20·15	—	102·17 ± 76·26	—	11·66 ± 26·47	—	275·2 ± 388·91	—	760·5 ± 677·83	—

1, mobile, water column fishes that occur in schools; 2, benthopelagic fishes that occur in schools in the water column, but remain relatively stationary near structure; 3, benthopelagic fishes that perform small vertical and lateral movements; 4, benthopelagic fishes that perform moderate vertical movements, but variable lateral movements; 5, benthopelagic fishes that perform small vertical and lateral movements; 6, benthopelagic fishes that are extremely sedentary, demonstrate high substratum and refuge dependence and almost no vertical or lateral movement.
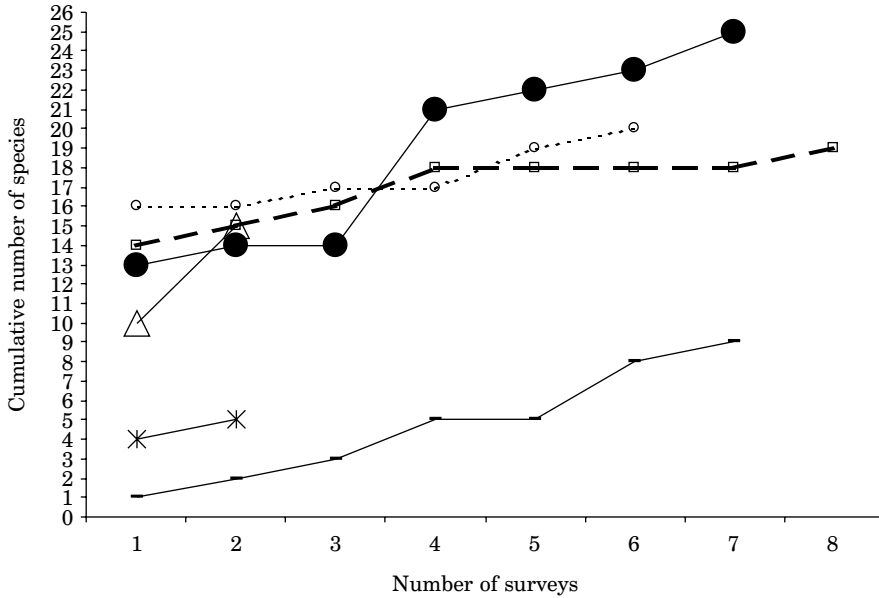
FIG. 2. Cumulative number of species according to the number of counts in each site [0–5 mRb (—■—), 0–5 m Vw (·-○-·), 10–15 mRb (—●—), 10–15 mS (——), 20–25 mS (—✳—) and 20–25 mRo (—△—); Table I] sampled in Cais do Carvão Bay.

bottom habitats at depths from 10 to 15 m (Mann–Whitney U-test, $P < 0.05$). The hard bottom sites showed higher values of H' and E, and the lowest E was found over sandy bottoms (20–25 mS).
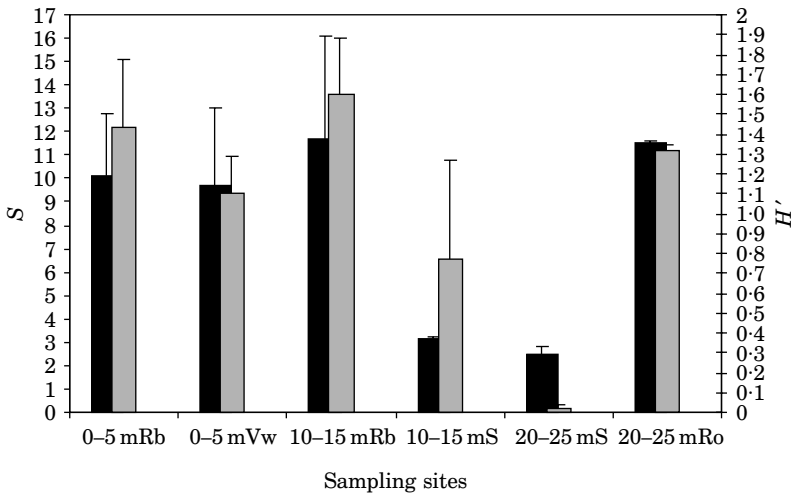

FIG. 3. Mean ± S.D. species richness (■) and Shannon–Weaver diversity (■) of fish assemblages from sampling sites (see Table I) at Cais do Carvão Bay.

SPECIES DISTRIBUTION

Canary damselfish *Abudefduf luridus* (Cuvier) and ornate wrasse *Thalassoma pavo* (L.) were observed over a wider range of depths than other species, but exclusively over hard bottom with sighting frequency of 100% at all rocky sites. Azores chromis *Chromis limbata* (Valenciennes), sharpnose puffer *Canthigaster capistratus* (Lowe) and Guinnean puffer *Sphoeroides marmoratus* (Lowe) were frequent over all depth intervals sampled (0–25 m) and were also common in almost all substrata sampled. In contrast, garden eels *Heteroconger longissimus* Günther were only observed over sand substratum and the grey triggerfish *Balistes capriscus* Gmelin was seen at the rocky outcropping in 20–25 m depth. Four species [*C. capistratus*, *S. marmoratus*, *Coris julis* (L.) and *Centrolabrus trutta* (Lowe)] were common at some sites, but with low overall abundance, while schooling species [*e.g. Boops boops* (L.) and *Trachurus picturatus* (Bowdich)] had high abundance at few stations (Table II). Of the total species observed, four species [*A. luridus*, *C. trutta*, *Mycteroperca fusca* (Lowe) and *Muraena augusti* (Kaup)] were Macaronesian endemics (Heemstra, 1991; Lloris *et al.*, 1991).

FISH COMMUNITIES

Cluster analyses using densities data revealed the existence of two distinct assemblages of fishes: one inhabiting hard bottoms and one inhabiting sand bottoms. The analyses also suggested aggregation of the fish assemblages according to depth in the rocky substratum sites; nonetheless there was not a distinctive pattern (Fig. 4).

FISH DENSITIES

Fish densities recorded at Cais do Carvão Bay (Table II) ranged from $760 \cdot 5 \pm 677 \cdot 8$ individuals per 100 m^2 at the deepest rocky bottom site (20–25 mRo) to $11 \cdot 7 \pm 26 \cdot 5$ individuals per 100 m^2 at the shallowest sand bottom site. The high value at the 20–25 mRo was due the presence of shoals of *B. boops*, *C. limbata* and *Pomadasys incisus* (Bowdich). The second highest density was found at the deepest sand site (20–25 mS), where the assemblage was dominated by *H. longissimus* colonies. Significant differences in total mean density were only found between the rocky boulder site at 10–15 m depth and the sand habitat at the same depth strata (Mann–Whitney U-test, $P < 0 \cdot 001$).

TROPHIC STRUCTURE

Herbivores (Table II) were represented by only one species [*Sarpa salpa* (L.)]. *Canthigaster capistratus*, *Oblada melanura* (L.), *Sparisoma cretense* (L.) and *A. luridus* were included in the omnivore category while the carnivores were represented by *Serranus atricauda* Günther, *T. picturatus*, *Diplodus vulgaris* Geoffroy Saint-Hilaire and *C. limbata*. Sand bottom fish communities comprised mainly micro-carnivores while the rocky sites had a wider representation of all trophic categories. The shallowest sites (depth interval 0–5 m) were dominated
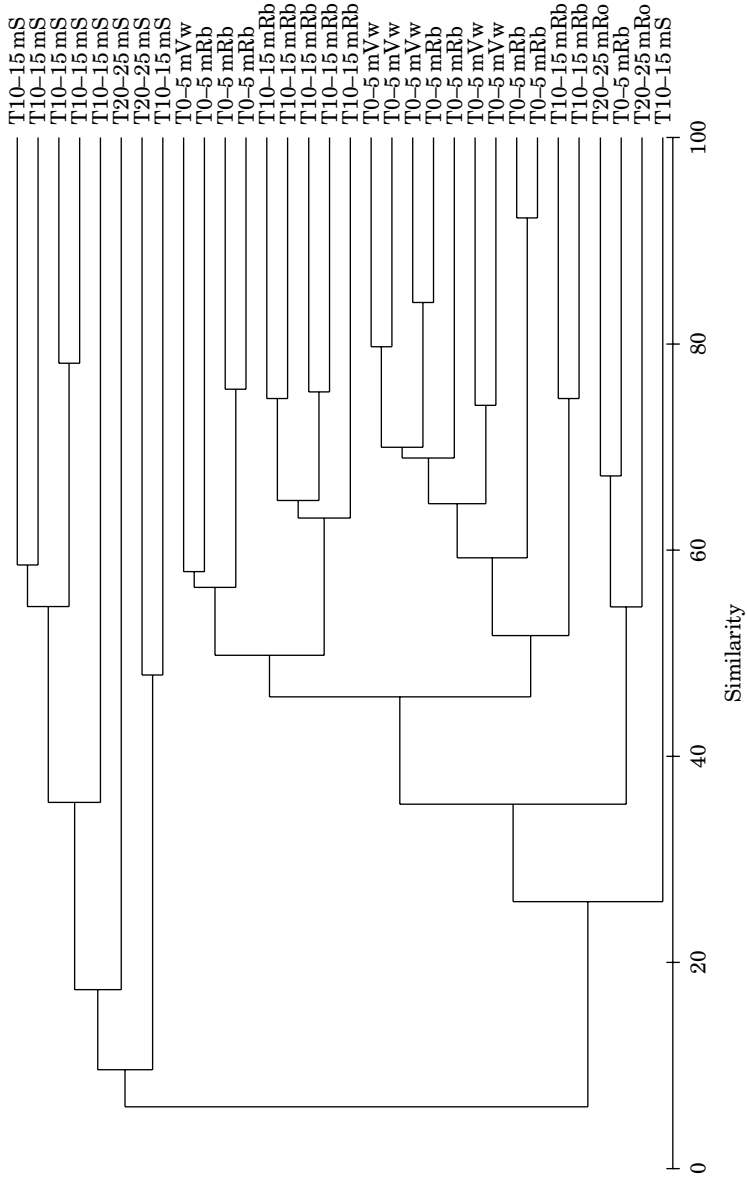
FIG. 4. Cluster diagram of stations (see Table I) using the Bray–Curtis similarity index on square root transformed abundance data. T, transect.

by herbivores and omnivores (micro and macro); in the deeper sites with hard bottom (10–15 and 20–25 m), carnivores were more frequent with almost all classified as micro-carnivores. Significant differences were registered in abundance of omnivores (Mann–Whitney U-test, $P < 0.01$) and abundance of carnivores (Mann–Whitney U-test, $P < 0.05$) between the sand and rocky boulder sites from the 10 to 15 m depth interval.

SIZE DISTRIBUTION

Most fishes observed were in the medium size category (Table III), however, fishes at the shallow vertical wall and shallow rocky boulder habitats were small fishes. Size distributions were significantly different between the shallow vertical wall and rocky boulder sites for medium-sized fishes (Mann–Whitney U-test, $P < 0.001$), and also between sand and rocky boulder sites of the 10–15 m depth interval for all size classes.

SPATIAL ORGANIZATION

Classification of species according to their spatial organization (Table II) resulted in several patterns of spatial distributions (Fig. 5). Schooling fishes, including pelagic (category 1) and benthopelagic (category 2) were more common at rocky-bottom sites, and category 2 fishes had high abundance at the deeper rocky outcrop site (20–25 mRo) due to the presence of large schools of *C. limbata*. Non-schooling benthoplegic fishes that occurred close to the bottom (categories 3, 4 and 5) also had their greatest density at the deep rocky outcrop and the rocky boulder site at the depth strata 10–15 m. The highest number of species fell into the benthopelagic categories (3–5) and included species that ranged from short to moderate distances into the water column and which varied in lateral movements. Category 6 was represented by 15 species with *H. longissimus* being the most abundant species of this category. The non-parametric test revealed significant differences in spatial organization of fishes among the substrata sampled. There were significant differences in densities of categories 1, 2, 3 and 5 between shallow rocky boulder and vertical substrata (0–5 mRb and 0–5 mVs) and between the intermediate-depth rocky boulder and sand habitats (10–15 mRb and 10–15 mS) in spatial distribution of species in these categories.

TABLE III. Demographic structure, expressed as per cent of total abundance of fish assemblages in Cais do Carvão Bay (see Table I)

	J (%)	S (%)	M (%)	L (%)
0–5 mRb	3·8	31	61·4	3·8
0–5 mVw	11	50·6	32·1	6·3
10–15 mRb	4·5	21·8	62·6	11·1
10–15 mS	–	6·4	92·6	1·0
20–25 mS	–	–	99·8	0·2
20–25 mRo	3·6	39	56·7	0·7

J, juveniles; S, small individuals; M, medium individuals; L, large individuals.
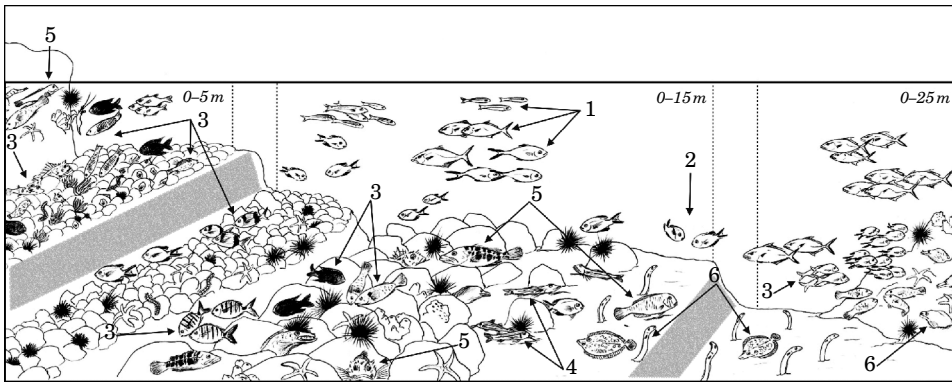
FIG. 5. Spatial organization of the fish assemblages from Cais do Carvão Bay (numbers represent categories as defined in Table II).

DISCUSSION

It is critical that fish abundance and diversity is recorded accurately and precisely for use in long-term monitoring surveys, such as those that will continue to be conducted at the study sites in Madeira Island. These estimates are particularly important in monitoring the effects of fishing and protective management, such as marine reserves, on the structure of fish assemblages. Evaluations of the most appropriate methods and sample sizes are essential, particularly in the complex habitats of the Macaronesia Atlantic Islands where few studies have been done. In visual census sampling, an adequate sample size is needed to fully characterize the fish assemblages (Bohnsack & Bannerot, 1986) and the present analysis indicated that surveys performed in most of the sites sampled at Cais do Carvão Bay were suitable to assess fish assemblages. At the two deepest sites (20–25 mRo and 20–25 mS), however, the number of surveys was too low. In spite of these limitations, the methods used did accurately describe fish assemblages from different habitats, using a simple method that can be incorporated into future monitoring.

Very high diversity and abundance of fishes on reefs can affect precision of visual estimates (Sanderson & Solonsky, 1986) and some variation in diversity and abundance among habitats was found in the present study. In Cais do Carvão Bay, however, they were not above the levels that could be accurately assessed by trained divers and training helped minimize observer biases and the effect of the divers on the fishes. The fish assemblages at Cais do Carvão Bay had some species that were specific to certain habitats, but most species could be found in most of the habitats sampled, except when contrasting rocky boulders and sand habitats (10–15 mRb v. 10–15 mS).

Many of the observed species in Cais do Carvão Bay had high abundance, but were infrequently encountered along transects, e.g. category 1 and 2 (schooling species). Because of the transient nature of schooling species (e.g. Seriola sp.), the species that occurred with a high frequency but not necessarily numerically dominant, might be better used to define assemblages of species associated with specific habitats. Cais do Carvão Bay showed similarities to other

assemblages from the south coast of Madeira Island (Andrade & Albuquerque, 1995; Delgado, 1998) and Canary Islands (Falcón *et al.*, 1996), with dominance of *T. pavo*, *C. limbata* and *A. luridus* on rocky substrata and *H. longissimus* on sand bottoms. The total number of species observed in Cais do Carvão Bay (44) was the same as that obtained by Delgado (1998) in the Garajau Marine Reserve, whilst Andrade & Albuquerque (1995), also on the south coast bottoms of Madeira Island, observed fewer species (31). The difference was also not too large when compared with the total number of species obtained by Bortone *et al.* (1991*b*) in the littoral habitats of El Hierro, Canary Islands (47 fish species recorded), however, it was a much larger difference when compared with the total of 76 species found in the littoral rock-substratum of four islands of the Canarian archipelago by Falcón *et al.* (1996), and with the 60 species found in the Selvagens Islands (Falcón *et al.*, 2001). These studies, however, had a much larger area, depth interval and a wider variety of sampled habitats.

The most obvious differences in the fish assemblages occurred between rocky and sand bottoms. This was due to the fact that the sand bottom had fewer microhabitats and provided less shelter and potential food sources than the rocky habitats. This is similar to other areas such as the Canaries where sandy bottoms also had less species richness than rocky reefs (Herrera *et al.*, 2002). Faunal diversity is generally related to the complexity of the habitat (MacArthur & MacArthur, 1961) and several researchers have considered that the distribution of reef fishes, as well as species richness and diversity, is a function of substratum and shelter characteristics (Risk, 1972; Emery, 1973; Clarke, 1977; Itzkowitz, 1977, Luckhurst & Luckhurst, 1978; Gladfelter *et al.*, 1980; Bell & Galzin, 1984; Shulman, 1985). This increase in complexity reflects not only the potential shelter sites available for fishes and their prey, but also the surface area available for occupation by algae and invertebrates. Thus, the results support the importance of the substratum complexity as a major correlate of high diversity and species richness.

Comparing the present results with studies in the Madeira Island, Andrade & Albuquerque (1995) and Delgado (1998) found also that fish assemblages in sand substrata were less diverse than in rocky substrata along the coast, indicating the influence of the substratum on the fish assemblages. The deep rocky outcropping was the site with the highest density of individuals and if the colonies of *H. longissimus* found on sand are not included, the remaining rocky sites also had higher densities than sand bottoms. This rocky outcrop and the surrounding environment contained many rocky crevices also along the vertical walls (many crevices, caves, overhangs and other shelters were observed, pers. obs.) and here fish category 5 had the highest density, revealing again the importance of substratum on species composition. The lowest density value, observed in the shallow sand habitat (10–15 mS), indicates that habitat homogeneity results in low species diversity and overall fish abundance. The findings suggest that substratum characteristics may be useful in assessing the spatial heterogeneity on fishes, however, responses of fishes to the substratum are correlated with complex factors that may not have been considered.

Besides substrata, fish assemblages in Cais do Carvão Bay were influenced by depth. Cluster analyses showed the existence of groups of species characteristic of each depth interval. Nevertheless, others factors (such as water temperature,

turbidity and salinity) that were not considered in this study can also influence fish assemblage composition. A few investigations (Williams, 1991; McGehee, 1994) have indicated that water movement, depth and substratum are inter-related, affecting each other as well as fish species distributions on coral reefs. Although no significant differences were seen in trophic structure due to depth, suggestions that trophic structure was correlated with depth is shown by the absence of herbivores in the deeper sites (10–15 and 20–25 m). In coral reef fish communities, herbivores concentrate in the shallower zones because of better light penetration and higher algae productivity, representing an important trophic component of all reef fish communities and of most shallow surrounding areas (Gladfelter *et al.*, 1980). *Sarpa salpa*, the only herbivore observed in fish communities of Cais do Carvão Bay, was normally restricted to waters <10 m deep (Table II). The higher percentages of micro- and macro-omnivores at deeper stations also indicated the influence of depth on trophic structure. The results were in agreement with those of Sherman *et al.* (1999) who showed a trend of fishes of larger sizes (medium and large) aggregating in deeper sites (10–15 and 20–25 m depth intervals). Differences seen in the communities spatial organization, categories 3 and 5, seemed also to reveal the effect of depth, with a decrease in mean densities of these two categories between pairs of sites according to depth. This effect of depth over the fish assemblages could indicate some species are more depth specific than others and less flexible in their tolerance to habitats variations (Falcón *et al.*, 1996).

Results obtained in this study are important in that they provide important inventory data, prior to designation of an MPA, on fish assemblages from the Cais do Carvão Bay. They will also be valuable in assessing future man-made or natural perturbations.

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