

Effect of fishing pressure on the spatio-temporal variability of the parrotfish, *Sparisoma cretense* (Pisces: Scaridae), across the Canarian Archipelago (eastern Atlantic)

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Abstract

We investigated spatio-temporal variability in the population structure of the parrotfish, *Sparisoma cretense* (Linnaeus, 1758), throughout the Canarian Archipelago (eastern Atlantic Ocean) with underwater visual transects. By means of a multiscaled hierarchical sampling design spanning three orders of magnitude of spatial variability (from 10 s of meters between replicated 100 m² transects to 100 s of kilometres among islands) and four sampling times (twice a year in 2003 and 2004); we related differences between islands to differences in the degree of fishing pressure. The mean abundance of parrotfish across all counts was 6.79 ± 0.46 ind 100 m⁻² (mean \pm S.E., $n = 768$ transects), while the mean biomass was 593.81 ± 45.61 g 100 m⁻² (mean \pm S.E., $n = 768$). Abundances and biomasses of *S. cretense* clearly differed between islands, although they were relatively consistent between the sampling times. The different abundances and biomasses observed between islands were correlated with fishing pressure, providing evidence that fishing was responsible for the inter-island differences. Differences in the size-structure between the eastern and western islands suggest differences in the recruitment periodicity at both groups of islands, which could be related to large-scale spatial variation in the oceanographic conditions across an east–west gradient along the Canary Islands. © 2005 Elsevier B.V. All rights reserved.

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1. Introduction

The parrotfish, *Sparisoma cretense* (Linnaeus, 1758), is a demersal fish distributed in the eastern Atlantic and the Mediterranean. This species is usually observed inhabiting shallow rocky bottoms, especially vegetated reefs and seagrass beds (Guidetti and Boero, 2002). It is highly prized in both local recreational and commercial fisheries across the Macaronesian region, and especially throughout the Canarian Archipelago (Bortone et al., 1991; Bas et al., 1995).

Reef-associated fish respond to changes in the environmental conditions of the coastal ocean with spatio-temporal fluctuations operating at different scales of observation (Anderson and Millar, 2004). A major goal in ecology

is thus to understand the ecological nature of the natural and/or anthropogenic processes involved in this variability. The importance of implementing rigorous experimental designs to investigate patterns of distribution of marine species has recently been stressed (Guidetti and Boero, 2002), and in this sense, hierarchically structured designs provide a means of partitioning and quantifying the magnitude of variation at different scales (Underwood and Chapman, 1996; Benedetti–Cecchi et al., 2000; Anderson and Millar, 2004).

Several studies have investigated the decline of the coastal resources of the Canarian Archipelago as a consequence of decades of overexploitation (Bas et al., 1995; Falcon et al., 1996; Tuya et al., 2004). However, no study has yet empirically assessed the spatial distribution patterns of the parrotfish, *S. cretense*, across a hierarchy of spatial scales throughout the Canarian Archipelago (but see Falcon et al., 1996), and related patterns in its distribution to the degree

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of fishery exploitation. The goal of this paper was to analyze spatio-temporal variability in the population structure of *S. cretense* on shallow rocky reefs with underwater visual transects by means of a multiscaled design spanning three orders of magnitude of spatial variability (from 10 s of meters between replicated transects to 100 s of kilometres among surveyed islands), and four sampling times during the years 2003 and 2004. Specifically, we hypothesized that: (1) significant differences between islands are attributable to differences in fishing intensity and (2) variability between islands is consistent through time.

2. Methods

2.1. Sampling design, study locations and estimation of fishing pressure

We adopted a multiscaled perspective through a hierarchical or nested sampling design with randomly positioned study locations throughout the Canarian Archipelago (Underwood, 1997). We randomly selected three locations of rocky substrate in each of the seven islands of the Archipelago, as well as in a group of small islets at the north of Lanzarote Island, called the Chinijo Archipelago (Fig. 1). This protocol was repeated four times: March 2003, October 2003, March 2004 and October 2004. Sampling during March can be considered as representative of wintertime (SSTs ranged between 17 and 19 °C), while surveys in October are representative of summertime (SSTs ranged between 23 and 25 °C). All subtidal sampling was conducted between 10 and 18 m depth, along rocky-bottoms with similar slopes and complexity to minimize, as much as possible, the “habitat effect” (*sensu* Garcia-Charton and Perez-Ruzafa, 1999) on the distribution and patchiness of assemblages. Therefore, habitat variation was not incorporated into the sampling design. All sampled locations were outside areas completely closed to fishing.

The fishery along shallow bottoms of the Canarian Archipelago is multi-species and entirely artisanal. Hook and

line, gillnets and traps are the main gear types used in this artisanal fishery, and catch a large number of species (Bas et al., 1995; Melnychuk et al., 2001). Normally, local artisanal fishers sell all their catches directly at a great variety of ports and beaches, with a lack of year-round monitoring programs of landings. As a result, there are no accurate landing statistics, which reflect the evolution of the small artisanal fishery over the entire coastal area (Hernandez-Garcia et al., 1998). As an indicator, however, parrotfishes represented about 25% of the total demersal annual catch in 1982, with a total catch of 198 tonnes from all gear types (Melnychuk et al., 2001). Additionally, recreational fishing by using hook and line, as well as spearfishing, probably represent an important, and overlooked, volume of catches (personal observations). Market prices of parrotfish usually fluctuate between 9 and 15 € kg⁻¹.

Information on the levels of fishing pressure along coastlines is pivotal to the interpretation of spatial patterns of reef fish (Ferreira et al., 2004). We were unable to calculate absolute levels of artisanal fishing pressure between islands because of the lack of fisheries data and the difficulty of standardizing measures of fishing across the different gear types in use. However, we ranked fishing intensity between islands using the observed number of professional fishing boats per island (Bas et al., 1995), except for Chinijo Archipelago, where we used our own observations as well as information from fisheries officials. This index is indicative of fishing pressure on the coastal natural resources of oceanic archipelagos (Jennings et al., 1995; Hawkins and Roberts, 2004; Friedlander and Brown, 2004) (Fig. 1). Although our index of fishing pressure is simplistic, it represents an easy way to interpret and discuss our data, and enables comparisons to be made with the conservation status and large-scale spatial variability of fish populations in other oceanic archipelagos and their relationships with gradients of fishing intensity (Jennings et al., 1995; Chiappone et al., 2000; Hawkins and Roberts, 2003, 2004; Friedlander and Brown, 2004). In addition, we also considered the amount of coastal perimeter per island that was subject to special fishery regulations and management (Fig. 1); with limitations on the type and amount of

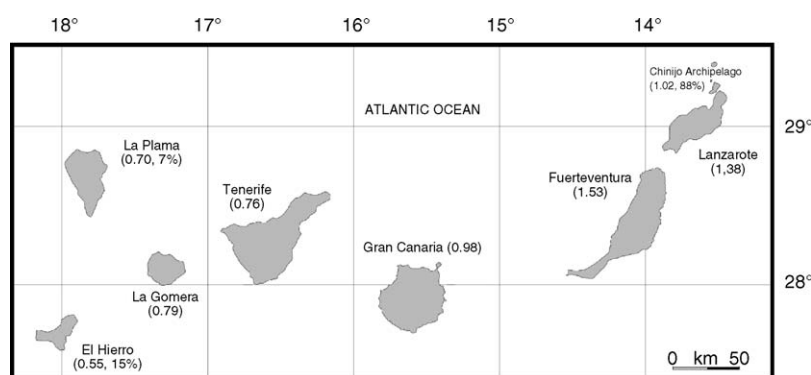


Fig. 1. Map of the study area, detailing in brackets the fishing intensity (number of fishing ships per km), and the % of coastal perimeter under special fishing regulations at each island, respectively.

fishing gear (e.g. no trapping allowed by local artisanal fishermen). To date, however, studies assessing the effectiveness of these fishing limitations are still lacking.

2.2. Fish surveys

Parrotfish populations (size >2 cm) were sampled by means of visual census techniques. At each sampling location, eight replicated 25 m long transects were haphazardly laid during daylight hours. The abundance and size of *Sparisoma cretense* was recorded on waterproof paper by a SCUBA diver within 2 m of either side of the transects, according to standard procedures (Brock, 1982; Lincoln-Smith, 1989; Kingsford and Battershill, 1998). This strip transect size gives optimal precision and accuracy for abundance and size-structure data of rocky-reef fish in the Canaries (Tuya et al., 2004). Biomass was calculated using an available length–weight relationship for the Canarian Archipelago (Gonzalez, 1990). All measured biotic variables were standardized to an area of 100 m².

2.3. Data analysis

Abundance and biomass data were analyzed by means of ANOVA models (Underwood, 1997) to test for differences between surveyed islands, sampled locations within islands and the four sampling times. The model incorporated the following experimental factors: (1) “Island” (fixed factor with eight levels corresponding to the seven main islands plus Chinijo Archipelago); (2) “Time” (random factor with four levels, and orthogonal to the previous factor); and (3) “Locations” (random factor nested within islands and times, with three levels). Before analysis, Cochran’s test was used to check for homogeneity of variances. Because fish-count data contain many zeros, they are usually non-normal and cannot be effectively transformed (Anderson and Millar, 2004; Hawkins and Roberts, 2004). No transformation rendered homogeneous variances (Cochran’s test, $P < 0.01$); so the significance level was set at the 0.01 level instead of 0.05, as ANOVA is robust to heterogeneity of variances, particularly for large balanced experiments (Underwood, 1997). We focused our interest on the interaction term between the factors “Time” and “Islands”, as both were involved in the stated hypotheses. If ANOVA detected significant differences

for “Islands”, as an interaction or as a main effect, further analyses were done by using the SNK a-posteriori multiple comparison test (Underwood, 1997).

Histograms were plotted to compare the size-frequency distributions of the parrotfish, *Sparisoma cretense*, between islands. The five considered size-class intervals were selected on the basis of facilitating the interpretation of the data. We focused our attention on the 20 cm-size limit, because it represents the minimum legal size to fish parrotfishes. ANOVA was used to test for the effect of “Islands”, “Times” and “Locations” on significant differences in mean biomass for each size class, following the same criteria considered before. As no temporal variability was detected by means of the ANOVAs, we pooled the observations for the four sampling times at each island to graphically display results.

Finally, non-linear regression models were carried out to find relationships between the mean abundance and biomass pooled over the four sampling times at each island and the considered index of fishing intensity.

3. Results

The mean abundance of the parrotfish (*S. cretense*) in our large-scale survey was 6.79 ± 0.46 ind 100 m⁻² (mean \pm S.E., $n = 768$ transects), which oscillated between 0 fish in several transects to a maximum of 116 ind 100 m⁻². The mean biomass was 593.81 ± 45.61 g 100 m⁻² (mean \pm S.E., $n = 768$), and varied between a minimum of 0 and a maximum of 12560.3 g 100 m⁻². The mean abundances and biomasses of *S. cretense* at each time and location within islands are shown in Figs. 2 and 3, respectively.

This species showed clear differences in the mean abundance and biomass among surveyed islands (Figs. 2 and 3, Table 1), which were consistent through time, as the ANOVAs indicated (non-significance of the interaction term “ $T \times I$ ”, Table 1). El Hierro Island was the island with the greatest abundance (34.23 ± 4.57 ; mean \pm S.E., $n = 96$) and biomass (1899.39 ± 119.34 ; mean \pm S.E., $n = 96$) through time (Figs. 2 and 3). The rest of the islands did not show significant differences in the mean abundance (Fig. 2), as indicated by a posteriori SNK tests ($P > 0.01$). However, we obtained a hierarchy of islands when we analyzed differences in the mean biomass through time (Fig. 2), as the

Table 1

Analysis of the effects of Time (random), Island (fixed and orthogonal), and Locations (random and nested within islands and times) on the mean abundance and biomass of the parrotfish *Sparisoma cretense*

Source of variation	DF	Mean abundance			Mean biomass		
		MS	<i>F</i>	<i>P</i>	MS	<i>F</i>	<i>P</i>
Time, <i>T</i>	3	0.50	0.12	0.94	95.58	0.12	0.95
Island, <i>I</i>	7	56.28	13.66	0.00	12441.95	13.09	0.00
Locations (<i>T</i> \times <i>I</i>)	64	4.11	6.09	0.00	820.68	4.72	0.00
<i>T</i> \times <i>I</i>	21	3.55	0.86	0.63	950.59	1.16	0.31
Residual	672	0.67			173.86		

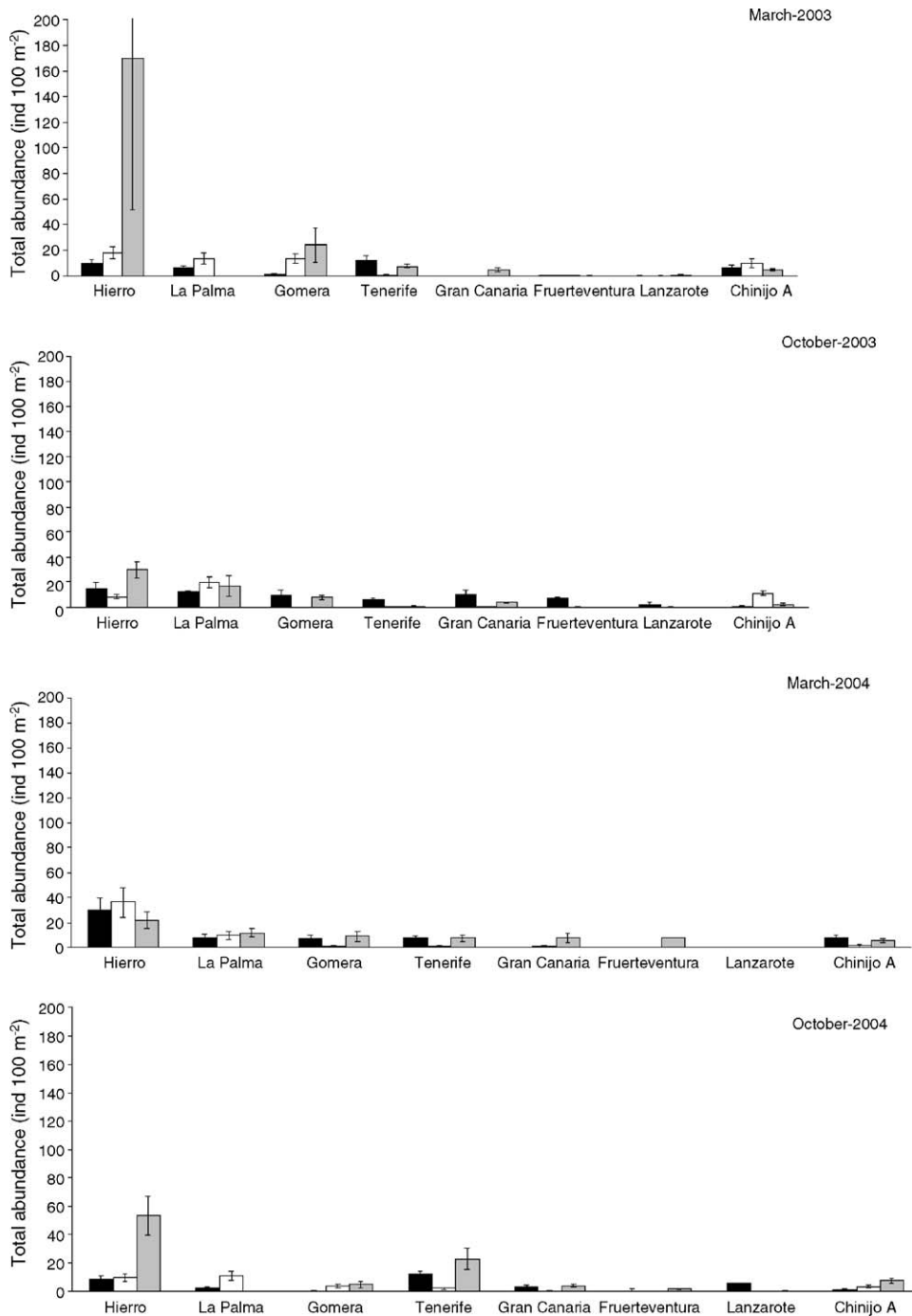


Fig. 2. Mean abundance at each location within each island throughout the study. Error bars are standard errors of mean values.

SNK tests indicated (El Hierro > Chinijo Archipelago > La Palma = Gomera = Tenerife = Gran Canaria = Fuerteventura = Lanzarote). Additionally, significant inter-island spatial variability was detected (differences between locations within each island at each time) (Table 1), reflecting differences in the spatial patchiness of this species within each island at each sampling time (Figs. 2 and 3). Nonetheless, this large spatial heterogeneity did not prevented the detection of significant differences between islands.

A clear lack of parrotfishes above the commercial-size range (>20 cm) was detected for the overall study area (Figs. 4 and 5), possibly indicative of overexploitation. In fact, the majority of the large-sized individuals (>35 cm) were observed either at El Hierro (32%, $n = 15$ individuals), which was subject to low fishing intensity; or especially in the Chinijo Archipelago (55%, $n = 26$ individuals) where the majority of the shoreline lies inside areas subject to fishing restrictions (Fig. 5). This outcome was corroborated by the

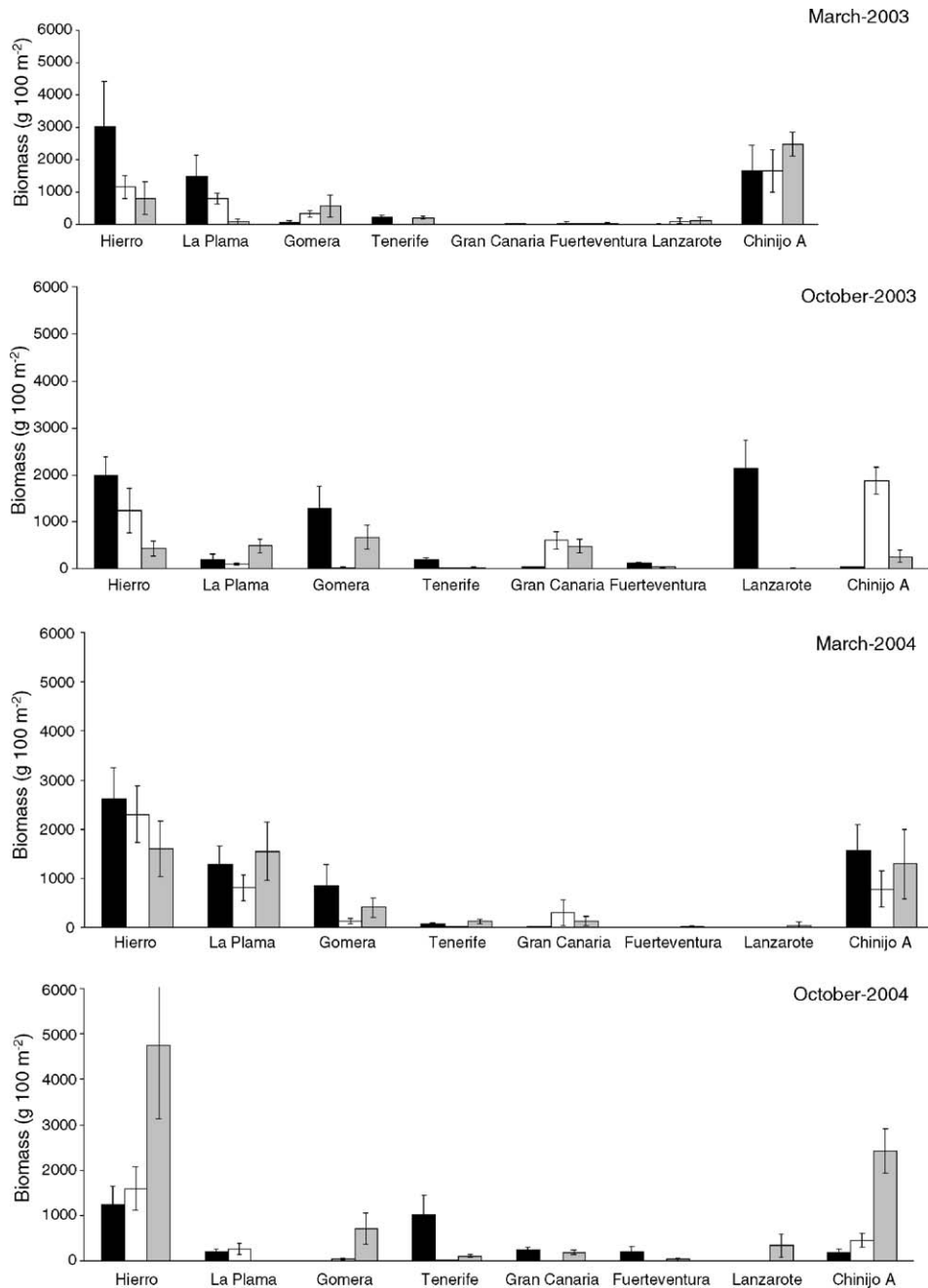


Fig. 3. Mean biomass at each location within each island throughout the study. Error bars are standard errors of mean values.

ANOVA (Table 2) performed on the mean biomasses for each size-class. A similar result was obtained for the size class between 20 and 35 cm (Table 2, Fig. 5). Thus, large numbers of parrotfishes within the 20–35 cm size class were significantly more observed in El Hierro and Chinijo Archipelago compared to the other islands (Table, Fig. 5).

Significant differences between islands were also detected for the mean biomasses of parrotfishes below the commercial-size range (>20 cm) (Table, Fig. 5). We observed an unexpected lack of small-sized parrotfish (new recruits <6 cm) around the eastern islands (Chinijo Archipelago, Lanzarote

and Fuerteventura, Fig. 4), in contrast to the rest of the islands that comprise the Canarian Archipelago. However, significant differences in the mean biomasses of individuals <6 cm between islands were not detected. It is worth noting that, again, the ANOVAs performed on the mean biomasses of each size-class detected a significant inter-island spatial variability (Table 2). Probably, this large variation between locations within each island prevented the detection of significant differences for the <6 cm size-class. In fact, we observed a large abundance of individuals <6 cm in a location in El Hierro Island in March 2003 that therefore resulted in a

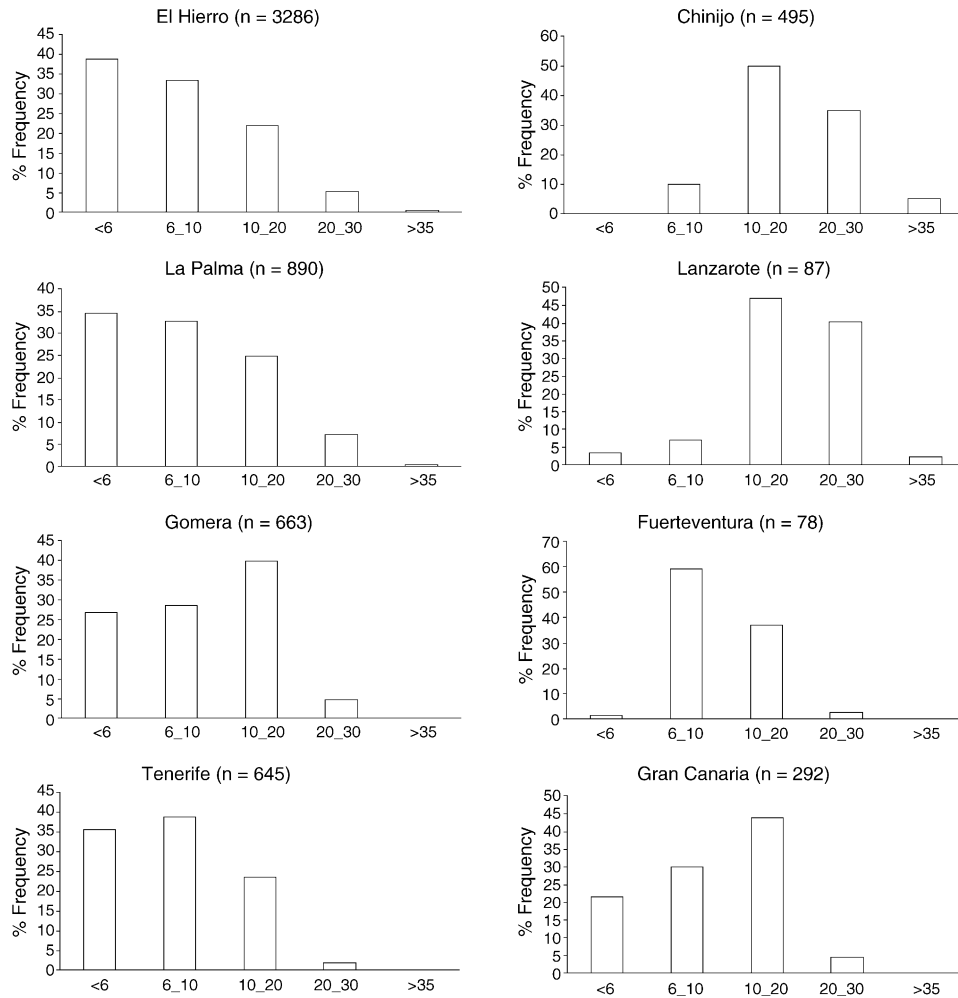


Fig. 4. Size-frequency distributions at each island for the entire study. Size class intervals are in cm.

significant interaction between “Islands” and “Times” for this size class (Table 2).

We recorded a strong non-linear decay of the mean abundance and biomass registered per island and the number of professional fishing boats operating per kilometre of coastal perimeter (Fig. 6). Therefore, the islands with the highest fishing pressure had the lowest mean abundances and biomasses of parrotfishes, and vice versa.

4. Discussion

The importance of fishing pressure as a determinant of reef fish communities has been widely emphasized (Ferreira et al., 2004, and references therein). Contrasting islands spanning a gradient in which fishing pressure has differed for a long time can potentially offer new insights into the effects of fishing pressure (Jennings et al., 1995; Hawkins and Roberts, 2004). Our observational approach has highlighted the important role of fishing pressure in affecting abundances, biomasses and size distributions of the parrotfish, *S. cretense*, across the different islands that comprise the Canary Archipelago.

This outcome is not surprising, as coastal fisheries in the Canary Archipelago have been facing overexploitation and severe depletion of fish populations for the last few decades (Aguilera et al., 1994; Bas et al., 1995; Falcon et al., 1996). This decline in the abundance and biomass of inshore fishery resources, particularly around the more populated and overexploited islands (Bortone et al., 1991), is likely the cumulative results of years of chronic overfishing. However, the drawback of our approach is that islands may differ in respects other than human pressure (e.g. habitat structure). Hence, caution is necessary in ascribing differences in the observed fish populations to human exploitation. In addition, we have used a correlational approach to infer that human pressure is the underlying causal factor. It should be borne in mind that causality can only be determined through experimental manipulation.

Scarids are an excellent family to target in a study that examines the influence of environmental and/or anthropogenic gradients on the structure and spatial patterns of coastal ichthyofauna, since they are one of the most abundant and widespread families of reef fishes (Gust et al., 2001). Moreover, parrotfishes show little response to presence of

Table 2
Analysis of the effects of Time (random), Island (fixed and orthogonal), and Locations (random and nested within islands and times) on the mean biomass of each size class of the parrotfish, *Sparisoma cretense*

Source of variation	DF	<6 cm		6–10 cm		10–20 cm		20–35 cm		>35 cm	
		MS	F	MS	F	MS	F	MS	F	MS	F
Time, T	3	3.94	2.17	0.71	0.08	17.81	0.93	4.56	0.28	5.34	1.55
Island, I	7	12.22	1.76	93.80	20.61*	183.20	7.60*	181.17	5.85*	11.62	4.00*
Locations (T × I)	64	1.81	2.87*	9.09	3.77*	19.23	3.88*	16.57	3.81*	3.44	2.81*
T × I	21	6.92	3.82*	4.55	0.50	24.10	1.25	30.96	1.87	2.90	0.84
Residual	672	0.63		2.40		4.96		4.34		1.22	
SNK tests				EH TF LP GO GC CH FT LZ		EH CH LP GO GC TF FT LZ		EH CH LP LZ GO GC TF FT		CH > HI LP LZ TF FT GO GC	

Acronyms to the islands are CH: Chinijo, LZ: Lanzarote, FV: Fuerteventura, GC: Gran Canaria, TF: Tenerife, GO: Gomera, LP: La Palma, EH: El Hierro.

* P < 0.01.

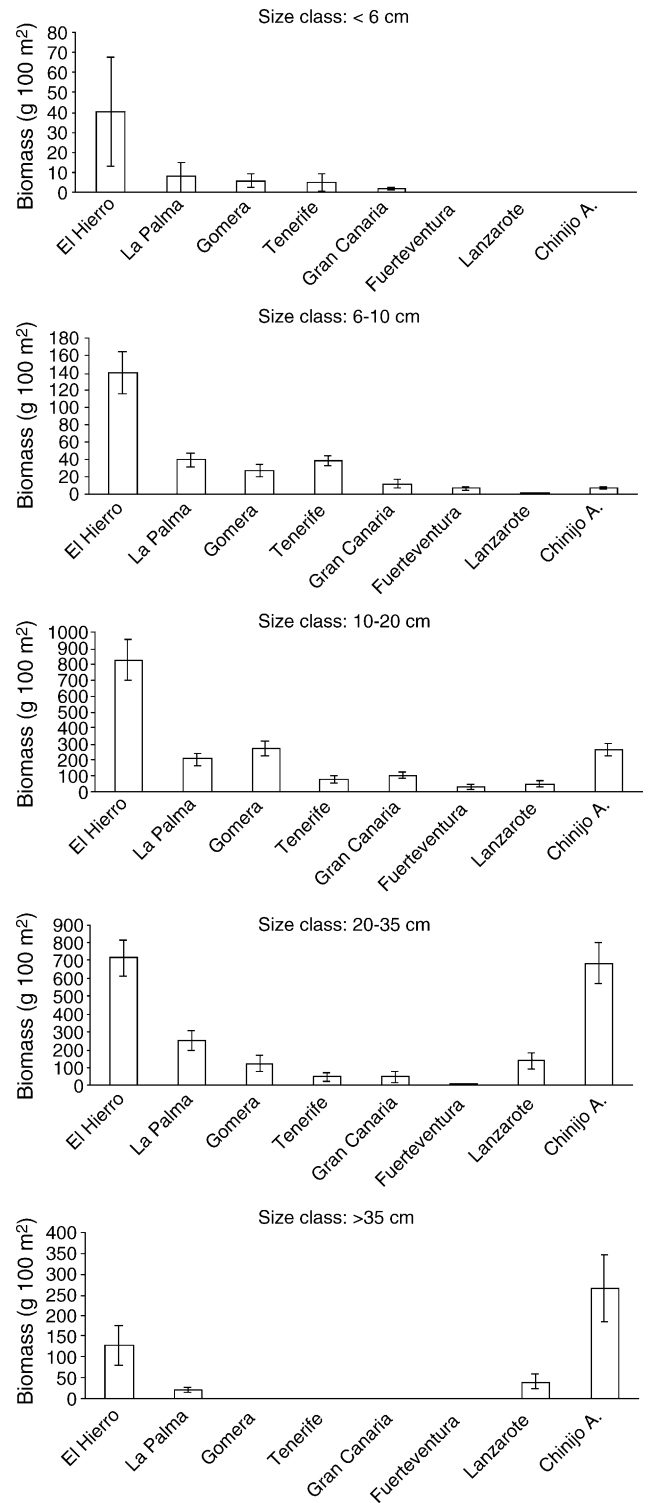


Fig. 5. Mean biomass of each size class at each island for the entire study. Error bars are standard errors of mean values.

SCUBA divers, so that underwater visual censusing can provide reliable measures of distribution, abundance and biomass (Samoilys and Carlos, 1992). Despite the acknowledged importance of sampling designs with hierarchical or nested structures in determining patterns of natural variation

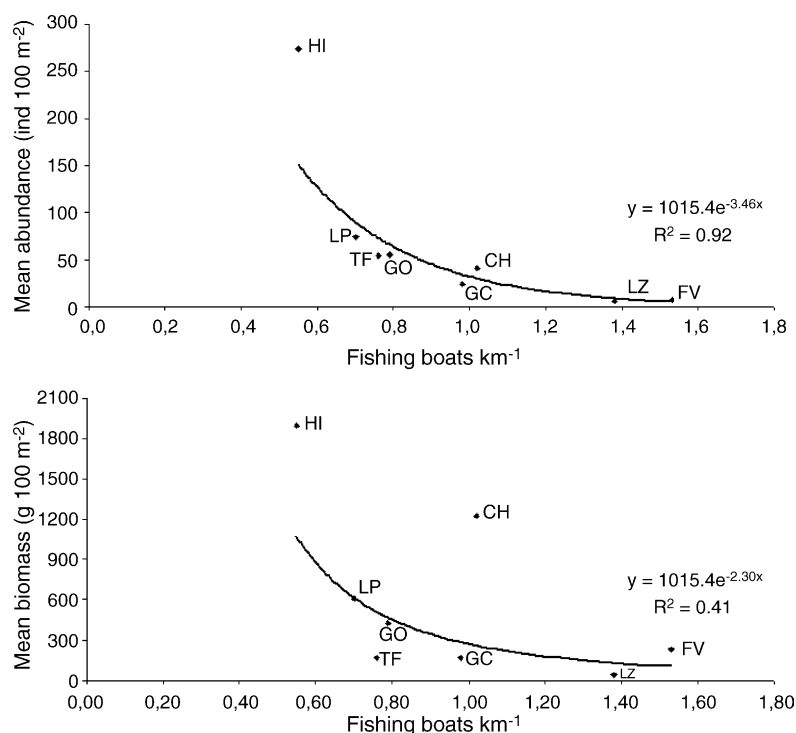


Fig. 6. Non-linear regressions between the mean abundance and biomass per island of the parrotfish (*Sparisoma cretense*) and the selected index of fishing pressure (number of professional fishing boats operating per km of island perimeter). Acronyms for islands are the following: CH = Chinijo, LZ = Lanzarote, FV = Fuerteventura, GC = Gran Canaria, TF = Tenerife, GO = Gomera, LP = La Palma, and HI = El Hierro.

in the distribution and abundance of reef fish, our multi-scale work provides the first data regarding the spatio-temporal distribution patterns of the parrotfish, *S. cretense*, across a hierarchy of scales in the eastern Atlantic. Differences in the abundance and biomass of the parrotfish, *S. cretense*, over a hierarchy of spatial and temporal scales have only been studied in the Mediterranean Sea (Guidetti and Boero, 2002). However, direct comparisons with this work are limited, due to the different structure and goals of their experimental design, and the different environmental conditions of the Mediterranean.

The few studies that have dealt with the ecology of coastal fish populations in the Canary Islands (Bortone et al., 1991; Falcon et al., 1996) were made within the last two decades, long after the enormous changes in the exploitation of marine resources of the Canarian Archipelago had occurred, especially since the beginning of the tourist boom in the late 1960s. Differences in the abundance and biomass of parrotfish over different spatial scales had never been investigated for the entire Canary Islands. The only available data were collected once at El Hierro Island (Bortone et al., 1991), and four islands of the Canaries (Falcon et al., 1996). Although our study and these investigations observed parrotfishes in 100 m² replicated visual censuses, we used strip transects instead of stationary point-counts (Bortone et al., 1991; Falcon et al., 1996). Both visual sampling techniques can be compared with caution for specific taxa such as parrotfishes (Floeter et al., 2004). In this sense, the mean abundance

detected by our work (6.79 ± 0.46 ind 100 m⁻²; mean \pm S.E., $n=768$ censuses) doubles that reported for four islands of the Canarian Archipelago (3.77 ± 5.58 ind 100 m⁻²; mean \pm S.D., $n=577$) (Falcon et al., 1996). Moreover, the mean abundance (34.23 ± 4.57 ind 100 m⁻²; mean \pm S.E., $n=96$ censuses) and biomass (1899.39 ± 119.34 g 100 m⁻²; mean \pm S.E., $n=96$) recorded at El Hierro Island were about five times greater than the mean values registered by Bortone et al. (1991) (6.70 ± 5.19 ind 100 m⁻², mean abundance \pm S.D.; mean biomass = 409.08 g 100 m⁻², $n=1045$). The higher values detected by our approach may be due, firstly, to the overestimation of reef fish populations by strip transects in comparison with stationary point-counts (see discussion by Samoilys and Carlos, 2000; Gust et al., 2001; Guidetti et al., 2005). Secondly, the greater abundance could be attributable to the longer duration of our approach. In fact, we observed numerous small-sized individuals in some locations of El Hierro Island, possibly indicative of successful recruitment in those locations at previous times (Fig. 3).

Differences in the size-structure between the eastern islands of the Canarian Archipelago (Chinijo Archipelago, Lanzarote and Fuerteventura) and the other islands could suggest differences in the recruitment periodicity for both groups of islands, which could be related to large spatial variation in the oceanographic conditions across an east–west gradient along the Canarian Archipelago (e.g. Davenport et al., 2002); and consequently, to different regimes of bottom-up effects (sensu Menge, 2000). In fact, this large-scale spatial

variability influences the composition and structure of rocky intertidal and shallow subtidal assemblages on opposite sides of the Canary Islands both quantitatively and qualitatively (western versus eastern islands) (Brito et al., 2003; Tuya et al., 2004; Navarro et al., 2005). While our observational findings and speculations are intriguing, future research at both small and large spatial scales over long time periods will be necessary to assess the nature and significance of the effects of bottom-up inputs in the structure of fish populations.

As far as temporal changes are concerned, our results indicate the time of sampling is relatively unimportant in determining differences in the abundances and biomasses of *S. cretense* among the islands of the Canarian Archipelago. In contrast, it is important to recognize that factors operating at small-scales (differences among locations within islands) were important in determining parrotfish distributions. Possibly other factors beyond the scope of this work, such as habitat availability and complexity, recruitment and settlement, are important drivers of spatial and temporal variability and determine the structure and patterns of distribution of *S. cretense* throughout the Canarian Archipelago.

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