Universidade de Cabo Verde **Universidade do Algarve**

“Reef fish and benthic community structure of Santa Luzia marine reserve, Eastern Atlantic”

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``REEF FISH AND BENTHIC COMMUNITY STRUCTURE OF SANTA LUZIA MARINE RESERVE, EASTERN ATLANTIC´´

Dissertação apresentada ao Programa de Pós – Graduação em Recursos do Mar e Gestão Costeira, curso de Mestrado Inter-Universitário da Universidade de Cabo Verde (UniCV) e da Universidade do Algarve (UAlg), como requisito parcial para obtenção do grau de Mestre em Recursos Marinhos e Gestão Costeira.
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(1) Esta dissertação é apresentada em inglês e em formato apropriado à apresentação, à posteriori desta tese, a uma revista Africana com arbitragem científica e na seguinte ordem dos autores:

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RESUMO

A ilha de Santa Luzia (SL), situada no arquipélago de Cabo Verde (CV), foi designada reserva marinha desde os anos 90. Recentemente, em 2003, foi reclassificada como reserva natural integral e esse estatuto não foi ainda estabelecido na prática. Conduzimos em 2009 a primeira abordagem de avaliação de peixes recifais em diferentes locais na Reserva Marinha de SL com base em censos visuais e de cobertura bentónica por fotoquadrados. Os objectivos específicos foram os de descrever os padrões gerais de biomassa e densidade por grupos tróficos para Santa Luzia e relaciona-los com bentos. De 25 de Setembro a 2 de Outubro de 2009, 11 locais/pontos à volta da ilha foram seleccionados, com vista a testar diferentes efeitos bióticos, abióticos e da pesca. A biomassa foi calculada por transformações alométricas através de pontos médios por classes de tamanho; padrões gerais de densidade e biomassa de peixes e categorias de cobertura bentónica entre locais foram comparados. Métodos por análise multivariada (componentes principais e agrupamento hierárquico) foram utilizados para agrupar sítios baseados no tipo de bentos e a análise da abundância de peixes por locais foi possível através de descritores de intensidade de pesca, correntes, complexidade e tipo de substrato. Um total de 51.507 indivíduos de 67 espécies ao longo de 32 famílias foi registado em 198 transeptos. Riqueza espécies por família foi: Muraenidae (7 sp.), Pomacentridae e Labridae (ambos 6 sp.), Epinephelidae e Sparidae (ambos 4), 11 (2-3 sp.) e 16 famílias com único representante. As 10 espécies mais abundantes contabilizaram 90,53% de todos os censos e a respectiva lista por ordem decrescente foi: *Chromis lubbocki* (endémico), *Chromis multilineata*, *Thalassoma pavo*, *Parapristipoma humile*, *Sparisoma cretense*, *Myripristis jacobus*, *Coris atlantica*, *Gobius tetrophthalmus* (endémico), *Parablennius salensis* (endémico) e *Stegastes imbricatus*. 40,3% (27 sp.) dos peixes do infra-litoral de SL são comerciais e 37,3% são espécies sem valor comercial, maioritariamente espécies crípticas e pequenas, e o restante com baixo valor de mercado. Biogeográficamente os peixes de SL são no geral Guineanas, constituídos por 27 espécies anfi-Atlânticas, 25 sp. com distribuição repartida entre o Oeste Africano e Atlântico Oriental, 11 espécies (16,4%) endémicas de CV e 4 taxa com distribuição restrita às ilhas da Macaronesia (incluindo CV). A riqueza média de espécies por transepto (40 m^2) foi de 12,08 ± 0,23 espécies e o número médio de indivíduos por transeptos excluindo os *Chromis* spp. (espécie gregária) foi de 80,32 ± 9,96 peixes (biomassa estimada de 12,54 ± 1,3 kg). A presença de dois pomacentrídeos planctívoros *Chromis* tende a desajustar um cenário possivelmente mais ideal de densidade e biomassa da comunidade de peixes recifais em SL. Por grupos tróficos de peixes, os planctívoros (4 sp.) contabilizaram cerca de 69% de todos os indivíduos registados em toda a SL, 17,9% de predadores de invertebrados móveis (13 sp.), 4,5% de omnívoros (10 sp.), 3,6% de carnívoros (23 sp.), 2,7% de herbívoros vagueadores (7 sp.), 1,57% de herbívoros territoriais (3 sp.) e, finalmente, um único predador de invertebrados sésseis (peixe borboleta). 70% da composição bentónica, de grupos funcionais, em Santa Luzia é constituída de areia e cascalho (33,1%), algas calcárias encrustantes (14,1%), macroalgas (13,4%) e tufo de algas (10,3%) e são significativamente diferentes ao longo dos locais de mergulho porém agrupam-se em 5 sítios do sul da ilha demonstrando uma explicação ambiental para a cobertura bentónica. Quando este ultimo foi analisado pela técnica de componentes principais com dados de peixe, foi notável a correlação com o coral duro e macroalgas, devido à complexidade de habitat nos locais do sul e sudoeste, sendo relativamente pobres os pontos do norte em diversidade (peixes), outrossim ricos em organismos encrustantes. Acções da pesca não se correlacionam com a densidade de peixes. A relativa ausência de grandes carnívoros e omnívoros e a prevalência de pequenos peixes planctívoros e criptobentónicos demonstra que a reserva marinha de Santa Luzia carece de atenção urgente nos planos/actos para conservação e, sobretudo, de se repensar a política das pescas para as áreas adjacentes à reserva.

ABSTRACT

Santa Luzia Island in the Cape Verde archipelago has been designated a marine reserve since the 1990s. In 2003 it was reclassified as an integral natural reserve but its official status has in practice not been operationalized. First assessment approach was conduct in 2009 in order to describe reef fish assemblages in different sites of Santa Luzia marine reserve using visual census and benthos coverage by photoquadrats. The specific aims were to describe general patterns of reef fish biomass, density, and fish trophic groups in Santa Luzia marine reserve e relate it with benthos. Between September 25th and October 2nd, of 2009, 11 study sites around the island were chosen for sampling in order to check for different biotic, abiotic and fisheries conditions/effects. Fish biomass was calculated using total length classes mid-point and weight relationships and general patterns of fish density, biomass, and categories of benthic cover between sites were compared. Methods by multivariate analysis (principal component analysis and clustering) were used for grouping sites based on benthic cover to analyse fish biomass and density among sites using descriptors of fishing intensity, water surge, complexity and substratum type. A total of 51,507 individuals of 67 species belonging to 32 families were recorded in 198 transects. Families' species richness was: Muraenidae (7 sp.), Pomacentridae and Labridae (both 6 sp.), Epinephelidae and Sparidae (both 4), 11 (2-3 sp.) and 16 by a single species each. The 10 most abundant species accounted for 90.53% of total census, and the list of fishes in decreasing order were: *Chromis lubbocki* (endemic), *Chromis multilineata*, *Thalassoma pavo*, *Parapristipoma humile*, *Sparisoma cretense*, *Myripristis jacobus*, *Coris atlantica*, *Gobius tetrophthalmus* (endemic), *Parablennius salensis* (endemic) and *Stegastes imbricatus*. 40.3% (27 sp.) of SL infra-littoral reef fish are commercial and 37.3% are non-commercial species, mainly cryptic or small fish, and the rest with low market value. By biogeography the fish of SL reefs are mainly Guinean composed by 27 tropical amphi-Atlantic species, 25 sp. are divided in West African/Eastern Atlantic distribution, 11 species (16.4%) endemic to the CV and 4 taxa shared by the Macaronesian islands (including CV). Mean species richness per census (40 m^2) was 12.08 ± 0.23 species and mean number of individuals per census/transect without *Chromis* spp. (gregarious species) was 80.32 ± 9.96 fish (estimated biomass of 12.54 ± 1.3 kg). The presence of two planktivores pomacentrids *Chromis* tends to decoupling the possible real picture of fish density and biomass of SL reef fish community. By trophic group of fish; the planktivores (4 sp.) accounted for 69% of all fish individuals recorded in all Santa Luzia, 17.9% of mobile invertebrate feeders (13 sp.), 4.5% of omnivores (10 sp.), 3.6% of carnivores (23 sp.), 2.7% roving herbivores (7 sp.), 1.57% of territorial herbivores (3 sp.), and finally sessile invertebrate feeders with a single butterflyfish. 70% of Santa Luzia's benthonic composition of functional categories consists of sand and rubble (33.1%), encrusting calcareous algae (14.1%), macroalgae (13.4%) and turf algae (10.3%) and were significantly different among sites but clustering of five of them in southern Santa Luzia denotes environmental explanation for benthic coverage. When benthic cover were tested by principal component analysis (PCA) with fish data correlations with hard coral and macroalgae were notably increased because of the complexity of habitats in the southern and southwestern sites, thus relatively poor in diversity (fish) at the northern sites (besides rich in encrusting organisms). Fishing action does not correlate with fish density. The relative absence of large carnivore and omnivore and prevalence of small planktivores and cryptobenthic fish shows that Santa Luzia marine reserve urgently needs attention for conservation, planning and also re-assessment of the applicable fisheries policy for nearby areas.

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INTRODUCTION

Marine reserves are becoming a popular tool for marine conservation and resource management worldwide. Most of these reserves have been created without much understanding of how they actually affect the areas they are intended to protect (Halpern & Warner, 2002). In recent years the benefits of marine reserves have been widely reported (PISCO, 2011), but very few attempts have been made to generalize their ecological effects (Claudet et al., 2008).

The protected areas initiative in the West African (WA) marine ecoregion, based on the Regional Strategy for West African Marine Protected Areas (MPA), was agreed in 2001 and is currently being implemented, including in the Cape Verde archipelago (central Eastern Atlantic). However, a new Guidebook for West Africa MPA managers is available (Rizk et al., 2012).

Little is known about the effects regarding fisheries (Brashares et al., 2004; Sale et al., 2005) and ecosystem restoration goals in the WA ecoregion. On the whole, it is internationally important as one of the major fishing zones worldwide (Christensen et al., 2004), but also as a natural sanctuary for marine biodiversity (Benchimol et al., 2009).

Colléter et al. (2012) attempted to model trophic flows in ecosystems to assess the efficiency of a MPA in Senegal and tested the efficiency and effects on the whole trophic network using tropho-dynamic models. Another important WA approach was the quantitative biological assessment of a newly established artificial reef in Yenne, Senegal (Terashima et al., 2007), an useful device to attract fish to low productivity areas, simply by adding complexity (Ferreira et al., 2001). For South Africa's MPAs, Solano-Fernández et al. (2012) assess the effectiveness by the quantitative evaluations of the ichthyofauna community in 14 protected sites.

Since the 1990s, Santa Luzia Island, in the Cape Verde archipelago, is designated a marine reserve. In 2003 it was reclassified as an integral natural reserve, but no management plan has been approved so far. Basic studies on marine biota have been carried out in the Cape Verde Islands since 2006, specifically for some sensitive marine areas, but the effectiveness of protective measures has not been evaluated (Almeida et al., 2010). Nature reserves and protected areas in Cape Verde effectively exist only on paper and their status as marine reserves has in practice not been established.

According to the Regional Strategy for MPAs, some of the 700 fish species reported in the region, mainly pelagic species which live in open water, move along the West African coast and back and forth across national boundaries.

Research on fish wildlife communities seems to respect certain environmental and ecology limitations, both in the description of the communities and in the compilation of check-lists of the ichthyofauna (Rodrigues, 2009). Many descriptions of marine fish communities have concentrated on reef-fish assemblages, including coralline community areas (as in the Cape Verde Is.) or recently on temperate reefs, but can be used to evaluate community responses to natural and artificial changes in marine biota (Ribeiro et al., 2005), as well as a monitoring tool for long-term effectiveness of MPA (García-Charton et al., 2008).

Fish assemblages are keystone for structure and resilience of the aquatic environment (Bellwood & Choat, 1990; Hughes et al., 2005; Menezes et al., 2012). Therefore, understanding spatial variation in patterns of reef fish communities (Ferreira et al., 2004) is key in the evaluation of protection measures in natural and/or explored areas (Floeter et al., 2006; Krajewski & Floeter, 2011). Several studies on reef fish community vs. benthic coverage have been carried out worldwide, e.g., at the Great Barrier Reef and other Pacific areas (cf. Sale, 2002; Dominici-Arosemena & Wolff, 2006), in the south-western Atlantic (cf. Krajewski & Floeter, 2011; Pinheiro et al., 2011; Gibran & Moura, 2012, and references therein), as well as intensifying efforts in the temperate Eastern Atlantic studies, e.g., in the Azores (Bertoncini et al., 2010; Menezes et al., 2012), Madeira (Ribeiro et al., 2005) or the Canary Islands (Hajagos & Van Tassell, 2001; Clemente et al., 2010, 2011; Espino et al., 2011).

One of the fundamental aims of community ecology is to determine which factors and respective roles influence the structure of natural communities (Ferreira et al., 2001). According to Floeter et al. (2007) the population relationship of biotic and physical gradients will explain the patterns of community structure in the marine environment.

Main factors driving the composition of the ichthyofauna (Mora et al., 2003) include: (1) regionally by latitudinal gradient of temperature (Ferreira et al., 2004; Willing & Bloch, 2006), evolutionary patterns (Harrison & Cornell, 2008), coastline distance and depth (Fox & Bellwood, 2007; Floeter et al., 2007) and biogeography (Mora et al., 2003); (2) locally with positive correlations of fish abundance by benthic coverage or structural topographic complexity of habitat, i.e. rugosity (Ferreira et al., 2001; Krajewski & Floeter, 2011); currents regimes and wave-induced energy exposure of water motion that negatively affect swimming performance of fish (Ferreira et al., 2001; Fulton et al., 2005; Floeter et al., 2007).

Gust (2012) emphasized the role of hydrodynamics, but Friedlander et al. (2003) considered that wave energy and water surge is less important than habitat structure effect (complexity) on availability of refuge and subtract habitat for food.

The effects of substratum variables on reef fish community structure has been studied, especially for coral reefs that form a complex framework, supporting a variety of microhabitats, therefore increasing fish diversity and richness (Ferreira et al., 2001).

Nevertheless, when water motion gradient is correlated with distance off the coast and the morphology of the islands, exposure gradient seems to be the most important driving force structuring both reef fish and benthic communities (Floeter et al., 2007).

Overall, density and biomass of fishes were positively correlated with coral cover and depth, and negatively correlated with wave exposure (Krajewski & Floeter, 2011).

Reef fishes are frequently found along the insular shelf of the Cape Verde Islands, while juveniles are associated with shallow water coralline communities (Almeida et al., 2007; González & Tariche, 2009).

The Canary current (CC) presents wider water motion from January to June, and weaker and near to the West African coast from July to December (Lázaro et al., 2005). The seawater temperature gradient, which is affected by the cold CC, does not allow in time the establishment of coral reefs in the tropical Capeverdien archipelago, consequently, the so-called 'coralline community' (Almeida et al., 2007) is mostly based on the environment framework of reef fish and macroalgae assemblages, encrusting calcareous algae, epilithic algal matrix (EAM by Wilson et al., 2003), invertebrates (Wirtz, 2001, 2009; Reimer et al., 2010), some *Scleractinia* hard coral including pavements of *Siderastrea* sp. (Moses et al., 2003) and hydrocoral species (Laborel, 1974), all as biogenic deposits above volcanic material.

The main CC cues direction down to the Cape Verde islands creates: (1) exposed rocky shores with some cliffs enclaves with major hydrodynamic forces at north, northeast by trade winds and (2) rocky-sandy shallow areas sheltered or moderate exposed in opposite side of islands configurations but receiving energetic seasonal south swells (Van der Land, 1993).

Reef fish assemblages in Cape Verde are amongst the most important due to their relative abundance and biomass availability in coastal areas, being however balanced against the low catches, specifically for demersal species along the West African coast (Adams et al., 2004; Brashares et al., 2004).

On the integrative catalogue of the fishes of the Cape Verde Islands, Reiner (1996) listed about 520 species but includes some old and erroneous records. Old studies, as Franca & Vasconcelos (1962) and others, investigated the ichthyofauna of the Cape Verde Islands and several new researchers publish nowadays with checklists and zoogeographical approaches (Reiner, 1996 and Brito et al., 2007, respectively). Currently, a validated check-list of coastal fish from the Cape Verde Islands was accepted for publication (Wirtz et al., unpub. data). We expected that the same routine can be done in next years for deep sea fishes of Cape Verde.

Monteiro et al. (2008) compiled a check-list of fish including data on biogeography, habitat, egg type, diet, conservation, and fisheries status of the fish species recorded at two seamounts in the Cape Verde archipelago, i.e. the Northwest Bank and João Valente Bank.

In recent years, taxonomic revisions, descriptions of new species, occurrences and new records of fishes in the area have increased (e.g., Edwards, 1986; Hensley, 1986; Matallanas & Brito, 1999; Brito & Miller, 2001; Wirtz, 2009; Freitas et al., unpub. data). More recently, Wirtz & Schliewen (2012) described a new species of perch serranid *Liopropoma* from the Cape Verde Is. and Fricke et al. (2010) new clingfish species of genus *Apletodon* to the Archipelago.

According to Brito et al. (2007), the littoral ichthyofauna of the Cape Verde Islands is zoogeographically tropical, with Guinean species clearly dominant, followed by tropical-subtropical amphi-Atlantic species, i.e. taxa distributed in the Atlantic and Mediterranean, and by the circumtropical ones.

The presence of twenty (Brito et al., 2007) or more (Wirtz et al., unpub. data) endemic taxa suggests speciation around Cape Verde waters, and notable by the presence of monotypic endemic genera of *Similiparma* (Pomacentridae) and *Virididentex* (Sparidae) (Hensley, 1986 and Osório, 1909 respectively). A large degree (three or more sp.) of endemism can be found in small cryptobenthic fishes of Blenniidae as well as in the Labrisomidae, Gobiidae and also Sparidae seabreams, with three endemic *Diplodus* spp. (Wirtz et al., unpub. data).

Floeter et al. (2008) proposed that the high endemism in the Cape Verde Islands may be related to: (1) isolation (from the mainland and between islands), (2) high heterogeneity of habitats, and (3) maintenance of warm tropical waters during glacial periods.

The Cape Verde Islands have a much larger degree of coastal fish endemism than the other Macaronesian archipelagos (Azores, Madeira, Selvages and Canary Islands) in the Eastern Atlantic and in the number of endemic taxa, the Cape Verde Islands were closer to the islands in the Gulf of Guinea and not to the Northwest African coast (Wirtz et al., unpub. data). From the point of view of marine biota community and zoogeography, Cape Verde diverts considerably from the rest of Macaronesian islands (Brito et al., 1999, 2007; Morri et al., 2000; Floeter et al., 2008).

Even more recently, feeding ecology and morphometric relationships amongst the white seabream, *Diplodus sargus lineatus*, a ‘relic’ species of seabream (Summerer et al., 2001), endemic to Cape Verde archipelago were shown by Soares et al. (2012) and a comparison study of the fish assemblages on natural and artificial reefs off Sal Island (Cape Verde) were done regarding the diving ecotourism growing in Cape Verde (Santos et al., 2012). Thus, Ramos et al. (2011), in the same island, performed a stakeholder perceptions study of decision-making process on marine biodiversity conservation and it seems that limitation of activities is the preferred management option to consider in the future.

Herrera (1998) reported, registered and photographed some fish species by SCUBA diving, either captured using dredge devices in shallow waters south of Santa Luzia Island. No systematic marine biota studies have been undertaken in this MPA area from Cape Verde. In addition, a preliminary study on behaviour fish cleaning station ecology from Cape Verde were done, e.g., cleaning mutualism and new records of facultative cleaner fish species in Santa Luzia were also published (Quimbayo et al., 2012).

We conduct the first assessment approach to describe and document reef fish assemblages in different sites of Santa Luzia marine reserve using a visual census technique and benthos coverage by photoquadrats techniques and to make available a baseline data-set for use in the future MPA of Santa Luzia and other marine reserves in the Cape Verde Islands. The main objective is: (1) to describe the general patterns of reef fish biomass, density and fish trophic groups for the Santa Luzia marine reserve, (2) compare these among sites and (3) enhance our understanding of biotic and abiotic factors/variables that explain the patterns of abundance/density and biomass of trophic groups in Santa Luzia Island, an oceanic West African MPA.

MATERIALS AND METHODS

Study Area — The Cape Verde (CV) Islands are located in the central Eastern Atlantic (Fig. 1, 14°50′–17°20′N, 22°40′–25°30′W), ca. 750 km of Senegal in West Africa (Duarte & Romeiras, 2009). There are 10 islands (of which nine are inhabited) and eight islets, totalling a land area of 4,033 km^2. The archipelago was formed by rock accumulation, resulting from eruptions from a hotspot under submarine platforms (Laborel, 1974). The coastline is about 965 km long and the shelf (depth <200 m) is 5,934 km^2 (Bravo de Laguna, 1985; DGMP, 1998). The archipelago is situated at the Eastern border of the North Atlantic subtropical gyre and the southern limit of the Canary Current and affected by large scale interactions between the Canary Current, the North Equatorial Current and the North Equatorial Counter Current (Lázaro et al., 2005). The climate in the region is tropical, with two weather regimes (seasons) alternating during the year: a moderate cold season (December to June, 22-23ºC average) and a hot season (26-27ºC) (Almada, 1993).

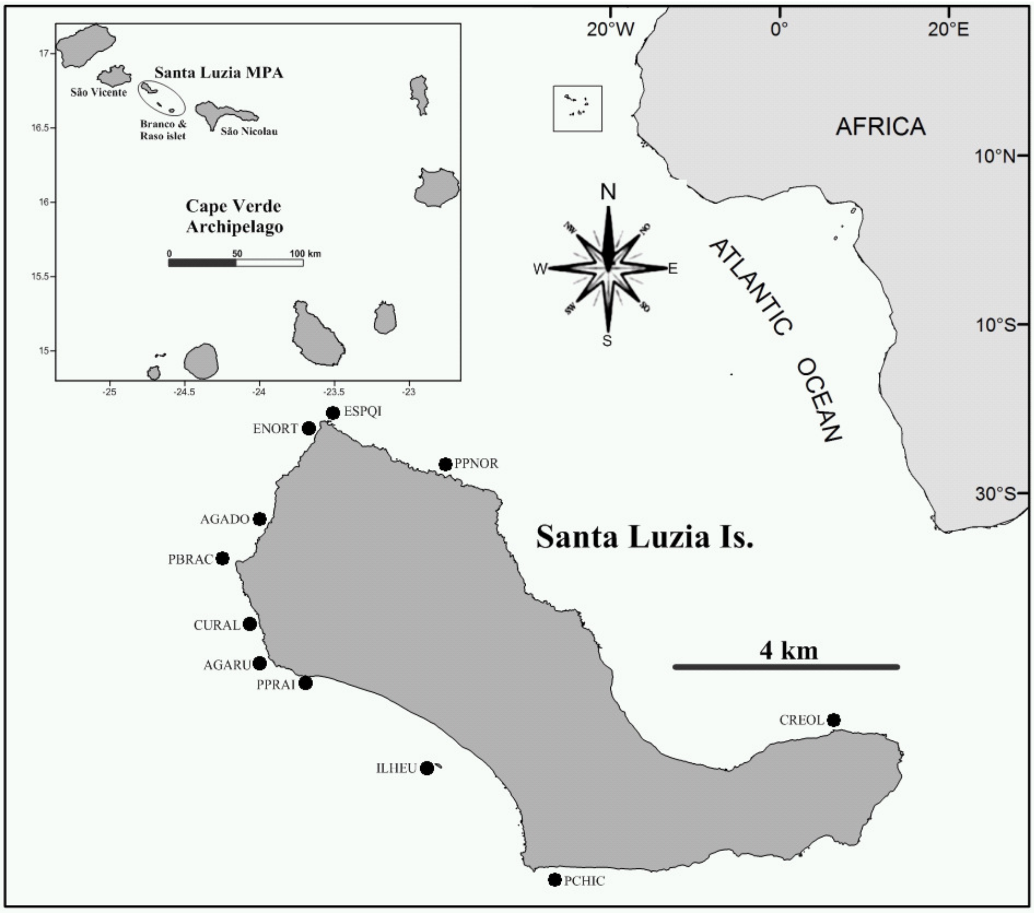

Figure 1 – Map showing the geographical position of the Cape Verde archipelago in West Africa and the study sites in the north-western island of Santa Luzia, including nearby islands and islets. The 11 reefs studied at Santa Luzia are: (AGADO) Água Doce, (PPRAI) Ponta Praia, (AGARU) Água Ruim, (ILHEU) Ílheuzinho, (ESPQI) Espequinho, (PPNOR) Ponta Preta Norte, (CREOL) Ponta Creolo, (ENORT) Enseadinha Norte, (PCHIC) Ponta Chica, (CURAL) Curral and (PBRAC) Ponta Branca.

Santa Luzia (SL) island (16°45′ N; 24°44′ W), with 34.27 km^2 of land area the smallest island in Cape Verde, is situated 5 nautical miles (9.26 km) from São Vicente. SL, Branco (2.78 km^2) and Raso (5.76 km^2) islets are uninhabited and together constitute an important MPA in Cape Verde. However, the effectiveness of protection and restrictions on artisanal fisheries within the marine reserve (mainly from nearby São Vicente and São Nicolau) is limited and remains largely unenforced (Almeida et al., 2010).

With a coastline of about 34.7 km, SL island and the nearby islets are positioned in a NW-SE direction, situated in the second largest shelf (depth < 200 m) area in Cape Verde and contouring all the north-western islands, being a significant source of biomass and biodiversity (Almeida et al., 2010). The northeastern areas of the island consist of cliffs and rocky shores, being much exposed to wave energy, while the southern to southwestern areas are shallower (Van der Land, 1993), with sandy beaches or rhodoliths covering infra-littoral bottoms. The western coast of SL shows mixed conditions and is apparently richest in reef fish diversity, so this part was given high priority in the present study. Overall, water transparency and water flow are much higher at tidal a current, which is amplified by the edge effect of the island's configurations and the canals between islands and islets.

Sampling survey Procedures — Between 25 September and 2 October 2009, 11 study sites (Fig. 1) were chosen for sampling at Santa Luzia in order to encompass contrasting environmental conditions and to search for differences in community structure of fishes and benthic organisms, influenced by different conditions of wave movement, fisheries intensity and relative benthic coverage of the benthos categories. The selection of sites, as first survey approach, was based on knowledge of the local marine fauna, fisheries activities in the area and tidal currents conditions, but also on logistics constrains.

Replicated visual transects using SCUBA diving were performed at each site. The composition of reef fish communities at Santa Luzia was assessed during a total of 198 strip belt transects (20×2 m), a procedure widely used (Krajewski & Floeter, 2011; Pinheiro et al., 2011, and references therein) by recording all larger mobile fishes as well improving the sampling of cryptic species, keeping the sample units within a defined habitat structure on reef areas, and allowing a good density estimation for all species (Ferreira et al., 2001, 2004; Floeter et al., 2007). Different numbers of transects was taken for each study site (unbalanced) and the position of the transects was chosen randomly within each depth zone and performed as much as possible within stationary tidal currents, thus avoiding bias due to size of fishes and to accommodate divers to synchronize with each other. During transects the number of individuals of each species was classified into five size classes, with 5 cm intervals of total length (TL). All data were recorded on a prepared acrylic sheet enclosed in PVC tubes. Water transparency ranged from 10 to 25 m and water temperature from 23.5 to 27°C at all sites.

In total, 1,259 randomly selected photo-quadrats (25x25 cm of area) were photographed along the fish transects, sampling all zones at each site. The relative abundance of each substratum type (percent of benthic coverage) in each transect was estimated at 25 intercept points per frame, and the organism below each intercept point was recorded and analysed with the Coral Point Count with Excel Extension software (CPCe v3.6) (Kohler & Gill, 2006). Fifty-eight items, mostly benthic organisms, was grouped/classified in 10 functional categories; e.g. sand & rubble, macroalgae, turf algae, encrusting calcareous algae, bare rocky, zoanthids, millepores, other invertebrates, rhodoliths and hard coral.

Data Analysis — The topographic complexity of the substrata within each transect was classified as high (2) or average to low (1), a modification of Pinheiro et al. (2011). Zoogeographical categorization of Santa Luzia fishes followed an updated Atlantic reef fish database by Floeter et al. (2008) listed by phylogeny from Eschmeyer (2012) (see Table 1). Commercial values on the market were also considered for overall species ranked by commercial species, no commercial ones and species with low commercial value (cf. Claudet et al., 2008; González & Tariche, 2009). The established composition of species by zoogeography and commercial value was checked by chi-square test (χ^2) for independence.

Fishes were grouped into eight trophic categories according to Ferreira et al. (2001, 2004) and mostly following Krajewski & Floeter (2011) and validated by appendices to the check-list of Halpern & Floeter (2008). Groups comprised carnivores, territorial herbivores (Terr. Herbiv.), roving herbivores (Rov. Herbiv.), mobile invertebrate feeders (Mob. Invert.), sessile invertebrate feeders (Sessile Invert.), omnivores, piscivores and planktivores (Planktiv.). Fish biomass was calculated using TL classes mid-point and weight relationships with parameters available at Fishbase.org or, if possible, from genus average constants for allometric equation (Froese & Pauly, 2012).

General patterns of fish density, biomass and categories of benthic cover between sites in Santa Luzia were compared testing a non parametric ranking ANOVA of Kruskal-Wallis (KW) (Zar, 1999). Correspondence analysis (CA) on matrix between sites and % of categories of benthic cover were performed and the sites were grouped by Agglomerative Hierarchical Clustering (AHC). Fish biomass and density among sites were analyzed through a multivariate technique of Principal Component Analysis (PCA) using descriptors of FI (fishing intensity), WS (water surge = hydrodynamics + exposure), C (complexity) and also ST (substratum type) from quadrats analysis. The assessment of mean fishing intensity and water surge by site (ordinal ranking scale 1 to 5) was possible by individuals' inquiry (n=8), e.g. biologist, users with area knowledge, as well from local fishermen. WS evaluation was based on mean tidal currents through the sites and FI based on historical use of sites for fisheries and mean effort per day or week.

RESULTS

Fish community structure — During the study period, a total of 51,507 individuals of 67 species (Table 1) belonging to 32 families were recorded/counted (198 transects), including one elasmobranch, viz. nurse shark *Ginglymostoma cirratum*, recorded four times during the study period. Three taxa were not identified to species level (Table 1). Most identified species belonged to the Muraenidae (seven species), followed by Pomacentridae and Labridae (both six) and Epinephelidae and Sparidae (both four), while 11 families were represented by 2-3 species and 16 families by a single species each.

The 15 most abundant species accounted for about 94.12% of all fishes recorded during this study. Nine of these were also among the 15 species with the highest biomass. Considering all Santa Luzia study sites collectively, the 10 most abundant fishes per transect were, in decreasing order (Table 1 and Fig. 7) *Chromis lubbocki* (endemic), *C. multilineata*, *Thalassoma pavo*, *Parapristipoma humile*, *Sparisoma cretense*, *Myripristis jacobus*, *Coris atlantica*, *Gobius tetrophthalmus* (endemic), *Parablennius salensis* (endemic) and *Stegastes imbricatus.* This particular group of abundant fish species was composed of planktivores (*Chromis* sp., which mostly occurred in large schools - gregarious species), mobile invertebrate cryptobenthic feeders species, a roving herbivore (*S. cretense*) and one small carnivore species. Of these, six are of no commercial value and only two are captured by local fishermen. Based on our criteria, 40.3% (27 sp.) of SL infra-littoral reef fish recorded are commercial and 37.3% are non-commercial species, mainly cryptic or small fish, and the rest of 22.4% of species with low market value (Table 1).

From a zoogeographical point of view, the fish assemblages of SL reefs (Fig. 2) are composed by 27 tropical amphi-atlantic species (40.3%), 25 (37.3%) species are divided between tropical West African species and species with an Eastern Atlantic distribution (e.g. Guinean species are well represented), 11 species (16.4%) endemic to the Cape Verde archipelago and four taxa that share that occur throughout the Macaronesian islands (see Table 1).

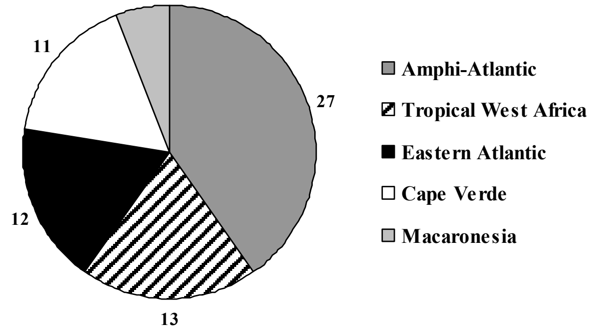

Figure 2 – Biogeographic characterization of Santa Luzia reef fishes (numbers indicate number of species).

Table 1 – Comparative composition of visual census of reef fishes among sites in the Santa Luzia Natural Reserve: Density/abundance per 40 m^2 (mean ± SE) per sites/species; frequency of occurrence (*F*) and estimated biomass per species. Commercial value, zoogeography and trophic group of species are also presented. Bold numbers indicate the 10 most abundant (density & biomass) and endemic fishes (CV) in the species list (taxonomy follows Eschmeyer, 2012).

No	Family & species	Zoog.	Com.	Trophic Group SL	Biomass (±SE g 40 m^2)	Abundance (±SE n 40 m^2)	*F*	PPRAI	AGARU	CURAL	PBRAC	AGADO	ENORT	ESPQI	PPNOR	CREOL	PCHIC	ILHEU
No	**Santa Luzia BMass./Abund. (40 m^2)**				**12,548 ± 1,301**	**260 ± 20**		**377 ± 42**	**565 ± 79**	**270 ± 72**	**153 ± 30**	**167 ± 18**	**88 ± 19**	**163 ± 24**	**214 ± 49**	**112 ± 12**	**188 ± 48**	**221 ± 26**
	Ginglymostomatidae																	
1	*Ginglymostoma cirratum*	AA	LC	Carnivores	4.54 ± 3.58	0.02 ± 0.02	0.01		0.09 ± 0.09								0.07 ± 0.07	
	Dasyatidae																	
2	*Dasyatis centroura*	AA	LC	Carnivores	8.14 ± 8.14	0.01 ± 0.01	0.01				0.05 ± 0.05							
	Muraenidae																	
3	*Enchelycore nigricans*	AA	C	Carnivores	1.10 ± 0.63	0.02 ± 0.01	0.02		0.03 ± 0.03	0.06 ± 0.06							0.07 ± 0.07	
4	*Gymnothorax miliaris*	AA	C	Carnivores	3.77 ± 1.30	0.05 ± 0.02	0.05	0.07 ± 0.07	0.03 ± 0.03		0.16 ± 0.12	0.11 ± 0.07		0.12 ± 0.08				0.09 ± 0.09
5	*Gymnothorax sp.*	AA	C	Carnivores	2.22 ± 0.77	0.04 ± 0.01	0.04		0.09 ± 0.05				0.09 ± 0.09		0.09 ± 0.06			0.18 ± 0.12
6	*Gymnothorax vicinus*	AA	C	Carnivores	1.90 ± 0.69	0.07 ± 0.02	0.05	0.13 ± 0.09	0.18 ± 0.12				0.09 ± 0.09			0.06 ± 0.06	0.13 ± 0.09	0.09 ± 0.09
7	*Muraena augusti*	MAC	C	Carnivores	0.42 ± 0.30	0.02 ± 0.01	0.02					0.16 ± 0.09			0.04 ± 0.04			
8	*Muraena melanotis*	TWA	C	Carnivores	1.27 ± 0.52	0.05 ± 0.02	0.04	0.07 ± 0.07	0.15 ± 0.10	0.06 ± 0.06							0.07 ± 0.07	0.09 ± 0.09
9	*Muraena robusta*	AA	C	Carnivores	0.28 ± 0.28	0.01 ± 0.01	0.01									0.06 ± 0.06		
	Synodontidae																	
10	*Synodus intermedius*	AA	NC	Piscivores	0.34 ± 0.19	0.03 ± 0.01	0.03	0.07 ± 0.07				0.05 ± 0.05			0.04 ± 0.04		0.13 ± 0.09	0.09 ± 0.09
11	*Synodus saurus*	AA	NC	Piscivores	0.15 ± 0.14	0.01 ± 0.01	0.01		0.03 ± 0.03		0.05 ± 0.05							
	Holocentridae																	
12	*Myripristis jacobus*	AA	LC	Carnivores	**682.63 ± 162.86**	**4.12 ± 0.94**	0.30	1.27 ± 0.99	**13.71 ± 4.49**	**4.06 ± 2.70**	0.89 ± 0.37	**1.47 ± 0.98**	0.55 ± 0.31	0.06 ± 0.06	0.70 ± 0.30	**1.75 ± 0.57**	1.00 ± 0.72	**13.36 ± 5.53**
13	*Sargocentron hastatum*	AA	LC	Carnivores	40.96 ± 10.04	0.41 ± 0.07	0.26	0.47 ± 0.17	0.41 ± 0.14	0.17 ± 0.12	0.16 ± 0.09	0.68 ± 0.38	0.55 ± 0.21	0.24 ± 0.11	0.35 ± 0.22	0.50 ± 0.20	0.27 ± 0.15	1.09 ± 0.65
	Aulostomidae																	
14	*Aulostomus strigosus*	AA	NC	Piscivores	6.77 ± 2.03	0.15 ± 0.05	0.08		0.35 ± 0.17	0.11 ± 0.11	0.32 ± 0.23	0.11 ± 0.07			0.13 ± 0.07	0.06 ± 0.06	0.27 ± 0.27	
	Fistulariidae																	
15	*Fistularia tabacaria*	AA	NC	Piscivores	0.59 ± 0.38	0.02 ± 0.01	0.02		0.06 ± 0.06			0.05 ± 0.05	0.09 ± 0.09					
	Epinephelidae																	
16	*Cephalopholis taeniops*	TWA	C	Carnivores	297.27 ± 36.32	**2.07 ± 0.18**	0.66	**2.13 ± 0.76**	1.94 ± 0.45	**3.61 ± 0.91**	**2.42 ± 0.76**	**1.95 ± 0.43**	**4.64 ± 0.85**	**1.47 ± 0.36**	**1.22 ± 0.35**	**1.75 ± 0.43**	1.00 ± 0.47	1.55 ± 0.49
17	*Mycteroperca fusca*	MAC	C	Piscivores	91.66 ± 36.26	0.33 ± 0.12	0.10		0.12 ± 0.07	0.06 ± 0.06	0.05 ± 0.05	0.58 ± 0.30		0.12 ± 0.08	0.09 ± 0.06		0.07 ± 0.07	**3.91 ± 1.81**
18	*Mycteroperca marginata*	AA	C	Carnivores	0.00 ± 0.00	0.11 ± 0.10	0.02		0.62 ± 0.59			0.05 ± 0.05						
19	*Rypticus aff. saponaceus*	EA	NC	Carnivores	1.38 ± 0.47	0.14 ± 0.03	0.11	0.20 ± 0.14	0.18 ± 0.08			0.16 ± 0.09	0.18 ± 0.12	0.06 ± 0.06	0.09 ± 0.06	0.19 ± 0.10	0.20 ± 0.14	0.45 ± 0.31
	Scorpaenidae																	
20	*Scorpaena sp.*	EA	LC	Carnivores	21.61 ± 9.08	0.19 ± 0.04	0.13	0.13 ± 0.09	0.18 ± 0.13	0.33 ± 0.14	0.05 ± 0.05	0.16 ± 0.09	0.09 ± 0.09	0.06 ± 0.06	0.26 ± 0.14	0.06 ± 0.06	0.47 ± 0.32	0.27 ± 0.14
	Priacanthidae																	
21	*Heteropriacanthus cruentatus*	AA	C	Carnivores	26.10 ± 5.06	0.53 ± 0.10	0.21		0.09 ± 0.09	0.17 ± 0.12	1.37 ± 0.52	0.63 ± 0.16	1.64 ± 0.51		0.26 ± 0.22	0.63 ± 0.22	1.07 ± 0.51	0.91 ± 0.91
	Apogonidae																	
22	*Apogon imberbis*	EA	NC	M. Invert.	0.74 ± 0.53	0.42 ± 0.40	0.02		0.03 ± 0.03								**5.33 ± 5.33**	0.27 ± 0.27
	Carangidae																	
23	*Caranx crysos*	AA	C	Carnivores	2.93 ± 2.93	0.02 ± 0.02	0.01			0.17 ± 0.17								
24	*Caranx lugubris*	AA	C	Piscivores	8.51 ± 8.51	0.02 ± 0.02	0.01		0.09 ± 0.09									
	Lutjanidae																	
25	*Apsilus fuscus*	TWA	C	Carnivores	1.00 ± 0.70	0.01 ± 0.01	0.01					0.11 ± 0.07						
26	*Lutjanus goreensis*	EA	C	Carnivores	2.99 ± 2.99	0.01 ± 0.01	0.01			0.06 ± 0.06								
27	*Lutjanus fulgens*	TWA	C	Carnivores	23.11 ± 23.11	0.51 ± 0.51	0.01		2.94 ± 2.94									
	Haemulidae																	
28	*Parapristipoma humile*	TWA	C	M. Invert.	309.14 ± 129.23	**6.82 ± 2.92**	0.06		**22.06 ± 7.95**								**36.67 ± 33.26**	**4.55 ± 4.55**
29	*Parapristipoma octolineatum*	EA	LC	M. Invert.	0.15 ± 0.15	0.10 ± 0.10	0.01										1.33 ± 1.33	
	Sparidae																	
30	*Diplodus fasciatus*	CV	LC	Omnivores	**798.22 ± 187.38**	1.60 ± 0.33	0.30	**1.80 ± 1.33**	0.79 ± 0.32	1.39 ± 0.65	**3.00 ± 1.72**	0.37 ± 0.28	1.82 ± 0.76	**1.59 ± 1.22**	**2.26 ± 0.66**	0.69 ± 0.36	**4.27 ± 2.86**	
31	*Diplodus sargus lineatus*	CV	LC	Omnivores	**450.34 ± 154.75**	1.11 ± 0.25	0.19	0.67 ± 0.67	0.74 ± 0.40	**3.22 ± 1.70**	**2.32 ± 1.37**	0.21 ± 0.14	**1.91 ± 1.00**	0.47 ± 0.30	0.65 ± 0.48	**1.75 ± 1.00**	0.33 ± 0.33	0.18 ± 0.18
32	*Diplodus prayensis*	CV	LC	Omnivores	**365.61 ± 90.21**	1.67 ± 0.56	0.28	**3.73 ± 1.63**	**3.59 ± 2.93**	**2.44 ± 1.65**	0.79 ± 0.39	1.00 ± 0.53	0.45 ± 0.45	0.18 ± 0.13	0.26 ± 0.11	0.06 ± 0.06	**3.53 ± 1.41**	0.64 ± 0.43
33	*Viridentex acromegalus*	CV	C	Carnivores	197.52 ± 108.77	0.39 ± 0.16	0.16	1.13 ± 0.69	0.18 ± 0.09	1.78 ± 1.66	0.21 ± 0.10	0.16 ± 0.12	0.09 ± 0.09	0.12 ± 0.08	0.26 ± 0.13	0.31 ± 0.12	0.13 ± 0.13	
	Centracanthidae																	
34	*Spicara melanurus*	TWA	C	M. Invert.	**342.29 ± 278.97**	1.39 ± 1.03	0.03		1.03 ± 0.78				**18.18 ± 18.18**	**1.76 ± 1.76**	0.43 ± 0.43			
	Sciaenidae																	
35	*Umbrina ronchus*	EA	C	Carnivores	0.19 ± 0.19	0.01 ± 0.01	0.01				0.05 ± 0.05							

Table 1 – (Continued).

Family & species	Zoog.	Com.	Trophic Group SL	Biomass (±SE g 40 m^2)	Abundance (±SE n 40 m^2)	%*F*	PPRAI	AGARU	CURAL	PBRAC	AGADO	ENORT	ESPQI	PPNOR	CREOL	PCHIC	ILHEU
Santa Luzia **No BMass./Abund. (40 m^2)**				**12,548 ± 1,301**	**260 ± 20**		**377 ± 42**	**565 ± 79**	**270 ± 72**	**153 ± 30**	**167 ± 18**	**88 ± 19**	**163 ± 24**	**214 ± 49**	**112 ± 12**	**188 ± 48**	**221 ± 26**
Mullidae																	
36 *Mulloidichthys martinicus*	AA	C	M. Invert.	42.61 ± 21.62	0.63 ± 0.27	0.11	0.40 ± 0.24	2.12 ± 1.47	0.56 ± 0.56	0.53 ± 0.53	0.53 ± 0.33		0.12 ± 0.12			0.93 ± 0.67	
37 *Pseudupeneus prayensis*	EA	C	M. Invert.	64.97 ± 21.80	0.58 ± 0.11	0.20	1.33 ± 0.71	0.53 ± 0.26	0.56 ± 0.28	0.84 ± 0.41	0.11 ± 0.11	0.73 ± 0.47	0.47 ± 0.27	0.09 ± 0.09		0.93 ± 0.54	1.45 ± 0.64
Kyphosidae																	
38 *Girella stuebeli*	CV	LC	Rov. Herbiv.	242.66 ± 79.70	0.37 ± 0.12	0.07		0.35 ± 0.21		**2.53 ± 0.97**		1.18 ± 0.52					
39 *Kyphosus incisor*	AA	LC	Rov. Herbiv.	**726.36 ± 424.78**	1.11 ± 0.62	0.04		**6.06 ± 3.51**				0.91 ± 0.91	0.06 ± 0.06		0.13 ± 0.13		
Chaetodontidae																	
40 *Chaetodon robustus*	TWA	NC	S. Invert.	20.42 ± 10.78	0.75 ± 0.38	0.08	0.13 ± 0.09	0.29 ± 0.16	0.22 ± 0.13		0.11 ± 0.07						**11.91 ± 6.21**
Pomacanthidae																	
41 *Holacanthus africanus*	TWA	NC	Omnivores	24.17 ± 4.50	0.41 ± 0.07	0.25	0.47 ± 0.22	0.85 ± 0.28	0.61 ± 0.24	0.11 ± 0.07	0.21 ± 0.10	0.27 ± 0.19	0.35 ± 0.12	0.39 ± 0.14	0.06 ± 0.06	0.53 ± 0.27	0.09 ± 0.09
Mugilidae																	
42 *Chelon bispinosus*	CV	LC	Rov. Herbiv.	7.21 ± 7.21	0.05 ± 0.05	0.01		0.29 ± 0.29									
Pomacentridae																	
43 *Abudefduf luridus*	MAC	NC	Omnivores	12.11 ± 2.81	0.31 ± 0.06	0.16	0.13 ± 0.13	0.18 ± 0.08	0.22 ± 0.15	0.32 ± 0.11	0.95 ± 0.35	0.27 ± 0.19	0.12 ± 0.08	0.17 ± 0.10			1.45 ± 0.68
44 *Abudefduf saxatilis*	AA	NC	Omnivores	112.59 ± 84.98	2.04 ± 1.54	0.05		**9.74 ± 8.84**	0.11 ± 0.11					**1.74 ± 1.74**	**1.94 ± 1.18**		
45 *Chromis lubbocki*	CV	NC	Planktiv.	**4109.90 ± 535.56**	**102.67 ± 10.26**	0.75	**214.20 ± 35.44**	**222.79 ± 35.83**	**115.72 ± 43.27**	**51.05 ± 16.58**	**54.26 ± 10.76**	0.91 ± 0.91	**58.76 ± 17.59**	**89.39 ± 26.84**	**28.25 ± 6.41**	**54.67 ± 20.40**	**101.82 ± 30.47**
46 *Chromis multilineata*	AA	LC	Planktiv.	**1382.06 ± 286.93**	**77.15 ± 8.08**	0.76	**79.47 ± 20.25**	**178.82 ± 30.54**	**64.94 ± 28.32**	**52.63 ± 13.48**	**75.05 ± 13.45**	**13.00 ± 5.22**	**40.71 ± 17.01**	**82.43 ± 26.89**	**44.69 ± 9.44**	**37.47 ± 17.23**	**36.36 ± 13.64**
47 *Similiparma hermani*	CV	NC	Omnivores	25.70 ± 4.27	0.45 ± 0.04	0.38	0.67 ± 0.13	0.41 ± 0.10	0.61 ± 0.18	0.53 ± 0.14	0.37 ± 0.16	0.36 ± 0.15	0.76 ± 0.18	0.39 ± 0.15	0.19 ± 0.10	0.40 ± 0.13	0.18 ± 0.12
48 *Stegastes imbricatus*	TWA	NC	Terr. Herbiv.	11.89 ± 2.06	**2.12 ± 0.21**	0.59	**1.47 ± 0.48**	2.35 ± 0.68	0.61 ± 0.30	0.95 ± 0.27	**2.47 ± 0.39**	**2.82 ± 0.85**	**1.47 ± 0.53**	**2.13 ± 0.44**	**6.81 ± 0.85**	1.40 ± 0.55	0.64 ± 0.28
Labridae																	
49 *Bodianus speciosus*	TWA	C	M. Invert.	244.01 ± 33.68	1.02 ± 0.12	0.44	1.27 ± 0.30	1.47 ± 0.37	1.44 ± 0.62	0.37 ± 0.23	**1.37 ± 0.56**	1.00 ± 0.43	0.94 ± 0.30	0.39 ± 0.16	0.94 ± 0.43	0.93 ± 0.40	0.82 ± 0.38
50 *Coris atlantica*	TWA	NC	M. Invert.	28.37 ± 5.36	**4.06 ± 0.72**	0.41	**12.67 ± 3.05**	**8.79 ± 3.30**	**6.72 ± 2.08**	1.42 ± 0.68	0.95 ± 0.43	**4.73 ± 3.18**	1.06 ± 0.54	0.13 ± 0.07	1.75 ± 0.67	1.60 ± 0.64	2.18 ± 0.98
51 *Thalassoma pavo*	EA	NC	M. Invert.	**398.32 ± 114.12**	**27.17 ± 4.13**	0.85	**28.40 ± 6.16**	**63.24 ± 21.16**	**37.28 ± 13.48**	**15.95 ± 2.14**	**10.79 ± 1.31**	**7.55 ± 2.55**	**36.53 ± 5.61**	**19.91 ± 4.62**	**7.81 ± 2.09**	**15.93 ± 3.01**	**8.91 ± 4.27**
52 *Scarus hoefleri*	TWA	C	Rov. Herbiv.	18.53 ± 6.94	0.05 ± 0.02	0.04		0.09 ± 0.05					0.29 ± 0.17		0.13 ± 0.09		
53 *Sparisoma cretense*	EA	C	Rov. Herbiv.	**847.66 ± 66.71**	**4.58 ± 0.34**	0.84	**3.80 ± 1.13**	3.56 ± 0.63	**5.17 ± 0.59**	**4.68 ± 0.67**	**2.42 ± 0.46**	**8.91 ± 3.22**	7.12 ± 1.41	**4.78 ± 1.36**	**3.38 ± 0.64**	**4.87 ± 1.06**	**4.00 ± 1.15**
54 *Sparisoma choati*	TWA	C	Rov. Herbiv.	70.11 ± 16.54	0.31 ± 0.06	0.17	0.07 ± 0.07	0.15 ± 0.06	0.17 ± 0.12	0.47 ± 0.23			0.41 ± 0.24	0.35 ± 0.12	0.75 ± 0.38	0.93 ± 0.46	0.27 ± 0.27
Labrisomidae																	
55 *Labrisomus nuchipinnis*	AA	NC	Carnivores	4.00 ± 1.51	0.62 ± 0.10	0.27	0.40 ± 0.19	0.26 ± 0.16	0.67 ± 0.45	0.68 ± 0.37	0.95 ± 0.33	1.09 ± 0.59	0.71 ± 0.24	0.17 ± 0.14	0.44 ± 0.20	1.33 ± 0.55	0.91 ± 0.31
Blenniidae																	
56 *Ophioblennius atlanticus*	MAC	NC	Terr. Herbiv.	3.48 ± 0.78	1.96 ± 0.23	0.49	0.47 ± 0.32	1.18 ± 0.51	0.44 ± 0.23	**2.68 ± 0.96**	**2.21 ± 0.60**	**6.55 ± 1.57**	**3.35 ± 0.90**	**2.70 ± 0.79**	1.56 ± 0.30	1.20 ± 0.45	0.55 ± 0.55
57 *Parablennius salensis*	CV	NC	Omnivores	112.53 ± 105.73	**2.93 ± 0.60**	0.43	1.07 ± 0.41	2.35 ± 0.91	2.00 ± 0.75	**2.32 ± 0.77**	1.16 ± 0.43	5.55 ± 1.91	**1.41 ± 0.62**	**0.78 ± 0.39**	**2.44 ± 0.79**	**3.20 ± 1.04**	**17.45 ± 9.09**
58 *Scartella caboverdiana*	CV	NC	Terr. Herbiv.	0.02 ± 0.02	0.01 ± 0.01	0.01				0.11 ± 0.11							
Gobiidae																	
59 *Gnatholepis thompsoni*	AA	NC	M. Invert.	0.30 ± 0.08	0.35 ± 0.09	0.13	0.67 ± 0.36	0.85 ± 0.45	0.17 ± 0.12	0.26 ± 0.18	0.79 ± 0.36	0.09 ± 0.09			0.06 ± 0.06	0.20 ± 0.20	0.27 ± 0.27
60 *Gobius tetrophthalmus*	CV	NC	M. Invert.	8.85 ± 1.94	**3.88 ± 0.56**	0.41	**16.27 ± 3.27**	**5.32 ± 1.44**	**9.39 ± 2.48**	1.37 ± 0.66	**2.63 ± 0.79**		0.47 ± 0.32	0.04 ± 0.04	0.38 ± 0.31	**3.67 ± 2.35**	**2.55 ± 1.05**
Acanthuridae																	
61 *Acanthurus monroviae*	EA	C	Rov. Herbiv.	262.57 ± 143.23	0.72 ± 0.16	0.26	1.00 ± 0.72	0.91 ± 0.27	2.22 ± 1.45	0.53 ± 0.33	0.47 ± 0.19	0.36 ± 0.20	0.76 ± 0.33	0.13 ± 0.10	0.56 ± 0.26	0.53 ± 0.19	
Balistidae																	
62 *Balistes punctatus*	EA	LC	M. Invert.	21.69 ± 7.65	0.13 ± 0.03	0.10	0.13 ± 0.09	0.18 ± 0.09	0.11 ± 0.08	0.16 ± 0.16			0.12 ± 0.12	0.04 ± 0.04		0.60 ± 0.16	0.09 ± 0.09
63 *Canthidermis sufflamen*	AA	LC	Planktiv.	12.90 ± 10.95	0.03 ± 0.03	0.01			0.28 ± 0.28				0.06 ± 0.06				
Monacanthidae																	
64 *Aluterus scriptus*	AA	NC	Omnivores	6.51 ± 2.44	0.08 ± 0.03	0.06	0.13 ± 0.09	0.18 ± 0.07	0.33 ± 0.24			0.09 ± 0.09					
Tetraodontidae																	
65 *Canthigaster rostrata*	AA	NC	Omnivores	27.96 ± 19.64	1.16 ± 0.23	0.50	0.67 ± 0.29	2.24 ± 1.22	1.28 ± 0.56	1.05 ± 0.32	1.11 ± 0.37	0.91 ± 0.37	1.12 ± 0.37	0.35 ± 0.13	1.38 ± 0.27	0.40 ± 0.16	1.27 ± 0.43
Tetraodontidae																	
66 *Sphoeroides marmoratus*	EA	NC	M. Invert.	0.92 ± 0.65	0.01 ± 0.01	0.01	0.13 ± 0.09										
Diodontidae																	
67 *Diodon holocanthus*	AA	NC	Planktiv.	1.04 ± 1.04	0.01 ± 0.01	0.01				0.05 ± 0.05							

Legend: Commercial value (**Com.**): C, commercial species; NC, non commercial species; LC, species of low commercial value. **Trophic Group**: M. Invert, Mobile invertebrate feeders; S. Invert., Sessil invertebrate feeders; Planktiv, Planktivores; Terr. Herbiv., Territorial herbivores; Rov. Herbiv., Roving herbivores, Carnivores, Omnivores and Piscivores. Zoogeography (**Zoog.**): AA, Amphi-Atlantic; TWA, Tropical West Africa; EA, Eastern Atlantic; CV, Cape Verde and MAC, Macaronesia. For sites full name, see map and legend on figure 1.

Mean species richness per census (±SE, standard error) was 12.08 ± 0.23 species 40 m^2, (range 5-22 sp.). The mean number of individuals per census (±SE) without *Chromis* spp. was 80.32 ± 9.96 (8-765 fish) and the estimated biomass was 12.54 ± 1.3 kg per 40 m^2 transect. Overall counts are presented in Table 1. The presence of two pomacentrids *Chromis* sp. with a mean of 5.49 ± 0.82 kg per 40 m^2 tends to decoupling the possible real picture of fish density and biomass of the SL reef fish community, especially in relation to the planktivores, as gregarious fishes. However, the parrotfish *Sparisoma cretense* (roving herbivore), the endemic omnivore *Diplodus fasciatus* and the macroalgae browser *Kyphosus incisor* follow *Chromis* spp. in terms of estimated biomass per 40 m^2 transects.

Regarding the trophic group of fish, the planktivores accounted for 69% of all fish individuals recorded in all Santa Luzia censuses, followed by 17.9% of mobile invertebrate feeders, 4.5% of omnivores, 3.6% of carnivores, 2.7% roving herbivores, and 1.57% of territorial herbivores (Fig. 3). Piscivores and sessile invertebrate feeders accounted for only 0.5% of the fish (260 individuals) recorded in study area and were excluded from Fig. 3. The majority of fishes counted were carnivores of 34.3% (23 species), followed by mobile invertebrate feeders with 19.4% (13 species), omnivores with 14.9% (10 species), roving herbivores with 10.4% (7 species), piscivores with 9% (6 species), planktivores with 6% (4 species), territorial herbivores with 3 species and finally sessile invertebrate feeders with a single butterflyfish, *Chaetodon robustus*. The mean composition per trophic group (Fig. 3) shows the difference in species richness and biomass importance for carnivores and omnivores, and especially roving herbivores (e.g., parrotfish), and the low densities of large fish. The small planktivores were the most abundant group in SL reserve. Mobile invertebrate feeders show intermediate results and are represented by cryptic species such as labrids and large haemulids in schools.

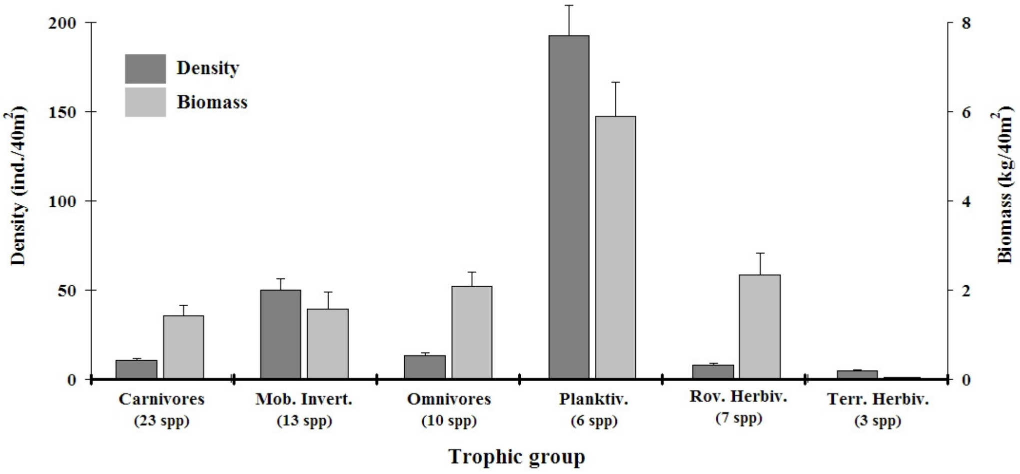

Figure 3 – The trophic groups recorded at the Santa Luzia, their mean (+SE) abundance/density and biomass, number of species and composition. Design layout is based on Krajewski & Floeter (2011). Abbreviations of trophic group: Mob. Invert. – Mobile invertebrate feeders, Planktiv. – Planktivores, Rov. Herbiv. – Roving herbivores and Terr. Herbiv. – Territorial herbivores. Obs.: The groups of Piscivores and sessile invertebrate feeders, even though they are evaluated, were not considered (very low values to be represented).

Distribution Patterns and Benthic Coverage — Santa Luzia census sites were not distributed systematically across the coastline. Assumed areas of special interest were chosen preferentially on hypothesis for suspected fauna richness or related to fisheries effort. This approach should be tested in the future reserve monitoring.

The southwestern sites (Fig. 4) in the prospected areas were the most abundant in fish density and biomass. The AGARU showed to be richest site in SL, mainly because of the abundance of planktivores and mobile invertebrate feeders, accounting for a maximum of 28.1 ± 5.2 kg or up 500 fish per 40 m^2 transect. In contrast the northwestern sites showed relatively low abundance but highest biomass (no *Chromis* effect), for instance as the ENORT point (‘Enseadinha Norte’ – sheltered haven in the north).

Multiple paired comparisons by KW Dunn post hoc tests reveal intermediate density grouping for CURAL, AGADO and southern ILHEU. Lower mean density and biomass per transect were found in the remote northeast single CREOL site. Biomass post hoc evaluation showed mostly homogeneous group and in case of AGADO and CREOL were split as single and extreme ratings. Biotic variables such as benthic coverage structure, fisheries effort history, physical effect on water surge and habitat complexity should explain this pattern of abundance and distribution in Santa Luzia.

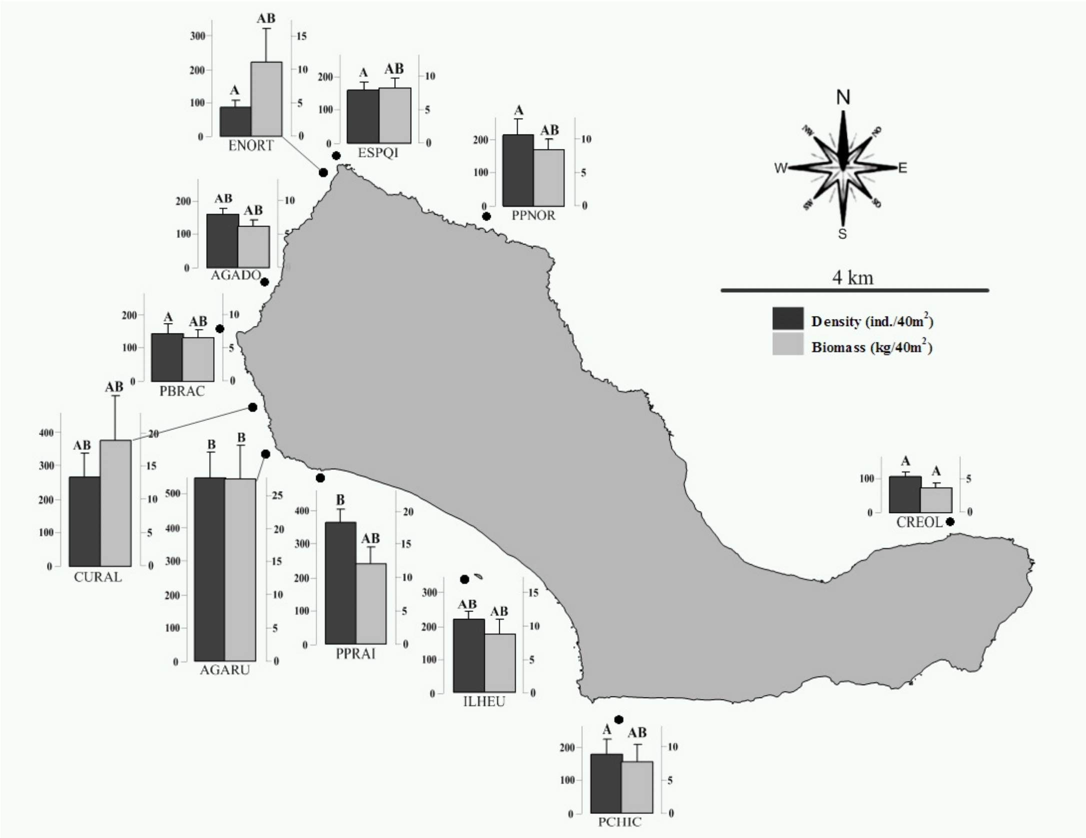

Figure 4 – Map of Santa Luzia marine reserve showing the position of sites, histograms (+SE) of density of fish (individuals) and estimated biomass (kg) per 40 m^2 transect in each site. Kruskal-Wallis tests (alfa = 0.05) showed significant differences in fish abundance and biomass among sites (KW, d.f. = 10, $p < 0.01$). Capital letters show statistical groupings (Dunn post hoc) with bars having different letters being significantly different and bars with the same letter considered as homogenous groups.

Benthic coverage evaluations along the study sites were performed in order to find correlation or first explanation of fish abundance (density and abundance) amongst sites. General evaluation of sites was performed across fish transects and discrimination was not based on variable effects (e.g. depth, exposure, etc.).

Overall, 70% of SL's benthonic composition of functional categories consists of sand and rubble (33.1%), encrusting calcareous algae (14.1%), macroalgae (13.4%) and turf algae (10.3%) called epilithic algal matrix (EAM) (Table 2). All 10 functional categories were significantly different among sites (KW, d.f. = variable, p < 0.01).

Table 2 – Summary of benthic habitat structure cover (mean % ±SE) groups in Santa Luzia. Bold % discriminate the four most important functional categories (n=10) of benthic coverage in each site.

Sites	AGADO	PPRAI	AGARU	ILHEU	ESPQI	PPNOR	CREOL	ENORT	PCHIC	CURAL	PBRAC
Total number of quadrats	158	162	211	45	173	10	30	48	76	157	189
Millepores	0.6 ± 0.3	4.6 ± 0.8	2.6 ± 0.5	1.6 ± 0.6	8.5 ± 1.3	4.4 ± 2.4	**9.7 ± 2.5**	4.6 ± 1.9	**3.6 ± 0.9**	2.2 ± 0.7	3.3 ± 0.8
Coral	0.5 ± 0.2	1.9 ± 0.8	1.4 ± 0.3	2.6 ± 1.0	0.8 ± 0.2	0.4 ± 0.4	1.3 ± 0.7	0.8 ± 0.3	2.9 ± 0.8	2.0 ± 0.5	0.7 ± 0.2
Sand & Rubble	**30.8 ± 2.1**	**44.0 ± 2.5**	**44.5 ± 2.1**	**36.5 ± 4.2**	**30.0 ± 2.3**	**19.6 ± 5.5**	**28.0 ± 3.6**	**13.7 ± 3.5**	**46.3 ± 3.3**	**40.3 ± 2.4**	**26.6 ± 2.1**
Bare Rocky	7.6 ± 1.1	5.5 ± 1.4	1.9 ± 0.4	6.3 ± 1.7	4.3 ± 0.8	**28.8 ± 2.7**	8.8 ± 2.1	8.5 ± 1.7	3.3 ± 1.3	2.2 ± 0.6	6.6 ± 0.8
Turf Algae	3.0 ± 0.5	**10.7 ± 1.4**	**12.2 ± 1.4**	**14.0 ± 4.1**	**12.2 ± 1.5**	**17.2 ± 3.9**	**25.9 ± 3.5**	**9.9 ± 1.9**	**8.8 ± 2.1**	**12.6 ± 1.7**	**9.9 ± 1.8**
Macroalgae	**13.9 ± 1.2**	**13.6 ± 1.6**	**26.5 ± 1.8**	**14.8 ± 2.4**	**11.1 ± 1.4**	**13.2 ± 3.2**	**13.1 ± 2.5**	4.8 ± 1.7	**31.3 ± 3.3**	**16.8 ± 2.0**	9.8 ± 1.2
Enc. Calcareous	**11.9 ± 1.3**	4.8 ± 1.0	2.7 ± 0.5	**7.7 ± 2.1**	**11.6 ± 1.3**	9.2 ± 5.5	9.3 ± 2.3	**41.6 ± 4.8**	3.0 ± 0.8	3.3 ± 0.8	**16.8 ± 2.0**
Zoanthids	**24.6 ± 2.4**	**9.8 ± 2.0**	3.6 ± 1.1	0.1 ± 0.1	10.7 ± 1.9	3.6 ± 3.6	—	**13.3 ± 3.8**	0.1 ± 0.1	**9.5 ± 2.0**	7.6 ± 1.6
Rhodoliths	5.7 ± 1.1	0.7 ± 0.3	0.1 ± 0.1	13.6 ± 3.6	—	—	—	—	0.3 ± 0.2	9.8 ± 1.8	**10.4 ± 2.2**
Oth. Invertebrates	1.4 ± 0.3	3.9 ± 0.8	**3.8 ± 0.7**	2.7 ± 0.9	10.6 ± 1.6	3.6 ± 1.1	3.6 ± 1.5	2.0 ± 1.0	0.3 ± 0.3	0.8 ± 0.4	8.0 ± 1.4

Kruskal-Wallis tests for the null hypothesis; median of all sites compared is the same in Santa Luzia Marine Reserve (Zar, 1999). Rejection for all benthic groups was considered and p<0.05 (p-value calculated). Sand & Rubble are composed by sand, gravel and biogenic material; Bare Rocky by detritus, stones and rock; Enc. Calcareous = Encrusting calcareous algae; Oth. = Others.

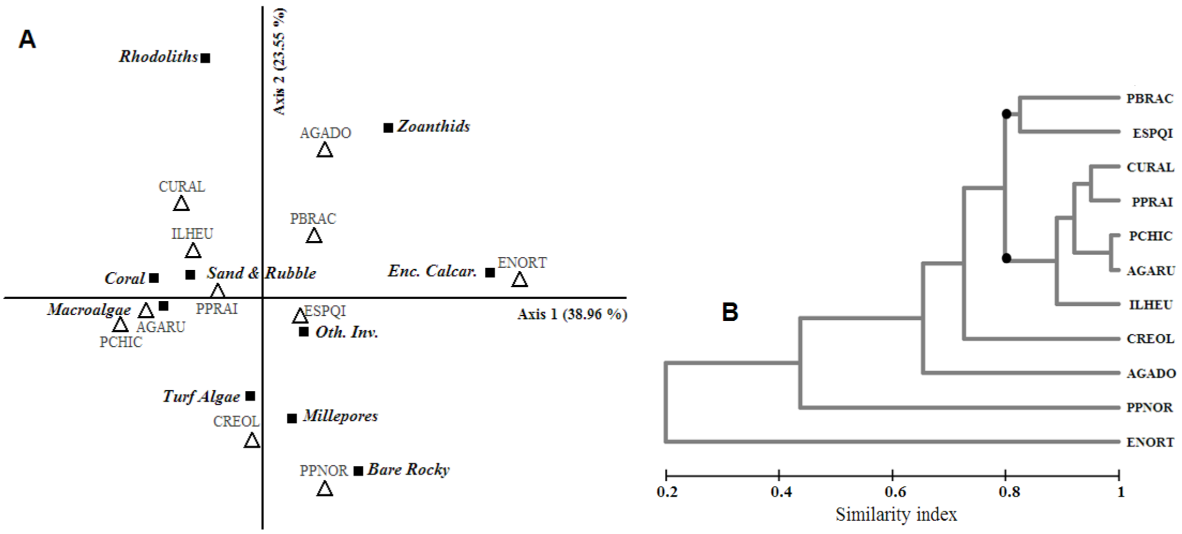

Figure 5 – (**A**): Correspondence analysis (CA) ordination diagram with the 10 benthic functional categories (■) at the studied sites (Δ) in Santa Luzia. Inertia of 62.5% was undertaken by CA two factors (total inertia: 0.43). (**B**): Agglomerative hierarchical clustering (AHC) of Santa Luzia sites based on % of benthos coverage (Pearson's correlation coefficient for similarity and Unweighted pair-group average for groupings). Data on CA and AHC multivariate analysis is from Table 2.

The cover of encrusting calcareous algae and sand and rubble, more densely represented in ENORT and PCHIC, were responsible for the horizontal point dispersal of the bi-plot ordination (38.9% of eigen-values in Axis 1). The vertical pattern (23.5%) was majorly explained by % of bare rocky and zoanthids occurring in the northern areas of PPNOR, CREOL and AGADO (Fig. 5ab).

The cluster of five sites in southern SL denotes environmental explanation for benthic coverage based on sand and rubble, macroalgae and corals. Other homogeneous groups can be set, as well the particularity of benthonic macro-invertebrates found along the western coast (PBRAC) of Santa Luzia and richest in ESPQI. However, the benthonic cover of habitats in the northern sites (PPNOR & CREOL) was entirely dominated and crustering by millepores, turf algae and bare rock.

Environmental Variables and Density / Biomass of Fishes Relationships — A principal component analysis (PCA) was conducted using site-specific estimates of fish density and biomass, fisheries data, environmental features and covering of the most six benthic functional groups (Fig. 6). This ordination is considered to be a powerful multivariate technique which is useful to rewrite the original variables into new variables through a coordinate transformation.

Nevertheless, when benthic cover vectors were analyzed in conjunction with fish data in the PCA, correlations with hard coral and macroalgae matrix were notably increased because of the complexity of habitats in the southern and southwestern sites (Fig. 6ab). In contrast, the northern sites are relatively poor in diversity (i.e. taxa) and structural complexity and richer in encrusting organisms (zoanthids and calcareous algae), with fish presence thus negatively correlated with macroalgae benthos cover. Fishing action at most sites (e.g. low water surge) does not correlate with fish density.

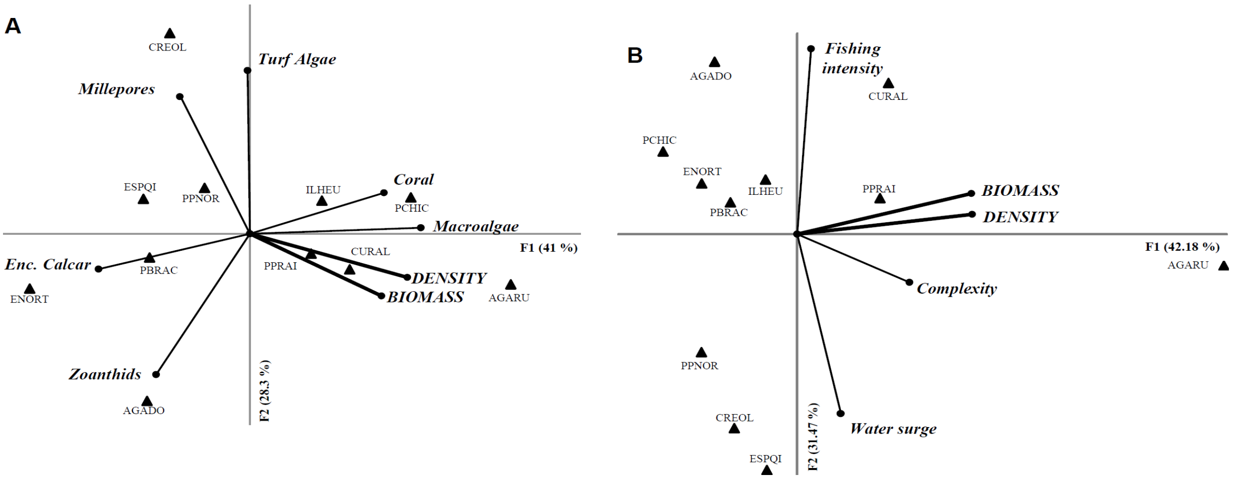

Figure 6 – Principal component analysis (PCA) exploring the density/biomass of fish in Santa Luzia marine reserve sites (▲) in combination with vectors of (**A**): the six most relevant benthic functional categories (●) at the studied sites (total eigenvalue 69.4%); (**B**): environmental descriptors (●) of fishing intensity, water surge (hydrodynamics + exposure) and complexity along the sites (total eigenvalue 73.6%).

DISCUSSION AND CONCLUSION

The northern and northeastern shores of Santa Luzia Island are very rugged and steep, buffeted by the currents, prevailing winds and the waves of the same quadrant. On the other hand, the relief is less steep and smoother at the southern and southwestern shores, which border plains and less mountainous areas, culminating in a coastline dominated by an extensive sandy beach and crystal clear and calm waters. This insular West African marine reserve was studied for the first time and data based on transects and benthic quadrats were evaluated to provide a baseline for future reef fish biology studies in the archipelago of Cape Verde. Additional data on assessment of reef fish from Cape Verde (Lino et al., 2011; Pereira et al., 2012; Wirtz et al., unpub. data) reinforce future research and allow for new areas of investigation, e.g. the effects of marine reserves on larval availability, regional biogeography in islands system (Edgar et al., 2004), dispersion and connectivity (Cudney-Bueno et al., 2009) around the MPA or nearby north-western Cape Verde islands.

Fish species richness (number of species per census) accounts 67 species in SL marine reserve, with the highest fish diversity (H´>2) in the moderately unexplored areas of ENORT, PCHIC and CREOL. However, AGADU site showed a maximum abundance and biomass estimative in the study area, as well, species richness (n=54). These results should be undertaken with precaution because half of the species in Santa Luzia came from only 22 families (16 of which with only a single species) with a presence of occurrence less than 10% (rare species, see *F* in Table 1).

Medina et al. (2008) suggested that demersal fish populations of an archipelago ecosystem are structured by island or island groups according to their degree of physical isolation and environment variability. The biogeographic composition of SL reef fishes are largely in accordance with the characterization by Brito et al. (2007), with Guinean species being dominant, followed by tropical-subtropical amphiatlantic species. Tuya et al. (2011) point out the relative influence of local to regional drivers of variation in reef fishes richness assessment, while Wirtz et al. (unpub. data) draw attention to the diversity of cryptobenthic reef fishes among the coastal fishes of the Cape Verde Islands. More studies of different areas of Cape Verde must be carried out in the future, focusing on reef fish and benthic community structure patterns among and between islands, thus highlighting functional groups (Bonaldo et al., 2005), with special attention for cryptic species biology and diversity (Dalben & Floeter, 2012).

Regarding commercial vs. zoogeographic distribution of species (χ^2=12.70, d.f. = 8, p-value=0.122) an interrelation does exists, e.g. most non-commercial species in SL are small cryptobenthic species, 30% of the species with a tropical West African and tropical-subtropical amphiatlantic distribution are of commercial interest and only one endemic species is commercially exploited.

Morays (low density spp.), pomacentrids and labrids dominate in diversity and damselfish *Chromis* spp. and small cryptic labrids are the dominant key species both in abundance and biomass, followed by medium sized fish such as haemulid *Parapristipoma humile* and parrotfish *Sparisoma cretense*. The five most abundant species in SL showed a frequency of occurrence up 70% for all transects in study area, excluding *P. humile* (6%) because low occurrence on large schools increasing its overall abundance. The relative absence of large carnivore (e.g., serranids that usually preys on *Chromis*) and omnivore fish (Fig. 3) and prevalence of small planktivores and cryptobenthic fish shows that Santa Luzia marine reserve urgently needs attention in conservation planning, e.g. precautionary measures must be implemented for restoring stocks.

Biomass estimation of medium-sized roving herbivore species (Fig. 3, mostly kyphosids and parrotfish – as macroalgae browser and scrapers respectively, cf. Halpern & Floeter, 2008) shows a high rate of mass conversion in size and should be related to the diet of these mostly herbivorous fishes by removing pieces of the substratum together with algae (Ferreira & Gonçalves, 2006). Parrotfish as the dominant consumers of benthic primary production on reefs, their rasping of the benthos shapes algal communities, erodes reefs, and contributes significantly to sedimentary processes (e.g., Bellwood, 1994; Bernardi et al., 2000). The fish abundance pattern per trophic group is quite similar for Trindade Island, a volcanic oceanic island located 1160 km off the coast of Brazil (Pinheiro et al., 2011).

In the present study, the AGARU site is the richest sampled area (diversity and abundance), but this is largely accounted for by the abundance of *Chromis* spp., predominating the fish community of Santa Luzia. If planktivores are excluded, the new results reveal significant mean reductions of 64% of the census abundance per site (maximum of 80% *Chromis* effect in PPNOR and minimum of 16% in ENORT). Estimated biomass showed the same pattern for minor mean effect of reductions of 38%. This result demonstrates the habitat preference of *Chromis* was influenced by wave exposure at northern sites or huge water surge at southern sites (cf. Floeter et al., 2007). Oceanographic conditions (e.g., tidal currents) should act controlling/difficult fisheries activities, which can also explain fish composition richness in those areas of water surge.

Partition of benthic covering around Santa Luzia is well-marked. The southern infra-littoral consists largely of sand and rubble, macroalgae and corals, while the exposed northern and northwestern areas are dominated by a mixture of encrusting organisms on bare rock. New studies must clarify the relationships of functional groups of fish with this particular environment and how the influence of exposure, benthic cover and depth can shift and structure the reef fish community (Floeter et al., 2007; Gibran & Moura, 2012).

Multivariate techniques like PCA can induce bias if fish biomass and benthic cover data are non-transformed or not standardized (Sandin et al., 2008), but in the present study ordination shows the same pattern of data if transformed. The results (Fig. 6) have shown that the heterogeneity of benthonic habitats of corals and macroalgae can affect the abundance structure of reef fishes, at the scale of Santa Luzia, and reinforce and extend previous observations for the south-western Atlantic (Ferreira et al., 2001; Dalben & Floeter, 2012).

Christensen et al. (2004) concludes that fish biomass (excluding small pelagics) in northwestern Africa has decreased to less than a quarter compared to 1950, with fishing intensity having increased 80 times since 1950, while catches only increased 18 times. Cape Verde EEZ in Eastern Atlantic and near shore areas are over-exploited by allowing EU long-line fishery for tuna, while Atlantic sharks face extinction due to overfishing and shark-finning (Pauly et al., 2005). Knowlton & Jackson (2008) evaluated the local impact and global change on coral reefs by 'shifting baseline' phenomenon and recently Walsh et al. (2012) warned for the fishery on top predators, which indirectly affects condition and reproduction in a reef fish community.

The current state of affairs provides plenty impetus to reinforce the effectiveness of the marine protected areas in Cape Verde and promote their management based on scientific research. The increase of abundance, size and biomass production in recently established or reinforced MPA was tested by Halpern & Warner (2002) based on data from 80 marine reserves and in most of these cases the variables (density, size and biomass) were highest inside the protected zones (Ashworth & Ormond, 2005). However, changes in these communities or potential impacts may only be detected in time and space, depending on ongoing research and data relating to disturbed and undisturbed areas.

Acknowledgments

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ANNEXE

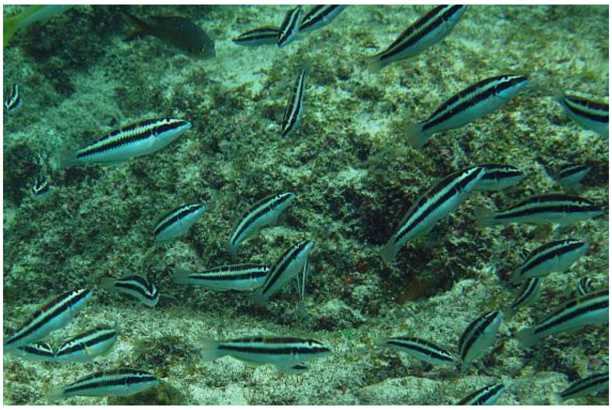
Figure 7

PHOTO LIST OF THE 10 MOST ABUNDANT FISHES IN SANTA LUZIA (CAPE VERDE)

"original photos from Santa Luzia 2009 survey database – several authors"

(1) Lubbock's chromis – ***Chromis lubbocki*** (endemic)

(2) Brown chromis – ***Chromis multilineata***



(3) Ornate wrasse – ***Thalassoma pavo***

(4) Guinean grunt – ***Parapristipoma humile***

(5) Parrotfish – ***Sparisoma cretense***

(6) Blackbar soldierfish – ***Myripristis jacobus***

(7) Rainbow wrasse – ***Coris atlantica***

(8) ***Gobius tetrophthalmus*** (endemic)

(9) ***Parablennius salensis*** (endemic)

(10) Cape Verde gregory – ***Stegastes imbricatus***

Figure 8

PHOTO OF FIELDWORK GROUP/STAFF – SANTA LUZIA SURVEY 2009

Top: Débora Querido (UniCV student), Antónia Rocha (Cook), Dário Évora (INDP diver - back), Nídia Silva (UniCV student), Eder Maurício (UniCV student), Mr. Engénio (Skipper), João Soares (UniCV Lab. technician), Livinio Tavares (SCUBA centre), Corrine Almeida (UniCV biologist - front), Carlos Ferreira (UFF biologist), Rui Freitas (UniCV biologist), Roberto Villaça (UFF benthologist), Carlos Rangel (UFF biologist - back) and Rámon Noguchi (UFF biologist).
Down: Jailson Andrade (SCUBA technician), Andreia Silva (UniCV student), Tommy Melo (Biosfera I biologist) and Sergio Floeter (UFSC biologist).