UNIVERSIDADE DO ALGARVE
FACULTY OF SCIENCES AND TECHNOLOGY

THE ROLE OF ARTIFICIAL REEFS TO PROMOTE BIODIVERSITY AND SUSTAINABILITY OF THE ECOTOURISM IN CAPE VERDE: ECOLOGICAL, BIOLOGICAL AND MANAGEMENT ASPECTS

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Thesis for the degree in Philosophy Doctor in Marine, Earth and Environmental Sciences, speciality in Marine Biodiversity

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UNIVERSIDADE DO ALGARVE
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O PAPEL DOS RECIFES ARTIFICIAIS NA PROMOÇÃO DA BIODIVERSIDADE E SUSTENTABILIDADE DO ECOTURISMO EM CABO VERDE: ASPECTOS BIOLÓGICOS, ECOLÓGICOS E DE ORDENAMENTO

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Abstract

This multidisciplinary study aimed to assess the impact of artificial reefs (ARs) deployment off Santa Maria (Sal Island), to promote biodiversity and sustainability of the ecotourism in Cape Verde. Local natural reefs (NRs) showed higher rugosity and structural complexity, with the benthic assemblages within Baía de Santa Maria presenting different structure and composition compared to ARs, but also between depth ranges. At lower depths the communities were characterised by low abundance and high species turnover, while at 25m depth the assemblages showed higher abundance and species richness and generally presented lower species turnover within each site. As regards the fish assemblages, similar number of species and mean densities were found, which demonstrates that decommissioned vessels can mimic the local NRs by supporting diverse fish assemblages similar to those from nearby natural habitats. Acoustic telemetry showed that the tagged *Cephalopholis taeniops* specimens remained in the ARs area for 44 days, denoting greater activity at night. A total of 8,328 specimens, belonging to 29 fish species across 14 families were sampled to estimate Weight-Length and Length-Length relationships for local reef fish species. Analytic hierarchy process (AHP) scrutinized stakeholders' perception on the best practice for marine biodiversity conservation, results showed that to submerge obsolete structures in rocky or mixed areas have a high potential, but does not gathers consensuality and seems that limitation of activities is the preferred management option to be consider. Willingness to pay (WTP) for the protection of local marine biodiversity through the creation of a trust fund showed that 32% of respondenst were unwilling to contribute and of those respondents who said they would be willing to contribute, 50% chose "fee" as the option where they were willing to pay less, whereas the "combined" option (i.e. including "donation", "fee" and "souvenir") was the one where respondents were willing to pay more, with around €1-7 and €0-800, respectively. ARs have promoted an increase in dive trips - acting as a complementary function to NRs. Nevertheless, local environmental campaigns and the promotion of the marine resources are fundamental to establish a relation between local population and the establishment of new activities (e.g. ecotourism) that can create new job opportunities and increase the income of local populations, a theoretical proposal was suggested, incorporating human and social dimensions into the management of scuba dive tourism in Sal, including Integrated Coastal Management (ICM) and Sustainable Tourism

Development (STD) in an integrative model and a species ID slates with diverse information on 124 species and four under water routes were also developed during the study. Furthermore, the AR should not be limited to decommissioned vessels, as more complex structures could possibly support the establishment of more species and providing them with a wide range of uses. On the other hand, the use of ARs should not be promoted indiscriminately, a community engagement and a management plan involving all the stakeholders is mandatory to avoid conflicts and maximize the extractive value of sustainable fishing along with other important economic values.

Keywords: Natural and artificial reefs; vessel reef; length-weight and length-length relationships; fish assemblages, macrofauna, Cephalopholis taeniops; habitat complexity, activity pattern, acoustic telemetry; AHP; CVM; WTP; economic analysis; diving tourism; marine biodiversity; conservation; Sal Island (Cape Verde).

RESUMO

Este estudo multidisciplinar teve como objectivo a avaliação do impacto da implantação de recifes artificiais (ARs) ao largo de Santa Maria (Ilha do Sal) na promoção da biodiversidade e da sustentabilidade do ecoturismo em Cabo Verde. Os recifes naturais (NRs) existentes evidenciaram uma maior rugosidade e complexidade estrutural. As comunidades bentónicas da Baía de Santa Maria apresentam composição e estrutura diferentes entre recifes naturais e artificiais e também entre diferentes profundidades. A baixa profundidade, as comunidades caracterizaram-se pela baixa abundância e uma alta variação nas espécies existentes, ao passo que a 25m de profundidade as comunidades mostraram maior abundância e riqueza de espécies e, genericamente, apresentaram menor rotatividade de espécies dentro de cada *site*. No que se refere às comunidades ictiológicas, observou-se um número idêntico de espécies e densidades médias, demonstrando que navios descomissionados podem imitar os NRs locais, dando suporte a comunidades ictiológicas semelhantes às dos habitats naturais próximos. A telemetria acústica mostrou que os espécimes de *Cephalopholis taeniops* marcados permaneceram na área dos ARs durante 44 dias, evidenciando uma maior actividade durante a noite. Um total de 8.328 espécimes, pertencentes a 29 espécies de peixes de 14 famílias, foram amostrados e estimaram-se as relações de peso-comprimento e de comprimento-comprimento de espécies de peixes de recife. Escrutinou-se a percepção dos utilizadores sobre as melhores práticas para a conservação da biodiversidade marinha na Ilha do Sal, com recurso ao processo analítico hierárquico (AHP - *Analytic Hierarchy Process*), tendo os resultados tornado evidente que o afundamento de estruturas obsoletas em áreas rochosas ou mistas parece ter um grande potencial, mas não reúne consenso, afigurando-se a limitação de actividades de mergulho como uma opção a considerar. O estudo da disposição para pagar (WTP - *willingness to pay*) a favor da protecção da biodiversidade marinha local através da criação de um fundo fiduciário mostrou que 32% dos inquiridos não se encontram dispostos a contribuir e, dos que afirmaram que estariam dispostos a contribuir, 50% escolheu "taxa" como a opção onde estão dispostos a pagar menos e a opção "combinado" (ou seja, incluindo "doação", "taxa" e/ou "lembrança") é a que recebe a maior disponibilidade para pagar pelos inquiridos, com aproximadamente 1-7€ e 0-800€, respectivamente. Os ARs têm promovido um aumento das saídas de mergulho, desempenhando uma função complementar à dos NRs. No entanto, campanhas ambientais locais e a promoção dos recursos marinhos são fundamentais para estabelecer uma relação entre a população local e a criação de novas actividades (e.g. ecoturismo) geradoras de novas oportunidades de emprego, contribuindo positivamente para a melhoria de vida das populações locais. Foi sugerida uma proposta teórica, incorporando as dimensões humana e social, para a gestão do turismo de mergulho na Ilha do Sal, num modelo integrativo de gestão costeira integrada (ICM) e desenvolvimento sustentável do turismo (DST). Um guia de identificação com diversas informações sobre 124 espécies e quatro percursos subaquáticos para mergulhadores foram também desenvolvidos durante o estudo. Os ARs não devem ser limitados a navios descomissionados, sendo que estruturas mais complexas poderiam apoiar o estabelecimento de um maior número de espécies e proporcionar-lhes uma ampla gama de utilizações. Porém, a utilização de ARs não deve ser promovida de forma indiscriminada - um envolvimento com a Comunidade e um plano de gestão, envolvendo todas as partes interessadas é fundamental para evitar conflitos e maximizar o valor extractivo e sustentável da pesca, juntamente com outros valores económicos importantes.

Palavras-chave: Recife Naturais; Recifes Artificiais; navio afundado; relações comprimento-peso e comprimento-comprimento; comunidade ictiológica; macrofauna; *Cephalopholis taeniops*; complexidade do habitat; padrões de actividade; telemetria acústica; AHP; CVM; WTP; análise económica; turismo; mergulho; biodiversidade marinha; conservação; Ilha do Sal (Cabo Verde).

Resumo Alargado

O turismo é a principal actividade económica de Cabo Verde, arquipélago onde predominam as ilhas de características desérticas, e que tem no mar os seus principais recursos. Por estes motivos, o mergulho com escafandro autónomo e a observação de fundos (*snorkelling* e embarcações de fundo de vidro) são actividades em grande expansão nalgumas das ilhas, daí resultando a necessidade de as promover de forma ambiental e economicamente sustentável.

A utilização de recifes artificiais tem vindo a generalizar-se ao longo dos últimos 30 anos, como resposta a problemas relacionados com os recursos costeiros e a biodiversidade, contribuindo, assim, para a implementação de planos de gestão e ordenamento de áreas marinhas.

Na costa Sul da Ilha do Sal (Baía de Santa Maria), o primeiro e ainda um dos principais pólos turístico de Cabo Verde, foram criados pelo Manta Diving Center e a Direcção Geral do Ambiente de Cabo Verde, dois recifes artificiais através do afundamento de dois navios - KWARCIT e SARGO, um arrastão soviético afundado a 6 de Janeiro de 2006 e um navio patrulha da Guarda Costeira da Marinha de Cabo Verde afundado a 28 de Abril de 2008, respectivamente. Estes passaram a constituir novos locais de mergulho, mas também novos habitats para um elevado número de espécies.

Inserido num projecto, iniciado em 2008, denominado *Rebuilding Nature – Criação de recifes artificiais em Cabo Verde*, o presente estudo, primeiro a ser realizado em Cabo Verde sobre o papel de recifes artificiais na promoção da biodiversidade e da sustentabilidade do eco-turismo em Cabo Verde, teve como principal objectivo a avaliação do impacto local dos recifes artificiais criados para promover a biodiversidade marinha e a sustentabilidade da indústria de mergulho em cabo Verde.

Uma equipa multidisciplinar de técnicos, que inclui especialistas Portugueses do *Instituto de Investigação das Pescas e do Mar* (IPMA, antigo IPIMAR), da *Universidade do Algarve* (FCT/CCMAR) e do *Oceanário de Lisboa*, instituições portuguesas com méritos reconhecidos internacionalmente, levou a cabo uma série de estudos, com o objetivo de 1) Caracterizar as comunidades macrobentónica e ictiológicas dos recifes artificiais e dos recifes naturais. A amostragem dos organismos macrobentónicos dos recifes foi efetuada com raspagens, efectuadas através de mergulho com escafandro autónomo. No que respeita à fauna ictiológica, a amostragem foi efetuada recorrendo também ao mergulho com escafandro autónomo e, considerando os objectivos, foram aplicadas as duas técnicas de observação *in situ*: i) s*pecies-time random count*, que permite obter informação relativa à estrutura e distribuição das populações ictiológicas e ii) transectos ao longo das estruturas recifais e a diferentes níveis de profundidade, durante os quais são efectuados censos, registando-se o número e dimensão dos peixes; 2) Comparar os povoamentos macrobentónicos e ictiológicos de recifes naturais com os de recifes artificiais, com recurso à utilização de mergulho com escafandro autónomo e às técnicas de amostragem já descritas; 3) Conhecer a dinâmica de utilização das estruturas recifais por parte de algumas das principais espécies ictiológicas com recurso a técnicas de telemetria com a colocação, em torno de um dos recifes artificiais, de uma rede de receptores e emissores implantados, através de cirurgia, nos peixes; 4) Avaliar os impactos sócio-económicos da implantação de recifes artificiais na promoção de ecoturismo subaquático em Cabo Verde. Neste sentido, foi analisada a base de dados de um operador turístico e elaborado um questionário, de modo a verificar que critérios têm prioridade no processo de escolha de um local de mergulho, e que tipo de local atrai a maior parte dos mergulhadores. Foi também efectuada a primeira caracterização sócio-económica do turista mergulhador da Ilha do Sal, Cabo Verde; 5) Endereçar medidas a serem estabelecidas pelos gestores, visando uma melhor conservação do meio ambiente e desenvolvimento sustentável do ecoturismo subaquático em Cabo Verde e 6) Produzir conteúdos para promover a consciência ambiental sobre a fauna e flora das águas de Cabo Verde.

Este trabalho fornece o primeiro estudo comparativo das comunidades ictiológicas e de macrofauna bentónica entre recifes naturais e recifes artificiais nas águas de Cabo Verde. Os recifes naturais existentes evidenciaram uma maior rugosidade e complexidade estrutural. As comunidades bentónicas da Baía de Santa Maria apresentam composição e estrutura diferentes entre recifes naturais e artificiais e também entre diferentes profundidades. A baixa profundidade, as comunidades caracterizaram-se pela baixa abundância e por uma alta variação nas espécies existentes, ao passo que a 25m de profundidade as comunidades evidenciaram maior abundância e riqueza de espécies e genericamente apresentaram menor rotatividade de espécies dentro de cada *site*. No que se refere as comunidades ictiológicas, observou-se número idêntico de espécies e densidades médias, demonstrando que navios descomissionados podem imitar os recifes naturais locais, dando suporte a comunidades ictiológicas semelhantes às dos habitats naturais próximos.

Na sequência das inúmeras amostragens dos organismos macrobentónicos, foi possível identificar um novo género e espécie da subfamília Caprellinae (Leach, 1814): *Mantacaprella macaronensis*. Segundo Vázquez-Luis *et al.* (2013) o termo *Mantacaprella* é dedicado ao Manta Diving Center (www.mantadivingcenter.cv) pela sua iniciativa de promoção dos recifes artificiais em Cabo Verde e do seu convite à equipa de investigadores que levaram a cabo o projeto *Rebuilding Nature*.

Com o recurso à telemetria acústica, demonstrou-se que os espécimes de *Cephalopholis taeniops* marcados com trabsmissores acústicos permaneceram na área dos recifes artificiais durante 44 dias, evidenciando uma maior atividade durante a noite.

Um total de 8.328 espécimes, pertencentes a 29 espécies de peixes de 14 famílias foram amostrados e estimaram-se as relações de peso-comprimento e de comprimento-comprimento de espécies de peixes de recife.

Escrutinou-se a percepção dos utilizadores sobre as melhores práticas para a conservação da biodiversidade marinha na Ilha do Sal, com recurso ao processo analítico hierárquico (AHP - *Analytic Hierarchy Process*), tendo os resultados tornado evidente que o afundamento de estruturas obsoletas em áreas rochosas ou mistas parece ter um grande potencial, mas não reúne consenso, afigurando-se a limitação de actividades de mergulho como uma opção a considerar. Em termos de recomendações de boas práticas para a gestão futura da actividade sustentável do mergulho, contribuindo para a conservação da biodiversidade marinha na ilha do Sal, propõem-se a promoção de maior protecção para os locais de mergulho do tipo rochoso e a utilização de estruturas obsoletas afundadas a fim de diversificar os locais de mergulho, aliviando a pressão exercida sobre os recifes naturais.

O estudo da disposição para pagar (WTP - *Willingness To Pay*) a favor da protecção da biodiversidade marinha local através da criação de um fundo fiduciário mostrou que 32% dos inquiridos não se encontram dispostos a contribuir e, dos que afirmaram que estariam dispostos a contribuir, 50% escolheu "taxa" como a opção onde estão dispostos a pagar menos e a opção "combinado" (ou seja, incluindo "doação", "taxa" e/ou "lembrança") é a que recebe a maior disponibilidade para pagar pelos inquiridos, com aproximadamente 1-7€ e 0-800€, respectivamente. Uma limitação deste estudo foi a indefinição sobre a forma futura como o fundo de conservação da biodiversidade seria usado. A clarificação e transparência na comunicação destas premissas parece de importância fundamental para fornecer informações adicionais aos inquiridos.

Os recifes artificiais contribuíram para um aumento em viagens de mergulho, actuando de forma complementar aos recifes naturais. Os resultados indicam que os mergulhadores poderiam ser desviados dos recifes naturais para as estruturas artificiais de modo a aliviar a pressão por eles exercida nos primeiros, encontrando-se estes disponíveis para colaborarem com uma taxa monetária de baixo valor económico para suportar os esforços de conservação.

A criação de recifes artificiais não deve ser limitada a navios descomissionados, já que estruturas mais complexas possibilitariam a fixação de outras espécies de maior valor económico e também a o ferta de uma ampla gama de utilizações. No entanto, a utilização de recifes artificiais não deve ser promovida de forma indiscriminada: um envolvimento com a comunidade e um plano de gestão, envolvendo todas as partes interessadas é aconselhável, de modo a evitar futuros conflitos e maximizar o valor do ecoturismo subaquático, da pesca sustentável e outros valores económicos importantes.

Campanhas ambientais locais e a promoção dos recursos marinhos são fundamentais para estabelecer uma relação entre a população local e seus recursos de valor real, razão pela qual foram elaboradas diversos suportes de comunicação e sensibilização. Entre outros, destaca-se: i) o livro *Sob os Mares de Cabo Verde,* publicado em 2008; ii) o *Guia de Identificação Subaquática* das principais espécies susceptíveis de serem avistadas pelos mergulhadores nas águas de Cabo Verde, publicado em 2009, no qual, para além das fotos das espécies e respectivo nome científico e comum, se apresenta compilada muita informação sobre aspectos relevantes da fauna e flora e iii) publicação, em 2013, dos roteiros de 4 dos principais locais de mergulho na Ilha do Sal – Kwarcit, Sargo, Três Grutas e Tchuklassa – que, para além da caracterização dos locais de mergulho, incluem alguns percursos subaquáticos, previamente definidos, com indicação dos locais para observação de aspectos relacionados com a fauna e flora do local.

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Oliveira M.T., Santos M.N., Coelho R., Monteiro V., Martins A., Lino P.G., 2015. Weight–length and length–length relationships for reef fish species from the Cape Verde Archipelago (tropical north-eastern Atlantic). *Journal of Applied Ichthyology*, 31: 236-241.

PAPER 2 (CHAPTER II)

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PAPER 3 (CHAPTER IV)

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PAPER 4 (CHAPTER V)

Ramos J., Oliveira M.T., Santos M.N., 2011. Stakeholder perception of decision making process on marine biodiversity conservation on Sal Island. *Brazilian Journal of Oceanography*, 59: 95-105.

PAPER 5 (CHAPTER VI)

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PAPER 7 (CHAPTER VII)

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INTRODUCTION AND OBJECTIVES

INTRODUCTION

Tourism is the main economic activity in Cape Verde, a country where tourism of masses has been privileged and depends on sun-and-sea products, not always taking into account concerns such as environmental sustainability and the quality of life of the local communities. Being an Archipelago where the islands of desert-like characteristics predominate, the sea is one of its main resources.

Nowadays, the product "sun-and-sea" is not by itself enough to attract the tourists, who have become more demanding and are constantly looking for complementary activities. For this reason, scuba diving is an activity with great expansion in the Archipelago of Cape Verde. However, marine biodiversity is undergoing a decline, as a result of an intense and uncontrolled fishing activity (Anonymous, 2004a), which causes the loss of the marine habitats' quality, normally visited by the eco-tourists. Thus, the sustainability of the scuba diving industry will only be viable with an inversion of this scenario, through the promotion of biodiversity and a regulation of the coastal activities.

It was in this scenario that the Manta Diving Center, one of the first diving centres in the country, and the Authorities of Cape Verde (Environmental Ministery) sunk two vessels off Santa Maria Bay, in Sal, the main island of the Archipelago with regard tourism activities. The first of these vessels, KWARCIT, an old Soviet fishing trawler, was sunk on the 6th of January, 2006 (Figure 0.1). On the 28th of April 2008, SARGO, an old Cape Verde Coast Guard patrol ship was also sunk (Figure 0.2).

Figure 0.1. Kwarcit – Deployment day (©Manta Diving Center)

Figure 0.2. Sargo P621 – Deployment day (© Miguel Tiago de Oliveira)

Consensual as it is, the notion that knowledge of biodiversity in areas of implementation of ecotourism is essential for its sustainable management (Lim and McAleer, 2005). Nonetheless, the information on marine biodiversity is scarse and dispersed in Cape Verde (Stromme *et al.*, 1981; Reiner, 1996; Wirtz and d'Udekem-d'Acoz, 2001; Vakily *et al.*, 2002). As highlighted in the National Environment Plan (anonymous, 2004a), one of the priorities is the maintenance of marine biodiversity, focusing on the improvement of knowledge on marine species in general (INMG, 2010), with an emphasis on the endagerous and endemic species and on a more rational management of coastal edges.

With two decades of accumulated experience in diving in Cape Verde and perfectly aware of the need to contribute positively to provide quick answers to the above mentioned issues, Manta Diving Center gave a first step in this direction, launching the Rebuilding Nature Project - *Creation of artificial reefs in Cape Verde*. This project was the result of the agreement between the Cape Verde Environmental General Direction and Manta Diving Center for studying the Santa Maria Bay artificial reefs. To fulfil this task, a team was set up composed of experts of internationally recognized merit in the marine resources domain.

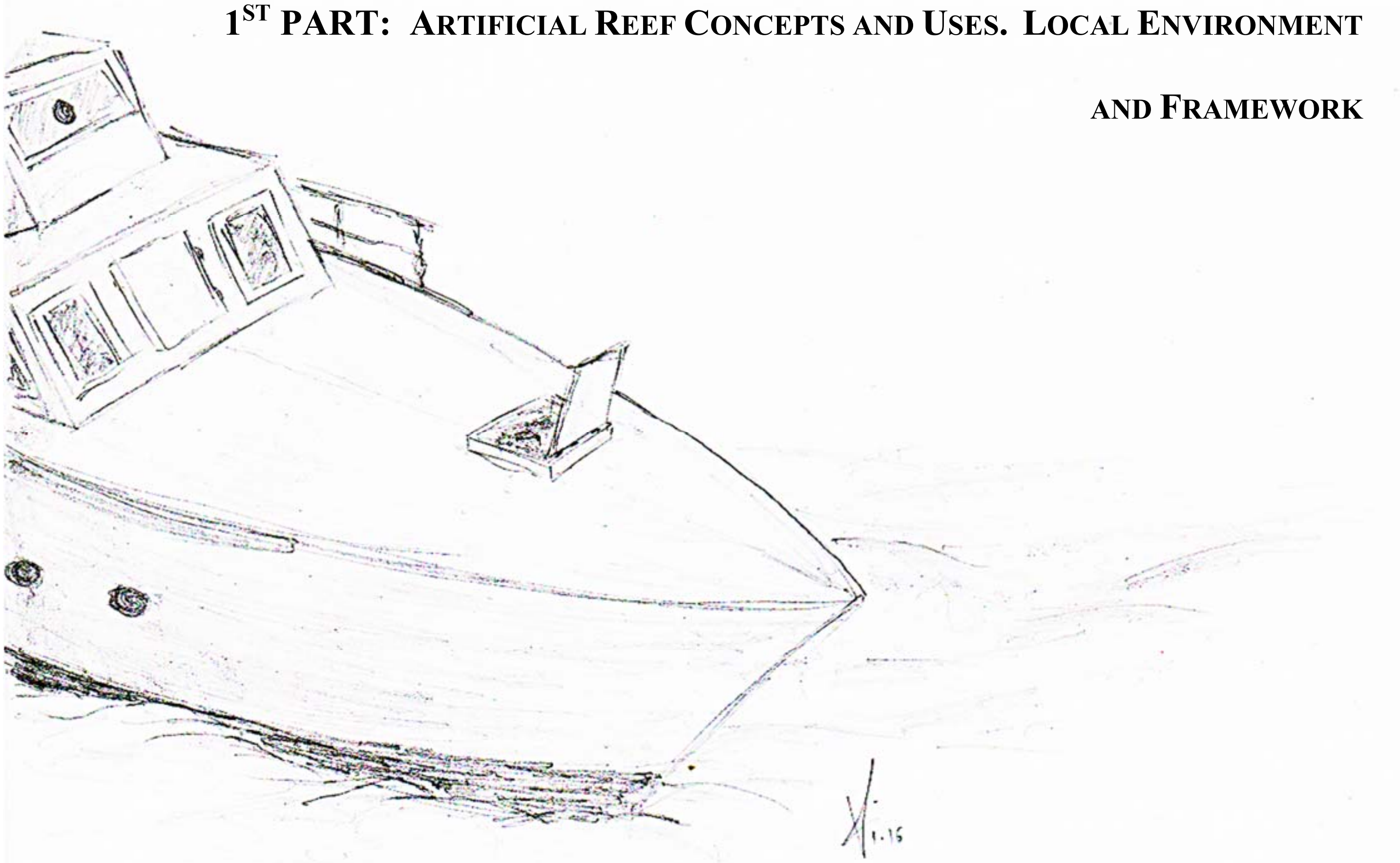
The Rebuilding Nature project aimed to improve the knowledge on the above mentioned aspects, namely to describe in detail the existing biodiversity and to evaluate the role that artificial reefs could play in Cape Verde, as currently occurring in several regions of the globe, where scuba diving is an important source of income. Furthermore, this project also aimed to study the marine related activities ongoing in Santa Maria Bay (Authorities, divers and fishing users, diving centres and general public), as a tool not only to reach the considered objectives, but also to guarantee the effectiveness of the coastal management proposals addressed.

OBJECTIVES

The main objective of this Thesis is the evaluation of the role of artificial reefs to promote marine biodiversity and sustainable ecotourism in Cape Verde. Additionally, a number of proposals related to management measures for the development of local diving ecotourism activities were also addressed. In this sense, the work developed was of a multidisciplinary nature, addressing the following specific objectives:

- ⇨ better understand the colonisation process of the artificial reefs, in terms of the macro benthic and ichthyologic communities;
- ⇨ compare the macro benthic and ichthyologic communities of a natural reef with those of the artificial reefs;
- ⇨ study the dynamics of use of artificial reefs structures for some of the most important fish species;
- ⇨ evaluate socio-economic impacts of artificial reef deployment in the promotion of underwater ecotourism in Cape Verde;
- ⇨ address measures to be established by coastal managers, aiming at improving environmental conservation and sustainable development of underwater ecotourism in Cape Verde;
- ⇨ produce contents for local environmental campaigns to promote the environmental conscience concerning fauna and flora in the Cape Verde waters.

1ST PART: ARTIFICIAL REEF CONCEPTS AND USES. LOCAL ENVIRONMENT AND FRAMEWORK



CHAPTER I

Artificial Reef Concepts and Uses.

Local Environmental and Framework.

1.1 ARTIFICIAL REEFS: HISTORY, CONCEPTS AND APPLICATIONS

1.1.1 Introduction

Physically stable structures, when submerged underwater, demonstrate a capacity to attract marine organisms. Over time, these structures may even mimic the characteristics displayed by naturally occurring reef systems of either coral or rock composition. Frequently referred to as artificial reefs, such structures occur worldwide in coastal waters.

The first use of artificial reefs could have happened in any place with a fishing tradition. However, the Japanese appear to be the first nation to systematically record reef building activities, beginning around the late 18th century (Santos, 1997). Nowadays, managed examples can be found all over the world, with submerged structures varying significantly according to their origins, morphology, complexity, purpose, composition, immersion depth and – if deliberately sunk – deployment costs (Stolk and Markwell, 2007).

Scientific research indicates that there are significant benefits of artificial reefs´ establishment (Whitmarsh *et al*, 2008), although there is some debate about whether they attract fish from surrounding areas, thus causing a concentration in one area, or truly contribute to enhanced production (Pickering and Whitmarsh, 1997).

By attracting marine species, artificial reefs also attract snorkling and diving enthusiasts seeking new experiences. Marine tourism and recreational activity is a rapidly increasing phenomenon (Orams, 1999), and many artificial reefs have significant potential for use as recreation resources. Artificial reefs have not been widely promoted as recreational resources (Seaman and Jensen, 2000), and most research on artificial reefs has focused mostly on reef ecology and structure.

The experiences provided by diving on and around artificial reef structures are valued by many divers (Stolk *et al.*, 2005) and recreational dive operators can benefit greatly from artificial reef development. Positive feedback from scuba divers, the demand for more artificial reef sites (Morgan *et al.*, 2009), and the opportunities that arise from related tourism development are some of the factors that have contributed to the growing interest in the deliberate creation of artificial reefs around the world.

According to Sportdiver (2015), of the world's 50 best wrecks, 16 are vessels deliberately deployed as AR (Table 1.1). These vessels are often important ecosystems for the organisms that inhabit them, providing as well a god provocative and commercial story telling for SCUBA promoters. SCUBA divers expect ARs to provide an enjoyable, visually appealing and high biodiversity dive (Tessier *et al*, 2015). These results were corroborated across several international studies on ARs and particularly applied to shipwreck sites (Ditton *et al*., 2002; Shani *et al*., 2012; Kirkbride-Smith *et al.*, 2013).

Table 1.1. Name, description, location, date, depth and ranking for the best deliberately deployed AR wrecks in the world in 2015 according to Sportdiver (2015).

AR Name	Description	Location	Deployed as AR	Depth (m)	Rank
HMNZS Waikato	Leander-class frigate was once part of the Armilla patrol during the Falklands conflict	Tutukaka Coast of Northland, New Zealand	2000	29.8	1
Carthaginian II	A whaling-vessel replica served for more than 20 years prior as a floating museum, examining Lahaina's old whaling days.	Maui, Hawaii	2005	28.9	6
M/V Pacific Gas	65 meters long vessel	Papua New Guinea	1986	43.5	7
Sea Tiger	Originally apprehended carrying 93 illegal Chinese immigrants, the Sea Tiger now sits just a short boat ride away from Waikiki Beach	Oahu, Hawaii	1999	24.3	15
El Aguila	The 70 meters long former freighter, El Aguila, was intentionally sunk off Roatan's north shore in 1997. One year later, Hurricane Mitch ripped it apart.	Roatan	1997	33.5	21
SS Stavronikita	a 110 meters long Greek freighter	Barbados	1978	39.6	29
C/V Charles L. Brown	"Charlie Brown" is the farthest dive site from St. Eustatius' coast	Statia	2003	-	31
C-53	Also known as the Felipe Xicotencatl, it's a 56m vessel	Cozumel	1999	24.9	32
Hilma Hooker	A former drug-smuggling vessel	Bonaire	1984	30.4	33
Um El Faroud	109 meters long tanker	Malta	1998	35	39
HMCS Saskatchewan	A 111meters battleship	British Columbia	1997	24.4	42
USS Oriskany	With 270 meters long, it's the world's largest artificial reef	Florida	2006	26	43
Lulu	A 82 meters freighter	Alabama	2013	35	45
HMCS Cape Breton	A 111meters Mackenzie class destroyer that served in the Royal Canadian Forces	British Columbia	1997	39.6	46
USNS Gen. Hoyt S. Vandenberg	A 158 meters long decommissioned U.S. Air Force missile-tracking ship	Florida	2009	39.6	48
Spiegel Grove	The massive 510-foot-long amphibious warfare ship once carried 330 troops, 18 officers and eight helicopters.	Florida	2002	25	49

Better understanding divers' attitudes, perceptions and satisfaction levels with regard to artificial reef environments is important in order to adequately plan for sustainable tourism and recreation in the future to avoid past examples like Hurghada on the Red Sea (Egypt) where rapid, unplanned tourism development has negatively impacted popular coral reefs through problems like sedimentation and eutrophication (Hawkins and Roberts, 1994; Jameson *et al.*, 2007).

Artificial reefs, if properly planned, designed and managed, may support diverse fish assemblages similar to those from nearby natural habitats (Santos *et al*, 2013) and improve the supply of marine resources available to diving enthusiasts.

1.1.2 History

Information concerning the specific origins of artificial reef development is vague in detail and authors believe that at some point in time ‘ancient’ people, perhaps thousands of years ago, discovered that foreign objects placed in or under the water attracted marine life (Stone *et al.*, 1991a; Seaman and Jensen, 2000). According to Ino (1974), in the Kansei era (1789-1801), a fisherman of the Awaji Island (Japan), while fishing with a *gochi-ami* (semi-surrounding seine net for catching breams), caught by chance several thousand yellow spotted grunt around a sunken ship. Some years later, after the sunken ship had deteriorated and the fish stopped schooling around it, the Awaji Island´s fishermen made large wooden frames mounted with bamboo, sandbags and wooden sticks and sank them on the sea bed. A few months later fishermen caught a greater amount of fish than they used to catch around the sunken ship. According to Santos (1997) the first artificial reef had been constructed and deployed, and several hundred of these structures were built in the 10 year period that followed.

Artificial reefs are widely used, and for numerous purposes, such as mitigating environmental impacts (Hueckel *et al.*, 1989; Ambrose, 1994). The placement of artificial reefs in modern times is motivated by more than just improvement of fishery harvests. Recreational fishing and diving, environmental restoration, natural resource management and scientific experimentation are now common motivations behind artificial reef developments (Seaman and Jensen, 2000). Despite the inexistence of a formal database to track or register global development of artificial habitats (Stone *et al.*, 1991b), USA, Japan and Europe are the major sources of artificial reef research and development in the world (Seaman, 1987; Coutin, 2001) and Canada has also been an active artificial reef developer, particularly for the disposal of vessels as artificial reefs. The Canadian government is well recognized for its leadership in the creation of environmental controls for artificial reef projects. However, the USA could be regarded as the world leader in the development of artificial reefs for marine-based recreation. Its south and south-eastern states, such as Florida, Texas and Louisiana, have had long term interests in artificial reefs and are particularly advanced in terms of the number of structures deployed, enacted legislation and related regulatory arrangements, management practices and research efforts (McGurrin *et al.*, 1989).

1.1.3 Reef Concepts and Definitions

1.1.3.1. Natural reefs

A natural reef is usually defined as a rocky formation on the seabed that can reach the surface. Reefs can be formed by any kind of rock, but generally consist of calcareous rock with a biogenic origin. The most familiar type of natural reef, however, is the coral reef and the most famous is probably the great Coral Barrier Reef in Australia. There are reefs of all possible shapes and sizes all over the world. Reefs modify the hydrological environment in such a way that their influence extends a considerable distance into the water column above (Wolanshi and Hammer, 1988).

Coral reefs are slowly declining around the globe (Wilkinson, 2004). Over 19% of reefs worldwide have disappeared in the last 60 years, and it is presumed that 20% of the world's remaining reefs, which are currently considered threatened, may be lost by the year 2050 (Wilkinson, 2004). Reef decline can be attributed to a range of causes (reviewed in Dubinsky and Stambler, 2011), such as outbreaks of coral predators, like the crown of thorns starfish- *Acanthaster planci* - (Bellwood *et al*., 2004) or the corallivorus gastropod – *Drupella cornus* - (Shafir *et al.*, 2008), or due to coral diseases (Santavy *et al*., 2005), severe storms, and tsunamis (Wilkinson *et al*., 2006), or to indirect stressors, such as climate change (Hoegh-Guldberg *et al*., 2007). Acording to Polak and Shashar (2012) part of the decline of coral reefs is attributed to the physical damage caused by divers and consequently, active efforts are made to mitigate the diving pressure on and around natural reefs.

1.1.3.2. Artificial Reefs

The term *artificial reef* is widely used in many publications but there are notable inconsistencies as to precisely determining which structures are suitable for inclusion or exclusion from this term (Pickering *et al.*, 1999). Distinctions are often made based on how the structure arrived in the marine environment. Under some definitions, shipwrecks, for example, are not considered artificial reefs because they were not intentionally sunk. This is despite the fact that they will emulate certain characteristics of a natural reef in just the same way as that of a vessel that has been deliberately sunk.

Seaman and Sprague (1991) use *artificial habitat* rather than artificial reef. A*rtificial habitat* has been generally used to classify any man-made structure deliberately or accidentally deployed in the aquatic environment. These include fish aggregating devices (FADs) and artificial reefs.

Fish Aggregating Devices (FADs) are permanent, semi-permanent or temporary structures or device made from any material and used to lure fish (FAO, 2005-2016 a) and are used widely in tropical and semitropical waters by recreational, artisanal and commercial fishers, to concentrate pelagic fish for capture. While artisanal fishers have known and used such associations for hundreds of years (e.g., Japan, Kakuma, 2000) to thousands (e.g., Mediterranean Sea, Morales-Nin *et al.*, 2000), largescale industrial fishing around FADs developed in the latter part of the 20th century (Fonteneau *et al.*, 2000).

Typical FADs (Figure 1.1) are manufactured from man-made materials, consisting of plastic or nylon streamers or mesh, framed in pieces of polyvinyl chloride (PVC) pipes, attached to line with an anchor at one end and a surface or mid-water float at the other (Grove *et al.*, 1991). Most FADs are short-lived, usually breaking away from their moorings within a matter of weeks to months (Buckley *et al.*, 1989). However, more recently, the life expectancy of a FAD has become greater if proper ocean engineering expertise and related technology are used for the construction of the mooring line (which must be strong and exclude risk of snags and kinks), for the surface buoys and structure (for easy location, day and night, easy avoidance by large vessels, but also to make theft more difficult) (FAO, 2005-2016a). According to Mottet (1981) some Japanese designs have an estimated structural lifespan of 15 years.

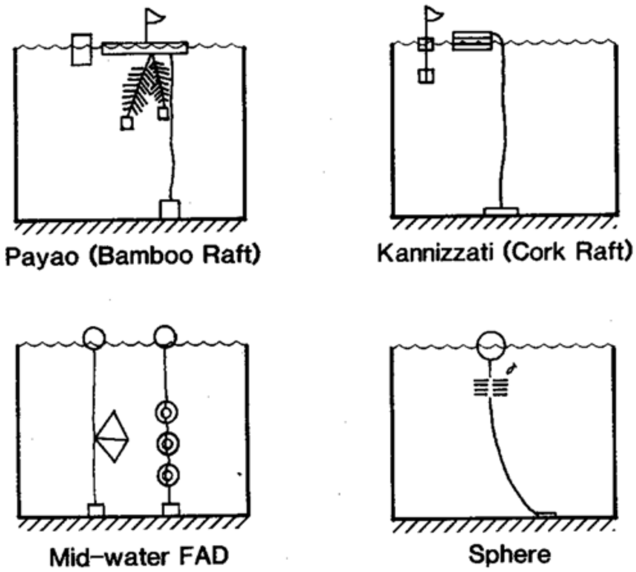


Figure 1.1. Representative examples of widely used fish aggregating devices (from Seaman and Sprague, 1991).

The bottom structures are commonly referred to as artificial reefs, but there is no universally accepted definition of an artificial reef and several definitions have been adopted. According to the FAO (2015-2016b) artificial reefs are structures, installations or constructions made by man and placed on the sea bottom to aggregate fish. Most artificial reefs are large, permanent structures set in rather shallow water. Artificial reefs are established for various purposes:

i) to enhance resources in coastal waters in order to facilitate exploitation;
ii) to create a biological reserve;
iii) to prevent the use of certain fishing gear, particularly bottom trawls, in a given area.

Table 1.2. presents definitions of artificial reefs along with the particular perspectives through which the definitions were developed and applied. For the purpose of this thesis, artificial reefs will be examined in the context of the definition given by Storrie *et al.* (2003) because of its more inclusive application to recreational activities around such reefs and across many different settings.

Table 1.2. Artificial reef definitions overview (Adapted from Stolk *et al*, 2007)

Author (Year)	***Definition***
Thierry (1988)	"…based on the evident analogy with natural reefs, the artificial reefs are artificially built structures installed in the sea area, intended for fisheries productivity enhancement"
Seaman and Sprague (1991)	Marine artificial reefs intend mimicking natural reefs at least by providing relief on flat, featureless ocean bottoms - and include concrete or steel modules, frames and other structures made to create design specifications; natural products such as quarry rock; and scrap man-made items including concrete culverts or other building materials (e.g., bridge demolition rubble); and steel structures such as storage tanks, petroleum production platforms and ships.
EARRN, see Jensen (1997) as cited in Pickering *et al.* (1999)	An artificial reef is a submerged structure placed on the substratum (seabed) deliberately, to mimic some characteristics of a natural reef.
Seaman and Jensen (2000)	An artificial reef is one or more objects of natural or human origin deployed purposefully on the seafloor to influence physical, biological or socioeconomic processes related to living marine resources. Artificial reefs are defined physically by the design and arrangement of materials used in construction and functionally according to their purpose.
Coutin (2001)	An artificial reef is a structure placed on the bottom of the sea, estuary or river for the purpose of modifying the existing habitat. It is a form of habitat alteration that is intended to enhance the aquatic environment for a particular purpose.
Storrie *et al.* (2003)	An artificial reef is any man-made structure that is colonised by plant and animal communities resembling those of a naturally occurring reef. Artificial reefs include scuttled vessels and other objects placed on the seabed, or any structure that extends offshore such as breakwaters, pipelines or even jetties.
Hynes *et al.* (2004)	An artificial reef is anything placed on the near-shore sea bottom out to a depth of about 200 meters whose purpose is to stimulate fish production or (at near-shore depths) serve as an attraction to divers.
OSPAR COMMISION (1999) and UNEP MAP (2005)	An artificial reef is a submerged structure deliberately placed on the seabed to mimic some functions of a natural reef such as protecting, regenerating, concentrating and/or enhancing population of living marine resources".

A constant in the more ecologically based definitions is the stipulation that a structure must be intentionally deployed to be considered an artificial reef. The separation of intentionally versus unintentionally sunk structures might be warranted where fishery, aquaculture or scientific organisations seek to manage a system of submerged structures. However, recreational use of artificial reefs seems to occur regardless of how or why the structure originated.

Grove and Sonu (1986) described 68 different varieties of reef modules, but more than 100 are currently in use in Japan (Santos, 1997). Reef modules of new shapes are continuously being introduced, and it is almost impossible to keep track of them all. According to the AGSMFC - Atlantic and Gulf States Marine Fisheries Commissions (2004), general criteria for materials that are to be used in the development of artificial reefs, including function, compatibility, durability and stability, and availability are being adopted in long term National Artificial Reef Plans. Nowadays, the use of ARs are consensual and received general acceptance in over 50 nations for practical purposes, including as platforms for rigorous ecological experimentation (Seaman *et al*, 2011). Some typical artificial habitats are depicted in Figure 1.2.

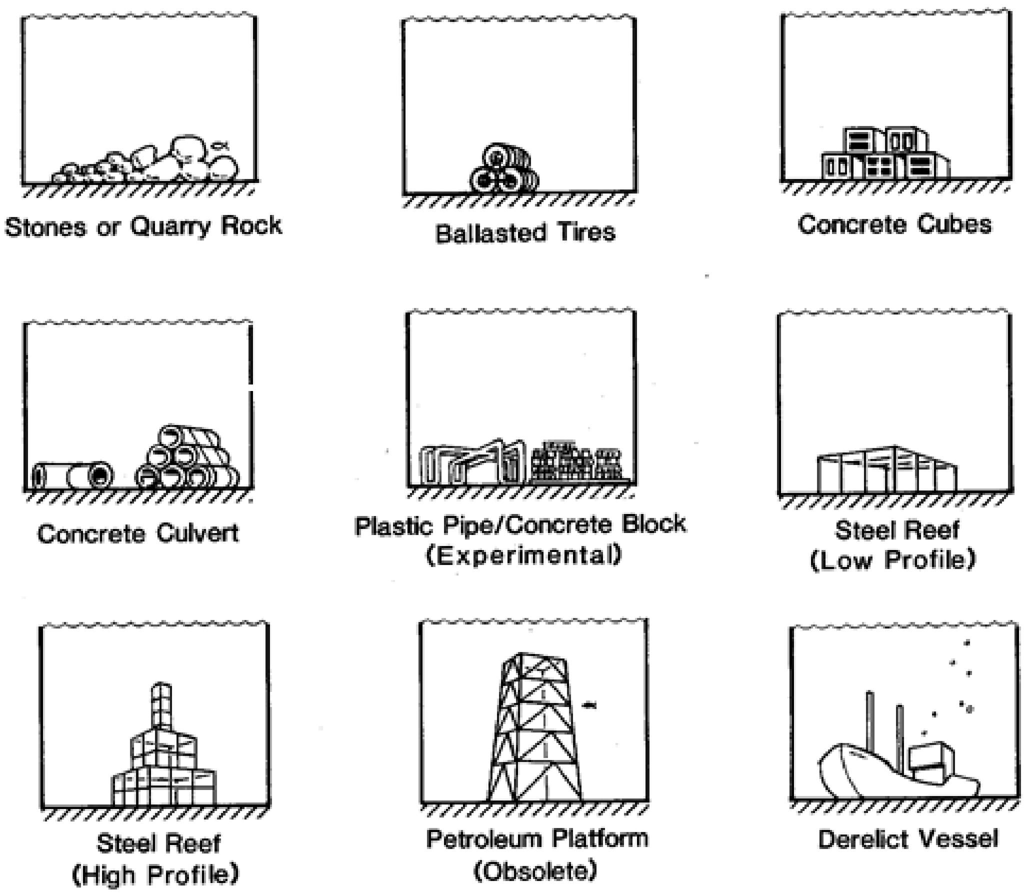


Figure 1.2. Materials commonly used for the deliberate creation of artificial reefs and approximately ordered in terms of site complexity (Adapted from Seaman and Sprague, 1991).

1.1.4 Artificial reef materials

Overtime there has been an effort to develop guidelines for AR materials. The 1997 and 2004 guidelines compiled by the Artificial Reef Subcommittee of the Technical Coordinating Committee Gulf States Marine Fisheries Commission and the Artificial Reef Subcommittees of the Atlantic and Gulf States Marine Fisheries Commissions, respectively, are examples of such publications aiming to improve materials selection for use in the development of marine artificial reefs, providing future AR developers with information that will increase the potential for successful efforts at habitat creation and enhancement.

Most early artificial reef development efforts were accomplished by volunteer groups interested in increasing fishing success. It was widely held that artificial reefs were successful; consequently, deployment of materials took a higher priority than other activities such as planning, research, and experimentation with various materials, including designed structures (Bohnsack, 1987).

Originally, ARs were deployed in restricted and shallow waters, and were made of natural materials such as bamboo, branches and rocks (Delmendo, 1991). According to McGurrin *et al.* (1989) in the Gulf of Mexico, ARs were constructed as early as the 1950s off Alabama. From that time to the present, over 80% of artificial reefs in United States waters have been created using secondary use materials. Secondary use materials include such natural materials as rock, shell, or trees, and such man-made materials as concrete, ships, barges, and oil and gas structures, among others. These materials are still in use in some regions, being used without assembly or significant modification (Bojos and Vande Vusse, 1988; DeMartini *et al.*, 1989; Spanier, 2000; Jensen, 2002).

Experimentation and small-scale deployment of specifically designed artificial reef structures for nature conservation purposes started in the late 1960s, with Monaco the European pioneer (Allemand *et al*, 2000) and in the late 1970s in the United States (McGurrin *et al.*, 1989), and continuing to the present. While secondary use materials are still used in the majority of artificial reef construction projects, several coastal states have, in recent years, begun utilizing designed reef structures to carry out artificial reef development objectives McGurrin *et al.* (1989).

Man-made materials have allowed the assembly of larger structures using: industrial waste combustion by-products (from fossil fuel-fired electricity generating plants) such as a mix of fly ash with fuel-gas desulfurisation scrubber sludge (Jensen *et al.*, 1994; Jensen, 2002); derelict vessels (Lindquist and Pietrafesa, 1989; Stephan and Lindquist, 1989; Santos *et al.*, 2013); military tanks (Heins, 1995); retired aeroplanes (Fritz, 1994); old toilets (Weisburd, 1986); car tires (Braden and Reimers, 1994; Reimers and Branden, 1994; Jensen, 2002); old offshore platforms (Bull and Kendall, 1994; Texas Parks and Wildlife, 1996); among others.

Research has lead to the development of more efficient but much more expensive reef structures such as blocks with special shapes and volumes suitable for specific environments (Santos, 1997). These involve the use of new materials such as: concrete (Hagino, 1991; Relini *et al.*, 1994; Monteiro *et al.*, 1994; Nelson *et al.*, 1994; Santos and Monteiro, 1997;

Relini, 2000a; Relini, 2000b; Falace and Bressan, 2000; Barnabé *et al*, 2000); plastic (Moffitt *et al.*, 1989); ceramic (Grove and Sonu, 1986); fiber (Moffitt et al., 1989; Allemand et al, 1995); iron and steel (Grove and Sonu, 1986; Sánchez-Jerez and Ramos-Esplá , 2000). In figure 1.3 and 1.4, some examples of reef modules and pictures of some deployed structures are shown.

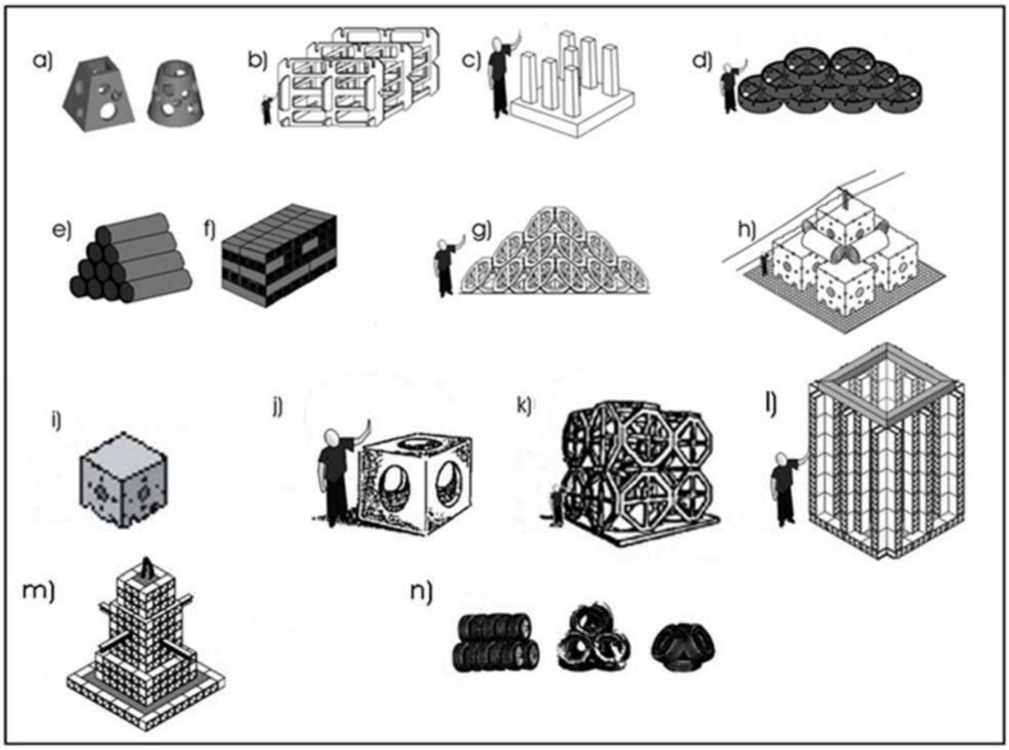


Figure 1.3. Examples of modules employed for artificial reef construction in Europe. a) Cyprus; b), c) France; d) Germany; e), f) Greece; g), h) Italy; i) Poland; j), k) Portugal; l), m) Spain; n) United Kingdom (From Fabi *et al.*, 2011).

The most recent advances in this domain are related to the research and development of new materials for artificial reef construction, because the high cost of such man-made materials does not allow a general use in artificial reefs. The use of opportunity materials for artificial reef construction is still an alternative, once problems related with pollution, efficiency and functioning are overcome at low cost.

Nevertheless, materials acceptable in the past are nowadays no longer an option. According to Sherman and Spieler (2006) unstable materials, such as tires, are not suitable for artificial reef construction and, if already deployed, should be removed to prevent physical damage to the natural habitat and to reduce the related negative biological impacts, in turn, limiting economic loss to local communities benefiting from use of the natural reef.

The investigation into environmentally acceptable waste materials may well serve to reduce building costs and resolve recycling issues in the terrestrial environment. New applications may be expected in areas where reef-based SCUBA diving, angling, or surfing can be developed.

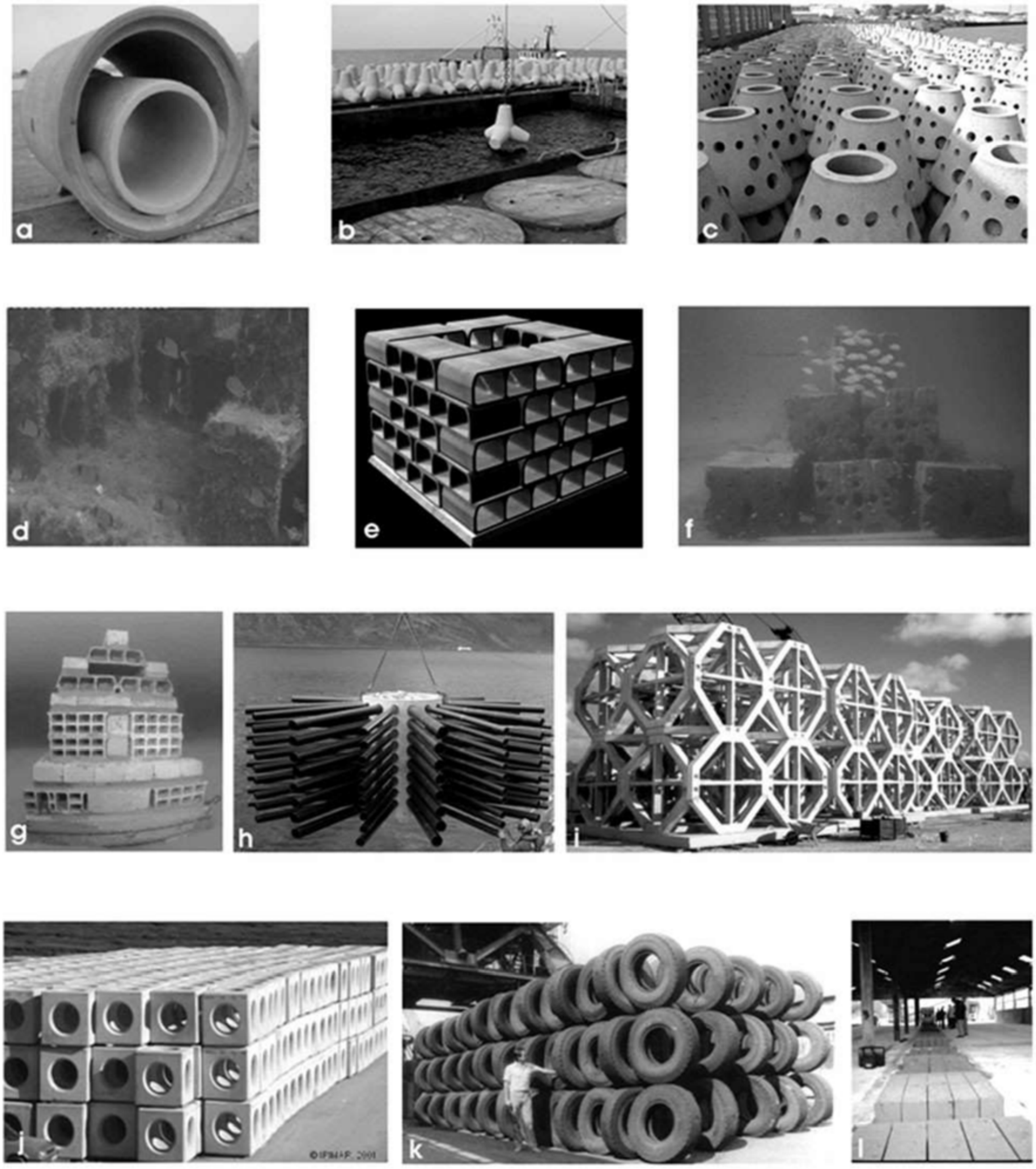


Figure 1.4. Pictures of some artificial structures deployed in European Seas (From Fabi *et al.*, 2011). a) Languedoc-Roussillon, France; b), c) Nienhagen, Germany (manhole rings, from Nickels *et al.*, 2006); d), e) Greece; f) Sicily, Italy; g) Larvotto Reserve, Monaco (www.gouv.mc); h) Nordfjorden, Norway (from HARTVIG, 2007); i) and j) Algarve, Portugal; k) Odessa, Ukraine (from Collins, www.soes.soton.ac.uk); l) Pool Bay, United Kingdom (from Collins, www.soes.soton.ac.uk).

1.1.5 Artificial reef structure and classification

The overall size of the reef, can be classified (Figure 1.5) in ascending order of size: reef unit, reef set, reef group, and reef complex/system (Grove *et al.*, 1991) and measured in volume or footprint, is another component of both natural and artificial reefs that has received attention due to its influence on fish assemblage structure. Assuming other factors are equal (e.g., rugosity, temperature, current, depth), with natural reefs a larger reef can potentially support more individuals and species than a smaller reef, but, depending on spatial scale, a smaller reef may have a higher fish density and a more diverse assemblage per volume (Gladfelter *et al.*, 1980 and Chittaro, 2002). Likewise, increases in fish abundance and species richness as a function of reef size have also been demonstrated on artificial reefs (Schroeder, 1987 and Molles, 1978). Further, larger fishes and higher biomass values often occur on larger, versus smaller, artificial reefs (Bohnsack *et al.*, 1994). But again, smaller artificial reefs may have greater fish richness and abundance per volume (Bohnsack *et al.*, 1994). This fact becomes an important consideration in surveying natural reefs as well as determining restoration scenarios. Presumably, a reef tract with patchy complexity (patch reefs, natural or artificial) could have higher fish richness and abundance than a much larger reef tract lacking such patchiness (Nanami and Nishihira, 2002), nevertheless reef size and isolation should be considered as habitat attributes capable of altering the structure and dynamics of reef fish assemblages (Jorden *et al.,* 2005).

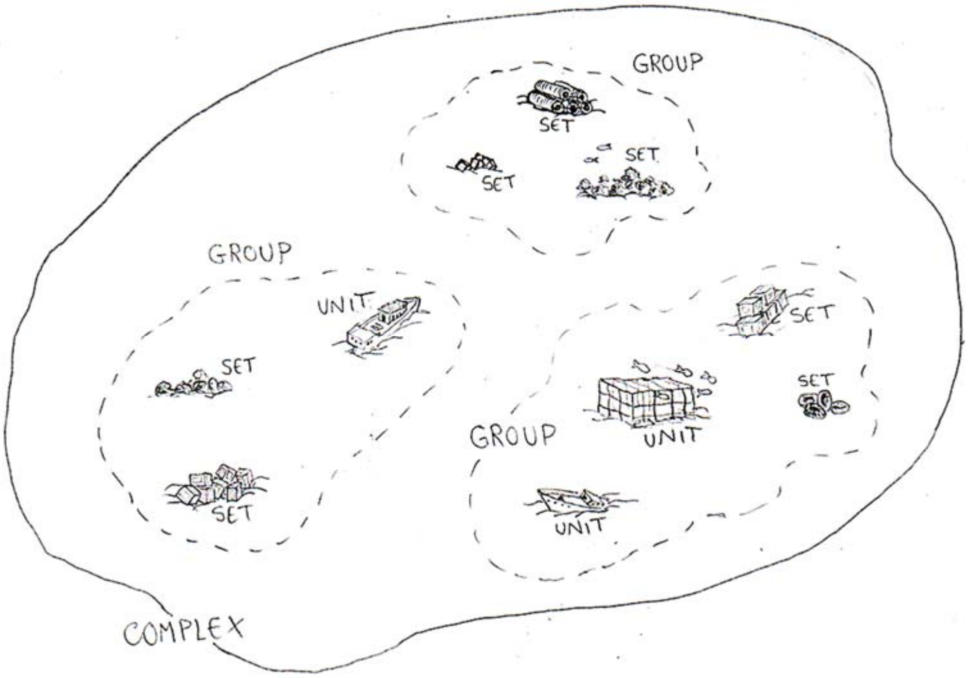


Figure 1.5. Hierarchy of Japanese reef deployment (© Gonçalo de Melo Oliveira, adapted from Grove *et al.*, 1991).

1.2 LOCAL ENVIRONMENT AND FRAMEWORK

1.2.1 Introduction

Here we characterise the coastal area where the artificial reefs of this study were deployed. We briefly describe the most important characteristics of the areas of reef deployment in the Santa Maria, Sal coastal waters. It is important to note that since there are few scientific reports on oceanographic data for the Cape Verde Islands, it was not possible to make a complete characterisation of this area.

1.2.2 Cape Verde - The territory characterization

The archipelago of Cape Verde is situated between the parallel 17° 12 ' and 14° 48 ' North and meridians 22° 44' and 25° 22' West (Figure 1.6). The country is composed of ten Islands, nine of which are inhabited, and several uninhabited islets, divided into two groups related with its location on the prevailing winds:

i) Windward, the North group is composed from West to East the islands of Santo Antão, São Vicente, Santa Luzia (uninhabited island), São Nicolau, Sal and Boavista. Also belonging to this group are the Branco and Raso Islets, located between Santa Luzia and São Nicolau, the Pássaro Islet off Mindelo Bay in the São Vicente Island, Rabo de Junco on Sal Island's West coast and the Islets of Sal Rei, Baluarte and Roque on Boavista Island's coast;

ii) Leeward, the South group is composed from East to West of the islands of Maio, Santiago, Fogo and Brava. Also belong to this group are the Santa Maria Islet, located close to Praia, the Islets Grande, Rombo, Baixo de Cima, Rei, Luís Carneiro and Sapado, located approximately 8 km from Brava Island and Areia Islet, off the coast of the same island.

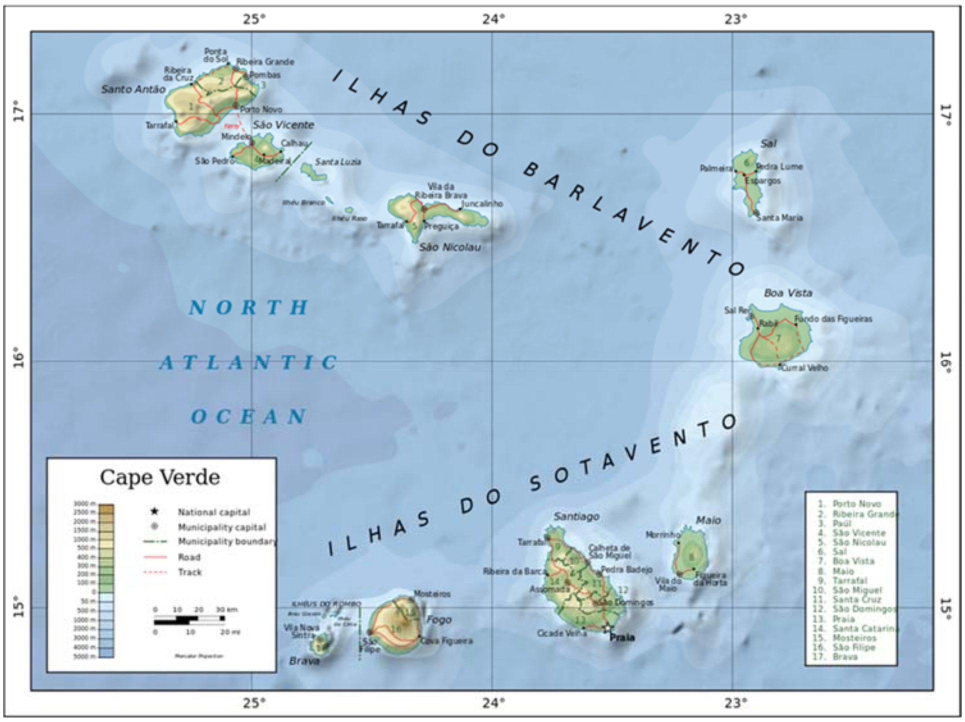


Figure 1.6. Cape Verde Geographical Location

(From https://en.wikipedia.org/wiki/Cape_Verde#/media/File:Topographic_map_of_Cape_Verde-en.svg)

The archipelago occupies a total land surface of 4033 km^2 and an Exclusive Economic Zone (EEZ) of approximately 734000 km^2. The coastline is relatively large, with about 1020 km of white and black sandy beaches alternating with rocky cliffs. The geomorphology of Cape Verde is a vulnerability shared by most small Island States, since the coastal zone requires special attention regarding the potential negative impacts arising from global climate change. Indeed, a possible sea level rise associated with other extreme events such as storms, tidal waves and floods would affect the coastal areas and their resident populations (about 80% of the total population), as well as the whole habitat, biodiversity and industrial activities linked to the artisanal fisheries and tourism.

Sal Island, a windward island of the Cape Verde Archipelago, is 30 km long, 12 km wide, and covers an area of 216 km^2. It has a fast growing human population, increasing from approximately 15000 residents in 2000 (Duarte and Romeiras, 2009) to about 26 000 residents (according to the 2010 census, as described by INE, 2013a). Predominantly small-scale and artisanal, local fisheries aim to supply local markets mostly from near-shore reefs, as the continental shelf is narrow (Oliveira *et al.*, 2015a). However, just two decades ago, Sal Island underwent increasing socio-economic changes; thereafter the major source of income has been tourism (Brito, 2012; Simão and Môsso, 2013).

1.2.3 The climate

Cape Verde is located in a region where the variability of the Subtropical Azores High Pressure acts as precipitation regulator, controlling the seasonal fluctuation of the trade winds of maritime and continental characteristics during the dry months (November to June). During the rainy season (July to October), influenced by the oscillatory motion of the Intertropical Convergence Zone (ITCZ) the weather is characterized by winds from Southeast with Eastern disturbances crossing from Africa. Between December and February, the archipelago suffers the influence of extra-tropical latitudes air masses moving towards the continent. This region of the Atlantic is under the effect of different atmospheric systems, including the ITCZ band of convective activity, the disruption and the eastern waves, depressions and tropical cyclones, the anticyclonic subtropical circulations and the Equatorial low pressures, which determine the type of circulation.

1.2.4 Temperature

The average annual temperature value is in the range of 25°C for coastal areas, and reaches 19°C in higher areas. The minimum values (between 20°C and 21°C), correspond to the months of January to April. The maximum values (of 26°C to 28°C), are recorded in the period from August to September. The absolute monthly minimum temperature is usually recorded between the months of December and February, and varies from one island to another (INMG, 2010).

The annual average sea surface temperature is 24°C, under the strong influence of the cold Canary current (below 21°C), and varies between 22°C and 24°C from July to November, and between 21°C and 23°C from December to June (Almada, 1993).

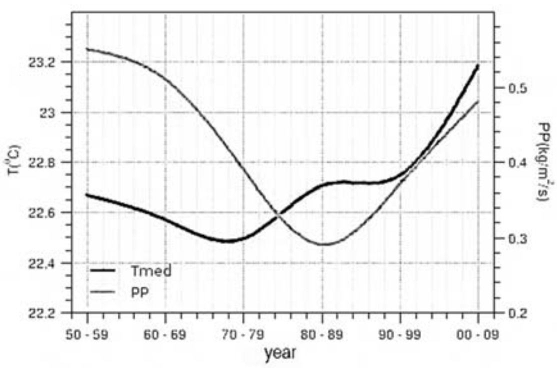


Figure 1.7. Mean annual temperature (Tmed) and Precipitacion (PP) in Sal Island (1950-2009) (Adapted from INMG, 2010).

1.2.5 Rain

The rainy season, from August to October, is very irregular and generally with low rainfall, especially in the islands of São Vicente and Sal, where there have been several years in a row without rain. The rugged Islands, such as Santiago, Santo Antão and Fogo, benefit from greater rainfall. Statistical analysis of annual precipitation between 1950 and 2009 allows asserting that in the southern islands precipitation is more frequent over the years. This slight rise in rainfall can be directly linked to the observed trend of the average temperature rise (Figure 1.7).

1.2.6 Wind

Consistent with the pressure field and being the archipelago on the periphery of the Azores Anticyclone, the NE trade winds are the prevailing winds in Cape Verde, with frequencies of 60% to 80% per year (Figure 1.8).

SW winds appear periodically with the approach of the ITCZ during the months of July to October corresponding to the rainy season.

During the dry season, the winds from the continent are predominant, being responsible for the transport of dust from desert. During this period, the visibility often reaches values below 1000 metres and the relative humidity is less than 35%.

In relation to the intensity of the wind, the trend is variable, with average speeds between 6 and 7 m/s.

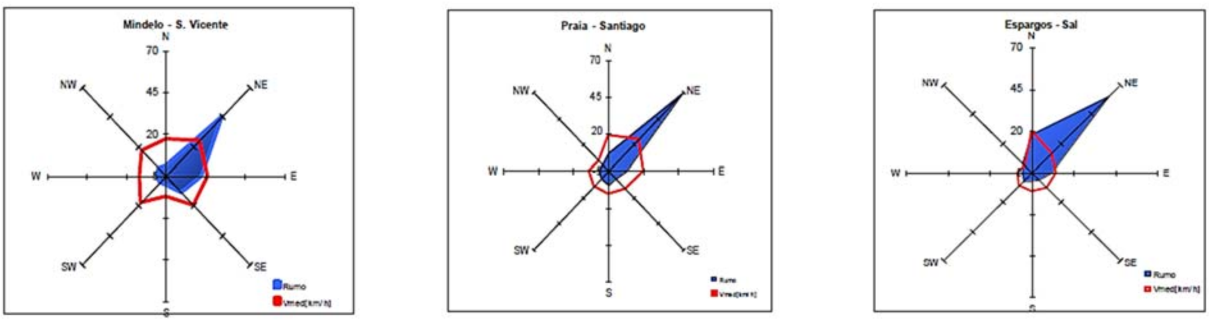


Figure 1.8. Wind direction for three main Islands. Wind direction in blue, Median velocity (km/h) in red (Adapted from INMG, 2010).

1.2.7 Legislation (Local and International)

Despite the potential benefits derived from the deployment of artificial reefs, their increasing use in worldwide coastal areas has given rise to some concerns regarding the possible negative impacts, especially due to the use of unsuitable materials and the dumping of waste.

Under Cape Verde law, there are no regulations regarding deployment of artificial reefs. Therefore, while there are currently no binding regulations on the placement of artificial reefs, some guidelines and protocols have been drawn up in different European regions and their principles were followed whenever possible.

Kwarcit and Sargo were supposed to be originally deployed by the local authorities in deeper waters without assembly or much modification. With the intervention of the Manta Diving Center within a close collaboration with Mindelo´s Port Authorities and the Environmental General Directorate both vessel received some physical preparation: Engine, hydraulic systems and most electric equipment and cabling ware removed; all diesel and oil piping and systems drained and removed; some doors and hatches were removed or fixed in order to guarantee a safety exit to future divers. Nevertheless the followed scientific work was carried under an agreement with the Environmental General Director, Drª. Maria Ivone Lopes established in June, 2008.

Artificial reef deployment falls under some general regulations, set out below, concerning the protection of the sea against pollution due to the dumping of unsuitable materials:

i) London Convention - Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (1972; replaced by the Protocol in 1996)

ii) OSPAR Convention - Convention for the Protection of the Marine Environment of the North East Atlantic (adopted in 1992 and in force since March 1998); this replaced the Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircrafts (Oslo Convention).

iii) Barcelona Convention - Convention for the Protection of the Mediterranean Sea against Pollution (1977).

iv) Helsinki Convention - Convention on the Protection of the Marine Environment of the Baltic Sea Area (1992; in force since 2000) signed by all the States bordering the Baltic Sea and by the EC.

v) Bucharest Convention - Convention on the Protection of the Black Sea against Pollution (1992; in force since 1994).

More specific Regional Plans which refer to the use of artificial reefs in the marine environment and/or Guidelines for the construction of artificial reefs have been derived from the above general Conventions. Examples are represented by the "OSPAR Guidelines on artificial reefs in relation to living marine resources (OSPAR COMMISION, 1999) and the "Guidelines for the placement at sea of matter for purpose other than mere disposal (construction of artificial reefs)" (UNEP MAP, 2005).

These guidelines state that an artificial reef is "*a submerged structure deliberately placed on the seabed to mimic some functions of a natural reef such as protecting, regenerating, concentrating and/or enhancing population of living marine resources*".

Materials, design, placement, administrative actions, monitoring, scientific experiments, management and liabilities are also addressed. The purpose is to assist Contracting Parties in:

i) assessing proposals for the placement of artificial reefs on the basis of scientifically sound criteria and development of an appropriate regulatory framework;

ii) implementing regulations on the artificial reefs´ construction;

iii) preventing pollution or degradation of the marine environment as a consequence of waste discharge.

Although the guidelines are not legally binding, the result is that most of the reefs deployed over the last two decades in Europe have been accurately planned, subjected to environmental impact assessment and carefully monitored to evaluate their effects (Fabi, 2011).

1.2.8 Tourism

Tourism in the Archipelago has a close relationship with marine-related activities, due to the tropical climate, sandy beaches, clear water and high diversity of marine species. Cape Verde was visited by 539.621 tourists in 2014 (INE, 2015b), with 41.5% visiting Sal Island, the main tourist area, followed by Boavista Island with 32.9% of the total number of visitors to the Archipelago (INE, 2015a). Tourism is one of the most dynamic sectors in terms of economic and social growth. It represents one of the main axes of sustained economic development, with important macroeconomic effect. Tourism activity contributes considerably to the entry of foreign currency, for the promotion of employment and to the GDP - Gross Domestic Product (INE, 2015c).

According to INE (2015a) in 2014 there were 229 hotel establishments with an offer of 18.188 beds in the archipelago. This represents a growth of 3,2% and 13,7%, respectively, compared with 2013 (Table 1.3)

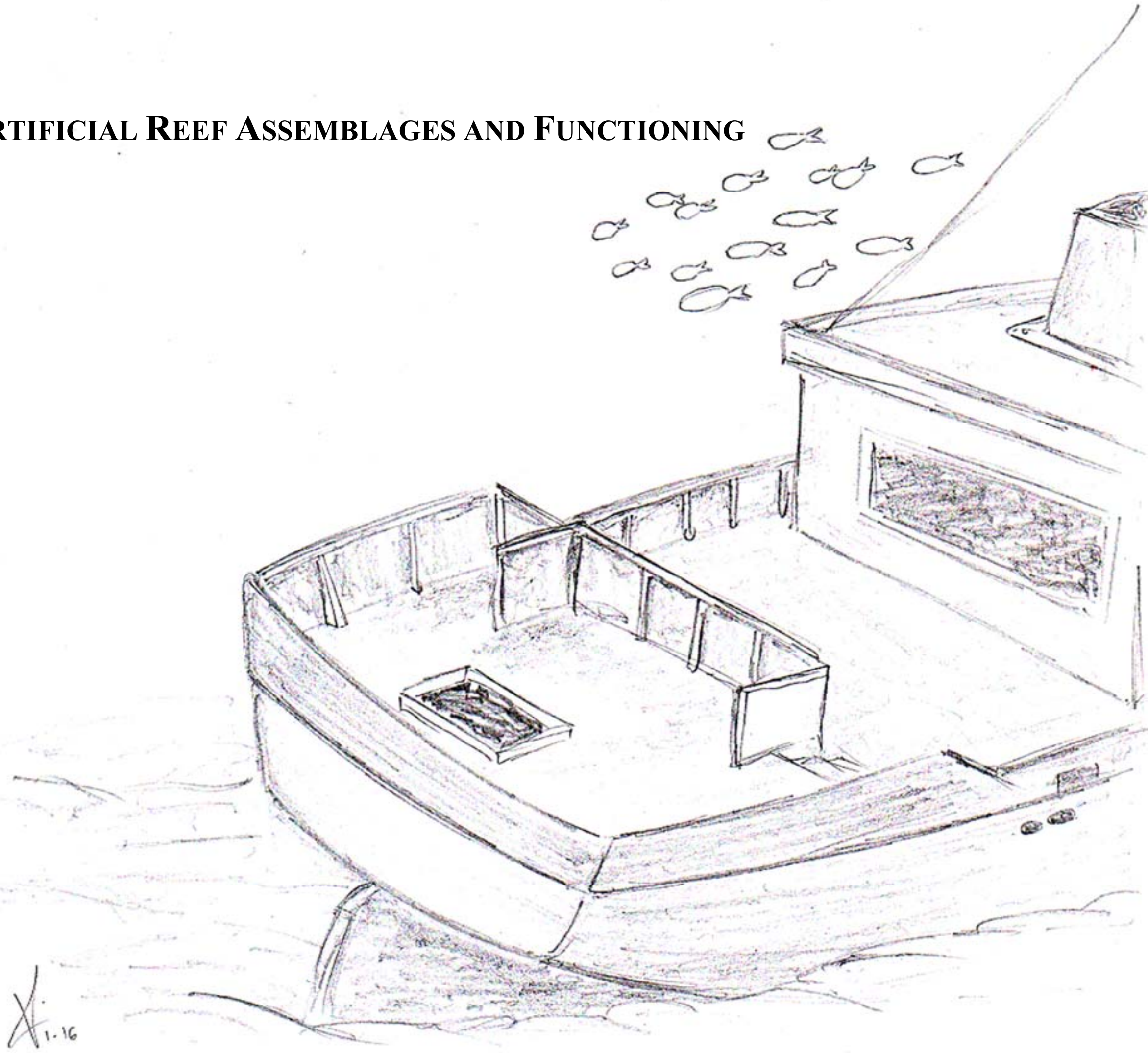
The available numbers for 2015, indicate increases of 0,1%, 4,8% and 14,9% for 1st, 2nd, 3th trimesters when compared with 2014 (INE, 2015c,d,e).

Table 1.3. Evolution of establishments, bedrooms, beds, accommodation capacity and persons employed, 2008 – 2014 (Adapted from INE, 2015a).

	2008	2009	2010	2011	2012	2013	2014	Evol. 2014/2013
Establishments (#)	158	173	178	195	207	222	229	3,2%
Bedrooms (#)	6.172	6.367	5.891	7.901	8.522	9.058	10.839	19,7%
Beds (#)	11.420	11.720	11.397	14.076	14.999	15.995	18.188	13,7%
Accommodation capacity (#)	13.708	14.096	13.862	17.025	18.194	19.428	23.171	19,3%
Persons employed (#)	4.081	4.120	4.058	5.178	5.385	5.755	6.282	9,2%

Although there are no statistics related with diving for Cape Verde, we have records of 10 dive centers currently operating in Cape Verde, one located in São Vicente Island (Oliveira, personal observation) and, according to Dive Report (2016), six dive centers in Santa Maria Bay, Sal Island, with three dive centers in Boavista Island.

2ND PART: ARTIFICIAL REEF ASSEMBLAGES AND FUNCTIONING



CHAPTER II

A comparison of the fish assemblages of natural and artificial reefs off Sal Island

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Adapted version

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A comparison of the fish assemblages of natural and artificial reefs off Sal Island

2.1 SUMMARY

Tourism is a growing activity in Cape Verde, which can lead to more intensive and uncontrolled fishing and diving activities, affecting the quality of marine habitats. To mitigate this biodiversity problem, a private diving operator, supported by the local authorities, decided to deploy the first artificial reefs (ARs) in the Archipelago just off Santa Maria Bay (Sal Island). To evaluate the ARs capacity to promote marine fish biodiversity in Santa Maria Bay, the fish assemblages were compared to those from nearby natural reefs (NRs), located at the same depth (10 and 28 m depth), by means of visual census. All study sites were surveyed by visual census in August 2009. A total of 64 species were recorded, mostly consisting of sedentary and/or benthophagous demersal species, followed by highly-sedentary benthic cryptic species. 'Tchuklassa' NR showed the highest species richness (58 species), while the lowest was recorded at 'Santo Antão' AR (48 species). An overall positive relationship was observed between habitat rugosity and mean species richness. The results showed a high percentage of common species on both reef types. Higher mean values of community descriptors (number of species, Shannon–Weaver diversity index, Simpson dominance index and equitability) and fish density were found on the ARs, with slightly higher densities recorded on the deeper reefs. These results suggest that ARs can have an important role promoting the local fish biodiversity and supporting local sustainable development of diving tourism.

Keywords: Natural and artificial reefs, fish assemblages, habitat complexity, diving tourism, Santa Maria Bay, Sal Island (Cape Verde).

2.2 INTRODUCTION

Artificial reefs (ARs) have been used for a variety of purposes other than for the improvement of commercial harvest. Furthermore, applications of ARs vary substantially, from fisheries programmes to recreational and environmental projects, and may be of natural or man-made materials (see reviews by D'Itri, 1986; Seaman and Sprague, 1991; Jensen *et al.*, 2000; Bortone *et al.*, 2011). ARs are often created by sinking decommissioned vessels, with the aim to enhance local fish diversity and abundance for the fishing industry, angling and/or ecotourism (i.e. snorkelling and SCUBA diving). Conversely, the deliberate use of some of these surplus materials is one of the most controversial aspects related to the creation of ARs worldwide (Baine and Side, 2003). To determine how well ARs mitigate biodiversity losses as a consequence of human activities on NRs, the performance of ARs should be evaluated using contemporaneous comparisons with relatively undisturbed NRs (Carr and Hixon, 1997). Past evaluations of AR efficiency, related to those man-made structures deployed for mitigation purposes have focused largely on the benefits to specific organisms or suites of species, and little attention has been given to comparisons to nearby NRs. In fact only a few studies have compared NRs to ARs to determine their efficacy as mitigation tools for damage on near-shore habitats (Palmer-Zwahlen and Aseltine, 1994; Carr and Hixon, 1997; Thanner *et al.*, 2006). Several studies have highlighted the importance of habitat and geomorphological features on the associated fish assemblages (Friedlander and Parrish, 1998; Gratwicke and Speight, 2005). However, such issues have been poorly investigated as regards ARs.

The Cape Verde Archipelago is composed of ten islands (and thirteen islets), located 750 km off Senegal (west coast of Africa), between 15–178N and 22–258W. Tourism is the country's main source of income and the source of socioeconomic development for several of the islands. Tourism in the Archipelago has a close relationship with marine-related activities, due to the warm weather, sandy beaches, clear water and high diversity of marine species. Sal Island was visited by more the 190,000 tourists in 2008, representing over 50% of the total number of visitors to the Archipelago (Anonymous, 2009a); local consumption of fish products increased by 60% between 1990 and 2000. Such demand has largely been supported by intensive and uncontrolled fishing activities (Anonymous, 2004a), making use of a wide range of techniques and gears (including set nets, longlines, hand lines, traps, explosives and spearfishing). A census regarding the local artisanal fishing industry revealed a total of 119 boats and fishermen in Sal Island coastal waters in 2005 (Anonymous, 2010). A decrease of

17.5% in the artisanal fishing captures (kg/trip) was recorded from 2000 to 2009 (Anonymous, 2010). SCUBA diving is an increasingly popular sport and, worldwide, the number of PADI individual divers increased by 66.1% between 1996 and 2010 (PADI, 2011). Although there are no statistics for Cape Verde, currently six dive centres operate in Santa Maria Bay (Sal Island), increasing the human pressure on local NRs. A number of studies have reported how divers can damage benthic marine organisms (hard and soft corals, sponges, ascidians and large bryozoans) directly (physical contact) or indirectly (raised sediments) (Rouphael and Inglis, 1997; Tratalos and Austin, 2001; Zakai and Chadwick-Furman, 2002; Luna *et al.*, 2009). Furthermore, fish can also be disturbed due to selective search by divers (e.g. cryptic species) and change their natural behaviour (e.g. during mating) (Uyarra and Cote´, 2007; Heyman *et al.*, 2010). The scientific information on local fish assemblages is very limited, consisting mostly of an inventory list of species (Lloris *et al.*, 1991; Reiner, 1996; Monteiro *et al.*, 2008). However, Roberts *et al.* (2002) listed Cape Verde in the top 10 coral reef biodiversity hotspots in the world and as in the top eight of threatened centres of endemism.

Following the development of this scenario, the local Environmental Authority decided to take steps to improve the sustainability of local development and invested in the restoration of impacted marine habitats. A method proposed by Clewell *et al.* (2000) was trialled, which consisted of deploying a functional habitat that can support high marine biodiversity, so that it can continue its natural maturation and evolve over a longer time-span in response to changing environmental conditions. The Ministry of Environment and Marine Resources of Cape Verde supported the proposal put forward by a private diving operator (Manta Diving Centre, Sal Island, Cape Verde) to deploy ARs in Cape Verde coastal waters. They deployed a first shipwreck (‘Kwarcit’) in 2006, followed by a second (‘Sargo’) in 2008. The two decommissioned vessels were sunk off Santa Maria Bay (southern coast of Sal Island), aiming to promote local biodiversity and the sustainable development of diving tourism. In the present study two ARs (‘Kwarcit’ and shipwreck ‘Santo Antão’) have been evaluated by comparing the local fish assemblages to those from two nearby NRs (‘Farol Baixo’ and ‘Tchuklassa’), in terms of species and assemblage structure (density and fish size). The effect of habitat complexity on the fish assemblages was also studied.

2.3 MATERIAL AND METHODS

Study sites

Two shipwrecks (‘Santo Antão’ and ‘Kwarcit’) and two NRs (‘Farol Baixo’ and ‘Tchuklassa’) were sampled off Santa Maria Bay (Figure 2.1).

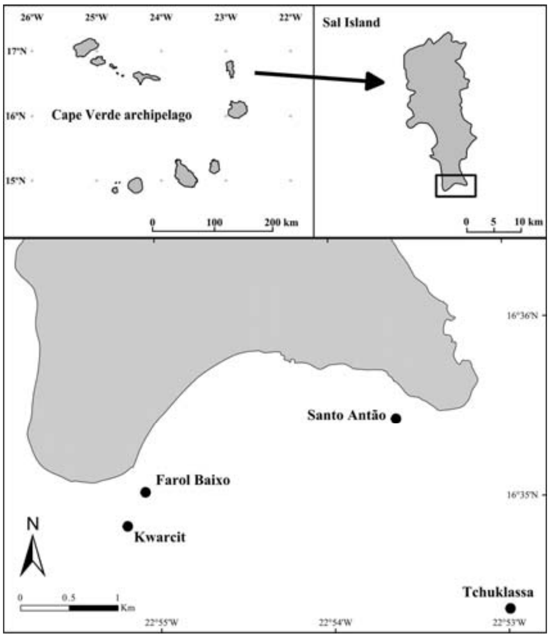

Figure 2.1. Location of the study sites at Santa Maria Bay (Sal Island, Cape Verde).

The NRs are located at two distinct depths-ranges: shallow reefs (4–11 m) and deep reefs (15– 30 m). Comparisons were made between reefs of the same depth-range:

‘Farol Baixo’—is located on a plateau with a gentle slope from 4 to 7 m depth to the top of a 3 m high wall, falling to about 10 m depth. The plateau and the wall have many small crevices, interrupted by narrow perpendicular channels. A few small caves can be observed on the base of the wall. This NR runs parallel to the shoreline for 200 m, beginning just 0.3 km from the coast (Figure 2.2).

Figure 2.2. Farol Baixo (©Vasco Pinhol)

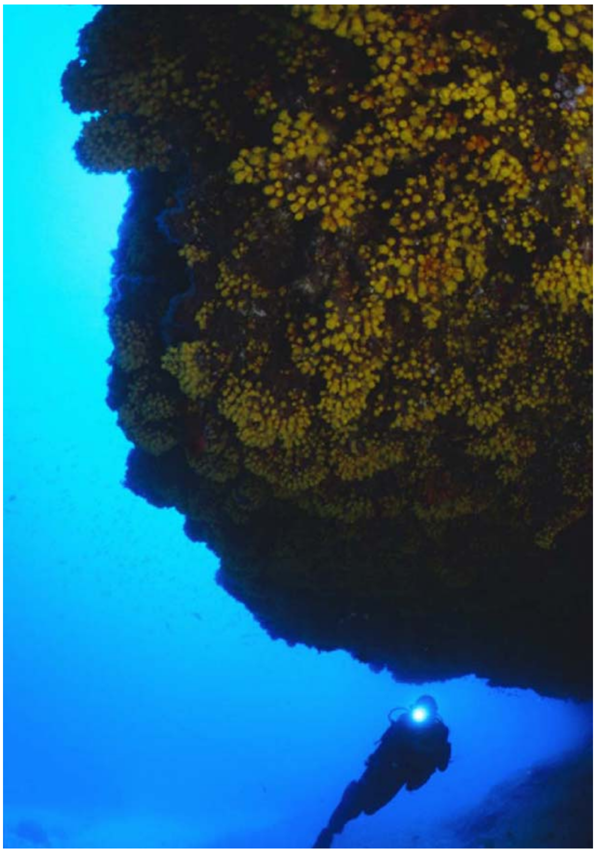

Figure 2.3. Tchuklassa (©Vasco Pinhol)

'Tchuklassa'—this rocky reef is on a plateau located further offshore (2.12 km from the shoreline) to the eastern side of the bay. The maximum depth on the north-western side is 30 m. The plateau has a large overhang at 15 m depth with vertical walls extending 30 m deep. The plateau comprises small rocks and some larger boulders, with small vertical reliefs, but presenting many crevices and narrow channels (Figure 2.3).

'**Santo Antão**'—is a former cargo vessel that was sunk during a storm in 1965 at a depth of 11 m. The vessel was 53 m long and 9 m wide, but it is now broken into several parts over an area of 50 m by 20 m. The maximum height is 5 m. It lies on a flat sandy bottom, 0.15 nm from the shoreline inside the bay (Figure 2.4).

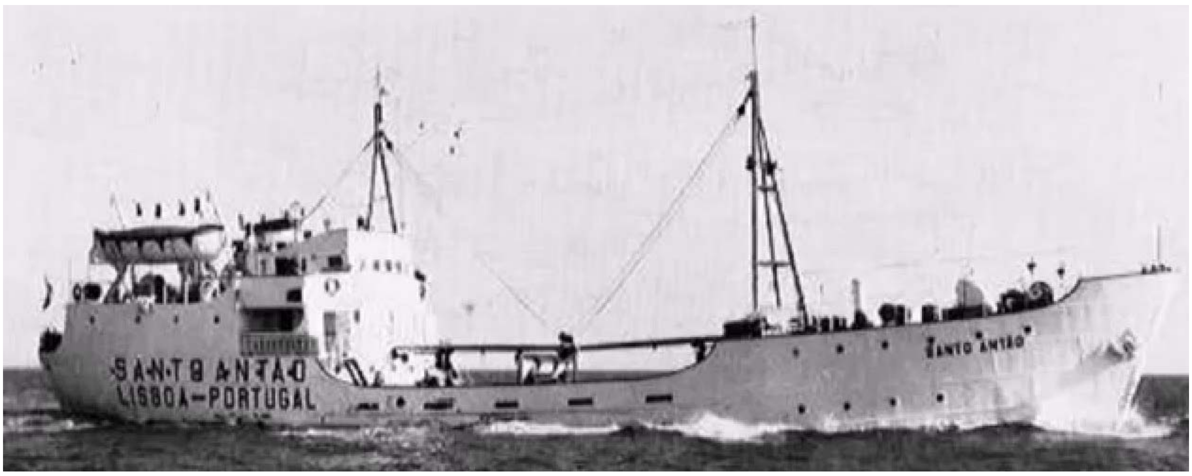

Figure 2.4. Santo Antão (©http://mindelosempre.blogspot.pt/)

'**Kwarcit**'—is a former soviet beam trawler that was deliberately sunk on the 6 January 2006. The vessel is 27 m long, 7 m wide and 10 m high. It lies on a flat rocky bottom covered by a thin layer of sand on the starboard side of the wreck. It is located 0.3 nm from the shoreline in the westernmost part of the bay at a depth of 28 m (Figure 2.5).

The distance between 'Santo Antão' and 'Farol Baixo' is 2.7 km, while 'Kwarcit' and 'Tchuklassa' are 4 km apart.

Figure 2.5. Kwarcit (©Vasco Pinhol)

Data collection

The four reefs were sampled in a relatively short period of time (two weeks in August 2009) to reduce bias from temporal variability. The visual censuses were performed by divers who recorded all fish species present within the area, as well as their size and abundance. Biomass was calculated based on fish size estimates and the weight- length relationships (WLRs) available on FishBase for the different species recorded. However, for a considerable number of species no WLRs were available for Cape Verde, therefore a total of 8,328 specimens, belonging to 29 fish species across 14 families were sampled to estimate WLRs for local reef fish species (see Annex I, Oliveira *et al.*, 2015). Due to the different habitat complexities and diving time limitations (due to depth), a combination of methodologies were used as suggested by Bortone *et al.* (2000): transect (Brock, 1954; Buckley and Hueckel, 1989) and species–time random count method (Thompson and Schmidt, 1977; Jones and Thompson, 1978).

The species–time random count method of Harmelin-Vivien *et al.* (1985) was used to determine the minimum time for the random counts. A five minute interval was considered, as this was the time estimated to observe 90% of the species on the four study sites. Due to the different habitat complexities, different strata were considered at:

- Shallow reefs ('Farol Baixo' and 'Santo Antão')—seabed (lower) and at the upper part of the reef (plateau or the top of the wreck);
- Deep reefs (Tchuklassa' and 'Kwarcit')—seabed (lower), middle (overhang or vessel deck) and upper part of the reef (plateau or the top of the vessel structure).

For each study site two geomorphological indices were estimated (for each stratum) using two methods: site topography (complexity) and rugosity measurements. Site complexity was estimated by visual assessment assigning each site a grading from 0 to 5, adapted from Wilson *et al.* (2007), where:

0—no vertical relief;

1—low and sparse relief;

2—low but widespread relief;

3—moderately complex, with rocks and/or boulders of several sizes;

4—very complex with numerous fissures and caves;

5—exceptionally complex with numerous caves, overhangs and canyons.

Rugosity was measured as the ratio between the distance along the surface (covered by a chain of 10 m length) and the straight-line shortest distance between the two perpendicular points at the ends of the chain (Figure 2.6). Rugosity was not measured at the middle stratum at 'Tchuklassa', due to its geomorphology (overhang with very low bottom relief, but with high rugosity at the roof). The location for data collecting was randomly selected. The number of replicates varied according to the site, varying from 5 (at the top stratum of 'Kwarcit') to 16 (at the top stratum of 'Farol Baixo'), increasing with site complexity.

Figure 2.6. Divers measuring rugosity at Santo Antão.

At each stratum divers recorded the fish species present along a standard transect (10 m long × 4 m wide and 2 m high), their abundance and size (according to pre-established length size-classes). Three replicate transects were made at each stratum, corresponding to a total of six and nine counts for each sample, at the shallow and deep reefs, respectively. A total of ten surveys were carried out at each study site in order to account for the natural variability of the fish assemblages. Sampling was conducted by the same two experienced divers simultaneously for each dive. Diver No. 1 performed the bottom transects counts, while diver No. 2 conducted the surveys at the middle and top of the reefs (Figure 2.7). This was kept constant throughout the study. Sampling was performed between 9:30 am and 3:30 pm, to take advantage of maximum sunlight and visibility and to avoid the natural differences of fish activity between dawn and dusk.

Figure 2.7. Recording fish species at Kwarcit.

Fish were assigned to spatial categories (SC), by slightly modifying those suggested by Harmelin (1987) for fish from Mediterranean rocky bottoms:

- Category 1 - highly mobile, gregarious, erratic pelagic species (e.g. *Pseudocaranx dentex* and *Seriola* spp.);
- Category 2 - planktophagous and relatively sedentary species, living throughout the water column (e.g. *Chromis lubbocki*);

- Category 3 - demersal mesophagous species, with medium-amplitude vertical movements and more-or-less important horizontal movements (e.g. *Acanthurus monroviae*);
- Category 4 - demersal benthophagous species, with medium-amplitude vertical movements and more-or-less important horizontal movements (e.g. *Aluterus scriptus*);
- Category 5 - demersal species, with limited vertical and considerable lateral movements (e.g. *Pseudupeneus prayensis*);
- Category 6 - sedentary demersal mesophagous species (e.g. *Sparisoma* spp.);
- Category 7 - highly-sedentary cryptic benthic species (e.g. *Gymnothorax* spp.).

Density was calculated as the number of fish per standard transect. The frequency of occurrence (FO) or appearance of a species at each site was calculated as a percentage of presence in all surveys in that site and expressed according to four levels as suggested by Harmelin (1987):

- level I (very frequent) >75%;
- ≤75% level II (frequent) >50%;
- ≤50% level III (uncommon) >25%;
- level IV (rare) ≤25%.

Data analysis

The analyses were conducted separately for the shallow and deep as the two ARs presented several differences (i.e. size, submersion time, etc.).

Univariate variables of the fish communities (N, abundance; S, number of species; H′, Shannon–Weaver diversity index; D_{-1}, Simpson index of diversity; and J′, equitability index) were analysed by two-way analysis of variance (ANOVA) with site (AR versus NR, fixed factor) and strata as factors (two strata at lower depth, Top versus Bottom; and three strata at deeper depths, Top versus Middle versus Bottom, fixed factors). Analyses of variance was followed on appropriate terms of the model by a posteriori Tukey's honestly significant difference (HSD) tests, which was found to be significant with $P < 0.05$. Whenever the assumptions of ANOVA were violated (homogeneity of variances and normality checked using Levene test and Lilliefors (Kolmogorov–Smirnov) test, respectively), appropriate transformations were used (Underwood, 1997). If violation persisted, non-parametric tests were used (Kruskal–Wallis, for factors with more than 3 levels, and Wilcoxon Rank Sum test (Mann–Whitney test)). The latter tests were performed for each factor separately, e.g. AR versus NR and AR_{Top} versus AR_{Bottom}, and similarly for the NRs. Rugosity and complexity was analysed using the non-parametric methods previously referred to, because sample size was substantially different, leading to very unbalanced designs. Multivariate methods were used to detect differences in the composition and structure of the assemblages, namely non-metric multidimensional scaling (n-MDS) and permutational multivariate analysis of variance (PERMANOVA) using abundance data. The similarity matrix used in the analysis was built using the Bray–Curtis similarity index (Legendre and Legendre, 1998; Clarke and Warwick, 2001; Clarke *et al.*, 2006).

Indicator species analysis (ISA) (Dufrêne and Legendre, 1997) was conducted on fish assemblage data from the two depth-ranges to assess associations of species to sites. ISA identifies taxa associated with groups (NR and AR) by calculating an indicator value (Indval, ranging from 0 to 1) taking into account the frequency of occurrence and the abundance of each taxon in defined groups. ISA allows for the examination of common and rare taxa within a community rather than focusing solely on common species with high indicator values. This reflects both high abundance and prevalence of taxon within a group. Significance of indicator values was assessed using Monte Carlo simulations. A total of 999 randomized runs were performed, with P values representing the probability of a similar observation using randomized data. To compare the size distribution of selected species (the ten most abundant species, plus those with an overall abundance of at least 250 specimens) between the NR and the AR at each depth, the non-parametric Wilcoxon rank sum test (Mann–Whitney test) was used (Sokal and Rohlf, 1987) to assess whether the two independent samples had equally large values (measures differences in location). The two sample Kolmogorov–Smirnov test was used to investigate the differences between the two distributions (high sensitivity to differences in dispersion and skewness). The relationship between fish assemblages (fish density and number of species) and habitat complexity (rugosity) was assessed using linear regression analysis. Analysis of covariance (ANCOVA) was used to test if the effects were consistent among sites (similar slopes and intercepts) (Bingham and Fry, 2010). All the analyses were conducted using the open source statistical software R v2.10.0 (R Development Core Team, 2005) and PERMANOVA computer program for MS-DOS (Anderson, 2001).

2.4 RESULTS

Habitat rugosity and complexity

The mean total habitat rugosity values obtained for the study sites varied from 0.15 (±0.075) at 'Santo Antão' and 0.22 (±0.102) at 'Farol Baixo' (Table 1), with significant differences between natural and ARs at low depth ($P < 0.001$; Table 2). With regards to complexity, the observed mean values ranged from 1.65 (±1.018) at 'Santo Antão' to 2.55 (±1.058) at 'Tchuklassa'. At the NRs a significant decrease in complexity was recorded from the top to the bottom, although the highest value for 'Tchuklassa' was recorded in the middle stratum (Table 2.1). The comparison of habitat complexity between sites showed significant differences between natural and artificial reefs at both depths ($P < 0.001$ and $P < 0.05$, for the shallow and deep reefs, respectively).

Furthermore, a strong positive linear relationship between the two habitat indices was observed (linear regression $R^2 = 0.593$, $P < 0.001$).

Table 2.1. Mean values (+standard deviation) recorded for the geomorphological (rugosity and complexity) and ecological indices: species richness (S), Shannon–Weaver diversity index (H′), Simpson diversity index (1-D), Pielou evenness (equitability) index (J′) and mean density (number of fish/standard transect).

Parameter	Layer/site: (depth)	Natural reefs 'Farol Baixo' (shallow)	Natural reefs 'Tchuklassa' (deep)	Artificial reefs 'Santo Antão' (shallow)	Artificial reefs 'Kwarcit' (deep)
Rugosity	Top	0.27 ± 0.06	0.19 ± 0.07	0.13 + 0.08	0.19 + 0.12
	Middle	–	–	–	0.21 + 0.15
	Bottom	0.18 ± 0.07	0.21 ± 0.14	0.18 + 0.12	0.13 + 0.08
	Average	0.22 ± 0.08	0.19 ± 0.10	0.15 + 0.10	0.17 + 0.12
Complexity	Top	3.00 ± 0.89	2.86 ± 0.36	1.53 + 0.64	2.40 + 0.89
	Middle	–	3.50 ± 0.55	–	2.75 + 1.39
	Bottom	2.13 ± 0.52	1.80 ± 1.40	1.30 + 1.16	1.50 + 0.54
	Average	2.46 ± 0.84	2.55 ± 1.06	1.65 + 1.02	2.42 + 1.21
S	Top	17.60 ± 4.43	18.90 ± 1.79	23.50 + 4.22	20.70 + 3.83
	Middle	–	20.20 ± 3.29	–	23.10 + 3.63
	Bottom	15.60 ± 4.22	20.50 ± 2.22	20.80 + 5.59	21.30 + 2.26
	Average	16.60 ± 4.33	19.87 ± 2.53	22.15 + 5.02	21.70 + 3.36
H′	Top	1.82 ± 0.30	1.92 ± 0.20	2.60 + 0.32	2.27 + 0.18
	Middle	–	1.77 ± 0.45	–	2.26 + 0.29
	Bottom	1.82 ± 0.23	2.08 ± 0.28	2.16 + 0.32	2.43 + 0.27
	Average	1.82 ± 0.26	1.92 ± 0.34	2.38 + 0.39	2.32 + 0.25
1-D	Top	0.72 ± 0.11	0.74 ± 0.06	0.89 + 0.05	0.83 + 0.05
	Middle	–	0.69 ± 0.16	–	0.82 + 0.07
	Bottom	0.74 ± 0.08	0.79 ± 0.08	0.81 + 0.07	0.86 + 0.05
	Average	0.73 ± 0.10	0.74 ± 0.11	0.85 + 0.07	0.83 + 0.06
J′	Top	0.64 ± 0.09	0.66 ± 0.08	0.83 + 0.07	0.76 + 0.07
	Middle	–	0.59 ± 0.13	–	0.72 + 0.07
	Bottom	0.67 ± 0.07	0.69 ± 0.10	0.72 + 0.11	0.80 + 0.07
	Average	0.68 ± 0.08	0.64 ± 0.11	0.77 + 0.10	0.76 + 0.07
Density	Top	129.41 ± 44.01	109.17 ± 46.64	108.38 + 22.71	146.192 + 51.22
	Middle	–	174.89 ± 70.44	–	169.61 + 55.79
	Bottom	131.67 ± 105.28	143.16 ± 61.17	140.06 + 58.68	117.36 + 29.44
	Average	130.54 ± 78.54	142.41 ± 64.19	124.22 + 46.25	144.39 + 50.22

Assemblage composition

A total of 64 species were recorded belonging to 32 families (Table 2.3). The most speciose families were Muraenidae (6 species) and Pomocentridae (5 species), with another 3 families (Carangidae, Lutjanidae and Sparidae) represented by 4 species each. Fifty-five species were found on the shallow reefs and 61 species on the deep reefs. A total of 39 species (61%) were common to the four study sites, while 43 (67%) species were common to the shallow reef and 51 (80%) species to the deeper reefs. Ten species had a high commercial value, 25 species had no commercial value, while the remaining ones were of medium to low economic interest (Table 2.3). With regards to the species category, a common pattern was observed in all sites (Table 2.3), with demersal species dominating in number (categories 4 and 6), followed by highly-sedentary benthic cryptic species (category 7). Rare species showed large dominance at all sites, representing over 94% (52) and 72% (44) at the shallow and deeper sites, respectively. Furthermore, very frequent species were not recorded at the shallow sites. 'Tchuklassa' showed the highest species richness (58 species, 2 exclusive to the site: *Ginglymostoma cirratum* and *Prognathodes marcellae*), followed by 'Kwarcit' (54 species, with two exclusive to the site: Antennarius pardalis and *Diplodus puntazzo*), 'Farol Baixo' (50 species) and 'Santo Antão' (48 species, 2 exclusive to the site: *Lethrinus atlanticus* and *Myrichthys pardalis*).

The mean species richness ranged from 16.6 at 'Farol Baixo' to 22.1 at 'Santo Antão' (Table 2.1). On the shallow reefs it increased from the bottom to the top, while on the deeper reefs the lowest figures were found at the top stratum. On the deeper reefs, the highest mean species richness was recorded on the middle stratum at 'Kwarcit' and at the bottom at 'Tchuklassa'. Significant differences were found between reefs mean species richness at similar depths, being higher on the ARs (Tables 2.1 and 2.2). The mean Shannon–Weaver diversity index (H′) varied from 1.8 at 'Farol Baixo' and 2.4 at 'Santo Antão'. Higher values were observed at the artificial reefs, the highest values being recorded at 'Santo Antão' (Tables 2.1 and 2.2). The comparisons between strata showed no general trend among sites. Higher values were found at the top at 'Santo Antão', while at the deep reefs differences were only observed between the bottom and middle strata. Similar patterns as those described above for H′ were found for the mean Pielou evenness (equitability) index. As regards the mean Simpson diversity index differences were observed at both depths, although the comparison among strata only revealed differences in the deeper sites (Table 2.1 and 2.2).

Table 2.2. Results of the statistical tests used for the inter- and intra-site comparisons for the geomorphological (rugosity and complexity) and ecological indices: species richness (S), mean Shannon–Weaver diversity index (H′), Simpson diversity index (1-D), Pielou evenness (equitability) index (J′) and mean density.

Parameter		Shallow reefs		Deep reefs	
		'Farol Baixo' versus 'Santo Antão'		'Tchuklassa' versus 'Kwarcit'	
Rugosity		***		ns	
Complexity		***		ns	
S		**		*	
J′		**		**	
H′		**		**	
1-D		**		**	
Density		ns		ns	
Parameter	**Stratum/site**	**'Farol Baixo'**	**'Santo Antão'**	**'Tchuklassa'**	**'Kwarcit'**
Rugosity	Top versus Bottom	***	ns	ns	ns
	Top versus Middle	–	–	–	ns
	Middle versus Bottom	–	–	–	**
Complexity	Top versus Bottom	**	ns	ns	ns
	Top versus Middle	–	–	*	ns
	Middle versus Bottom	–	–	*	*
S	Top versus Bottom	ns	ns	ns	ns
	Top versus Middle	–	–	ns	ns
	Middle versus Bottom	–	–	ns	ns
H′	Top versus Bottom	ns	ns	ns	ns
	Top versus Middle	–	–	ns	ns
	Middle versus Bottom	–	–	ns	ns
J′	Top versus Bottom	ns	ns	ns	ns
	Top versus Middle	–	–	ns	ns
	Middle versus Bottom	–	–	ns	ns
1-D	Top versus Bottom	ns	ns	ns	ns
	Top versus Middle	–	–	ns	ns
	Middle versus Bottom	–	–	ns	ns
Density	Top versus Bottom	ns	ns	ns	ns
	Top versus Middle	–	–	ns	ns
	Middle versus Bottom	–	–	ns	ns

An overall positive relationship was observed between habitat rugosity and species richness (see Figure 3.8; linear regression, $R^2= 0.1526$, $F_{1,55}= 9.91$, $P < 0.01$), although such a significant positive trend was only noted at one individual site ('Kwarcit', linear regression, $R^2= 0.4681$, $F_{1,12}= 10.56$, $P < 0.01$; Figure 2.8).

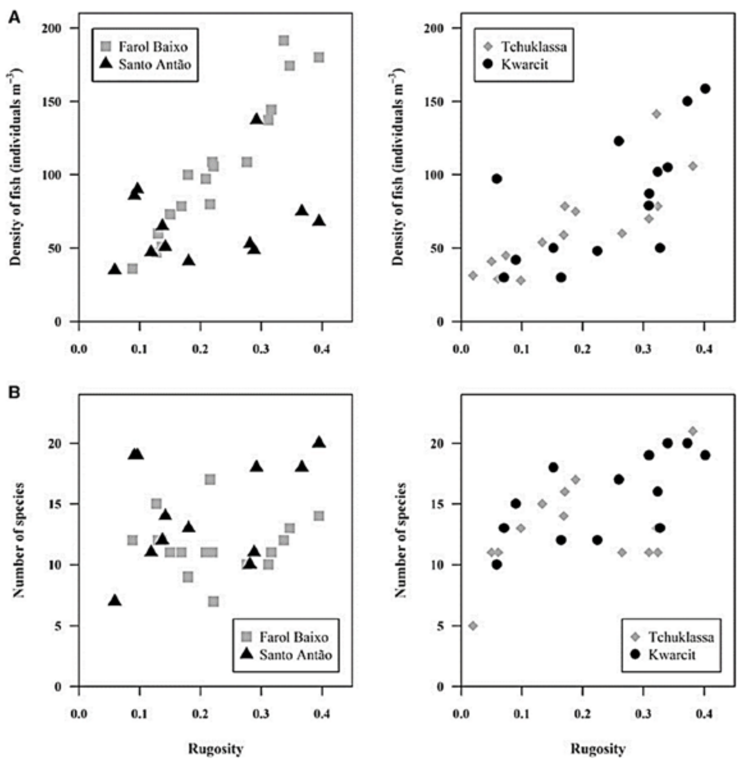

Figure 2.8. Relationship between habitat rugosity and (A) fish density and (B) number of species, for shallow (left) and deep reefs (right).

Table 2.3. Mean fish density (number of fish/standard transect) at the study sites (+standard deviation). Species economic value (EV): H, high; M, moderate; L, low; N, none. For details on the species spatial categories (SC) and frequency of occurrence levels (FO, roman numbers) see Materials and Methods section.

Family	Species	EV	Natural reefs					Artificial reefs			
			SC	FO	'Farol Baixo'	FO	'Tchuklassa'	FO	'Santo Antão'	FO	'Kwarcit'
Acanthuridae	*Acanthurus monroviae*	N	3	IV	0.52 (±1.63)	III	24.57 (±196.51)	III	4.21 (±18.47)	III	3.37 (±16.90)
Antennariidae	*Antennarius pardalis*	N	5							IV	0.02
Aulostomidae	*Aulostomuss strigosus*	N	3	III	3.48 (±15.33)	I	3.89 (±10.2)	III	3.48 (±6.67)	I	4.65 (±7.03)
Balistidae	*Balistes capriscus*	L	4			IV	0.02	IV	0.05	IV	0.02
	Balistes punctatus	L	4	IV	0.02	IV	0.13 (±2.86)	IV	0.64 (±2.24)	IV	0.08 (±3.03)
	Balistes vetula	L	4	IV	0.02			IV	0.10		
Blenniidae	*Ophioblennius atlanticus*	N	7	IV	0.50 (±1.2)	IV	0.02				
Carangidae	*Caranx crysos*	H	1			IV	0.02			IV	0.02
	Pseudocaranx dentex	H	1			IV	0.10			IV	3.43 (±31.80)
	Seriola dumerili	H	1			IV	0.19 (±8,08)			IV	0.10 (±0.82)
	Seriola rivoliana	H	6			IV	0.19 (±6.06)			IV	0.29 (±16.16)
Centracanthidae	*Spicara melanura*	L	7	IV	1.95 (±16,23)	IV	0.06	IV	4.52 (±39.47)	IV	1.24 (±13.22)
Chaetodontidae	*Chaetodon robustus*	N	6	IV	0.14 (±0.64)	III	1.43 (±3.87)	IV	0.74 (±3.51)	III	0.75 (±2.75)
	Prognathodes marcellae	N	4			IV	0.08 (±0,71)				
Clupeidae	*Sardinella maderensis*	L	6			IV	1.59			IV	1.27
Dasyatidae	*Taeniura grabata*	N	5	IV	0.02	IV	0.02		0.02	IV	0.02
Diodontidae	*Chilomyceterus reticulata*	N	4	IV	0.02	IV	0.06	IV	0.52 (±2.87)	IV	0.19 (±2.39)
	Diodon holacanthus	N	4	IV	0.07 (±1.01)	IV	0.06 (±0,82)	IV	1.74 (±9.28)	IV	0.03
Fistularidae	*Fistularia tabacaria*	N	3	IV	0.12 (±0.71)	IV	0.06	IV	0.07 (±1.01)	IV	0.13 (±2.97)
Ginglymostomidae	*Ginglymostoma cirratum*	L	7			IV	0.03				
Grammistidae	*Rypticus saponaceus*	N	6	IV	0.14 (±0.82)	IV	0.35 (±2.09)	IV	0.05	IV	0.38 (±3.97)
Haemulidae	*Parapristipoma humile*	L	4	IV	3.02 (±23,1)	IV	0.68 (±6,02)	III	3.45 (±25.78)	I	34.19 (±156.83)
	Parapristipoma octoolineatum	L	4	IV	0.17	IV	0.14			IV	0.03
Holocentridae	*Myripristis jacobus*	L	6	III	9.50 (±47,19)	I	26.17 (±124.60)	III	5.14 (±27.27)	I	7.75 (±21.77)
	Sargocentron hastatum	N	6	III	1.31 (±6.49)	I	4.68 (±23.62)	III	1.31 (±3.81)	I	3.29 (±12.88)
Kyphosidae	*Girella stubeli*	M	4	IV	0.02	IV	0.06 (±0,82)			IV	0.29 (±6.23)
	Kyphosus sectator	L	4	IV	0.02	IV	0.17 (±1.20)			IV	0.03
Labridae	*Bodianus speciosus*	M	6	IV	0.10 (±0.82)	III	1.40 (±3,00)	IV	0.21 (±2.47)	III	0.79 (±4.04)
	Coris atlantica	N	6	IV	1.95 (±20.77)	III	1.92 (±8.24)	III	2.48 (±12.39)	III	2.13 (±14.68)
	Thalassoma pavo	L	7	III	8.60 (±24.29)	III	3.81 (±27.88)	IV	0.57 (±6.9)	III	3.81 (±19.34)
Lethrinidae	*Lethrinus atlanticus*	M	4					IV	1.21 (±8.11)		
Lutjanidae	*Apsilus fuscus*	M	1	IV	0.02	IV	0.25 (±3.09)	IV	0.02	IV	0.19 (±1.17)
	Lutjanus agennes	M	3					IV	0.10	IV	0.05
	Lutjanus fulgens	M	3	IV	0.40 (±2.17)	IV	2.49 (±64.37)	III	23.93 (±100.99)	IV	1.92 (±20.91)
	Lutjanus goreensis	M	3	IV	1.55 (±47.47)	IV	0.29 (±8.92)	IV	5.38 (±50.91)	IV	2.37 (±34.28)
Monacanthidae	*Aluterus scriptus*	N	4	IV	0.24 (±2.74)	IV	0.29 (±3.44)	IV	0.21 (±3.57)	III	1.38 (±14.41)
Mullidae	*Mulloidichthys martinicus*	M	4	IV	11.71 (±140.06)	III	6.68 (±46.41)	III	19.76 (±74.00)	I	9.41 (±33.24)
	Pseudupeneus prayensis	M	5	IV	1.24 (±4.03)	III	3.05 (±16.53)	IV	1.64 (±8.69)	IV	1.30 (±6.20)
Muraenidae	*Gymnothorax miliaris*	N	7	IV	0.19 (±2.97)	IV	0.08 (±0.71)	IV	0.02	IV	0.05 (±1.01)
	Gymnothorax moringa	N	7			IV	0.30 (±1.06)	IV	0.02	IV	0.03

Continued

Table 2.3. Continued

Family	Species	EV	Natural reefs					Artificial reefs			
			SC	FO	'Farol Baixo'	FO	'Tchuklassa'	FO	'Santo Antão'	FO	'Kwarcit'
	Gymnothorax unicolor	M	7	IV	0.02	IV	0.02	IV	0.02		
	Gymnothorax vicinus	M	7	IV	0.12	IV	0.17 (±1.12)			IV	0.05
	Muraena melanotis	M	7	IV	0.02	IV	0.08	IV	0.02	IV	0.02
	Muraena robusta	M	7	IV	0.05	IV	0.02				
Ophichthidae	*Myrichthys pardalis*	N	7					IV	0.07		
Pomacanthidae	*Holacanthus africanus*	N	4	IV	0.02	IV	0.13 (±2.86)	IV	0.07	III	0.54 (±3.10)
	Abudefduf luridus	N	6	III	14.17 (±33.61)	III	2.46 (±23.17)	III	3.43 (±12.18)	III	0.94 (±9.51)
	Abudefduf saxatilis	N	6	III	5.02 (±60.88)	IV	0.11 (±0.82)	III	4.40 (±16.95)	IV	0.02
	Chromis lubbocki	N	2	III	48.76 155.09	I	40.06 (±122.14)	III	12.67 (±33.41)	I	33.95 (±142.28)
	Similiparma hermani	N	6	IV	0.02	IV	0.10 (±0.82)				
Priacanthidae	*Heteropriacanthus cruentatus*	L	6	III	4.83 (±49.55)	IV	0.29 (±6.23)	IV	1.52 (±12.82)	III	2.86 (±12.12)
Scaridae	*Scarus hoefleri*	M	7	IV	0.55 (±1.18)	III	0.86 (±5.40)	III	0.90 (±3.42)	III	1.29 (±4.92)
	Sparisoma cretense	M	6	III	2.48 (±11.98)	I	3.52 (±11.58)	III	3.81 (±6.63)	I	4.59 (±17.85)
	Sparisoma rubripinne	M	4	IV	0.31 (±1.74)	III	0.65 (±5.81)	IV	0.64 (±5.33)	IV	0.22 (±1.17)
Scorpaenidae	*Scorpaena scrofa*	L	1	IV	0.17 (±0.58)	IV	0.17 (±2.35)	IV	0.14 (±1.43)	IV	0.02
Serranidae	*Cephalopholis taeniops*	H	6	III	1.69 (±3.26)	III	2.38 (±7.88)	III	1.79 (±6.1)	I	3.52 (±9.94)
	Mycteroperca fusca	H	3	IV	0.05	IV	0.02	IV	0.02	III	0.70 (±4.37)
Sparidae	*Diplodus fasciatus*	H	4	IV	0.79 (±6.31)	I	2.41 (±14.83)	III	5.00 (±35.02)	I	3.86 (±10.06)
	Diplodus prayensis	H	4	IV	1.95 (±17.99)	III	1.33 (±13.76)	III	4.71 (±29.53)	III	1.78 (±13.00)
	Diplodus puntazzo	H	4							IV	0.38 (±4.81)
	Diplodus sargus	H	4	IV	0.76 (±7.28)	III	0.73 (±4.44)	III	1.69 (±4.37)	III	1.90 (±13.81)
Synodontidae	*Synodus saurus*	N	6	IV	0.02	IV	0.03	IV	0.17 (±0.58)		
Tetraodontidae	*Canthigaster rostrata*	N	6	III	1.62 (±7.96)	III	1.54 (±14.6)	III	1.52 (±5.56)	III	2.83 (±13.86)
	Sphoeroides marmoratus	N	2	IV	0.05	IV	0.02	IV	0.02	IV	0.02
		Mean fish density			130.55 (±52.19)		142.45 (±33.58)		124.26 (±29.47)		144.43 (±36.09)

Fish density and size structure

The mean density ranged from 124.2 (±46.25) fish/standard transect at 'Santo Antão' to 144.4 (±50.22) fish/standard transect at 'Kwarcit' with higher values recorded in deeper waters. Differences were only found between strata at the deep reefs (Tables 2.1 and 2.2).

The family Pomacentridae largely dominated the assemblages at 'Farol Baixo' (52%), 'Tchuklassa' (30%) and 'Kwarcit' (25%). Such dominance was mostly due to *C. lubbocki*. Holocentridae (22%) and Acanthuridae (17%) were also important families at 'Tchuklassa' and Haemulidae (24%) at 'Kwarcit'. At 'Santo Antão' the dominant families were Lutjanidae (24%), Mullidae (17%) and Pomacanthidae (17%). *Chromis lubbocki* (37%), *Abudefduf luridus* (11%) and *Mulloidichthys martinicus* (9%) were the dominant species at 'Farol Baixo'. At 'Santo Antão' the most important species were *Lutjanus fulgens* (19%), *M. martinicus* (16%) and *C. lubbocki* (10%). The latter species also dominated at 'Tchuklassa' (28%), followed by *Myripristis jacobus* (18%) and *A. monroviae* (17%). At 'Kwarcit' the assemblage was dominated by *Parapristipoma humile* and *C. lubbocki* (24%), followed by *M. martinicus* (7%) (see details in Table 2.3).

At shallow and deep reefs the two-way crossed PERMANOVA analyses pointed to a significant interaction between reefs and strata (shallow reefs: PERMANOVA, F= 2.34, P= 0.007; deep reefs: PERMANOVA, F= 2.10, P= 0.001). However, the multiple comparison tests showed that the structure of the fish assemblage in each site was different for each stratum (P< 0.001). Furthermore, consistent differences were observed when strata were compared between reefs (P< 0.001). Moreover, preliminary analyses using n-MDS (not presented) resulted in high stress (>0.2) twodimensional representations with no clear patterns due to the high variation in the data, possibly due to the interaction between factors. Therefore, the merged data for each sample (sum of strata densities) was further analysed using n-MDS. Concerning the shallow reefs, the latter analysis highlighted the differences between the two studied sites. In fact, the samples from the shallow reefs clustered in two different groups at the horizontal axis, with the vertical axis displaying variability among samples from each site (Figure 2.9). These results corroborated the PERMANOVA results of differences between reefs (P< 0.001, post-hoc comparisons among reefs within each stratum). The species which most contributed to these differences were: *Thalassoma pavo* (Indval= 0.937), *Abudefduf luridus* (Indval= 0.805), *C. lubbocki* (Indval= 0.794) and *Ophioblennius atlanticus* (Indval= 0.600), at 'Farol Baixo'; and *L. fulgens* (Indval= 0.983), *Balistes punctatus* (Indval= 0.964), *Diodon holacanthus* (Indval= 0.960), *Chilomycterus reticulatus*

(Indval= 0.900), *A. monroviae* (Indval= 0.889), *Diplodus fasciatus* (Indval= 0.889), *Chaetodon robustus* (Indval= 0.754) and *L. atlanticus* (Indval= 0.500) at 'Santo Antão' (Figure 2.9). The n-MDS analysis also revealed differences between 'Tchuklassa' and 'Kwarcit', as the samples from the two deep sites clustered in different groups at the horizontal axis, with the vertical axis again displaying the variability within each site (Figure 3.10). Again differences were highlighted by the PERMANOVA ($P< 0.01$, tests among reefs within each stratum). The species which most contributed to the differences between the deeper reefs were: *A. monroviae* (Indval= 0.880), *M. jacobus* (Indval= 0.772) and *P. prayensis* (Indval= 0.701), *C. robustus* (Indval= 0.657) and *Bodianus speciosus* (Indval= 0.638) at 'Tchuklassa'; and *Mycteroperca fusca* (Indval= 1.000), *P. humile* (Indval= 0.980), *Heteropriacanthus cruentatus* (Indval= 0.909), *Spicara melanura* (Indval= 0.761), *A. scriptus* (Indval= 0.746), *Holacanthus africanus* (indval= 0.729), *P. dentex* (Indval= 0.681), *D. fasciatus* (Indval= 0.615) and *Cephalopholis taeniops* (Indval= 0.638) at 'Kwarcit' (Figure 2.10).

The mean density of fish showed a positive relationship with habitat rugosity (linear regression, $R^2= 0.4556$, $F_{1,55}= 46.03$, $P< 0.001$; Figure 2.8). Significant trends were found at all individual sites except at 'Santo Antão'. At the deeper depth the relationship between habitat rugosity and fish density was reef independent (ANCOVA, $P< 0.001$).

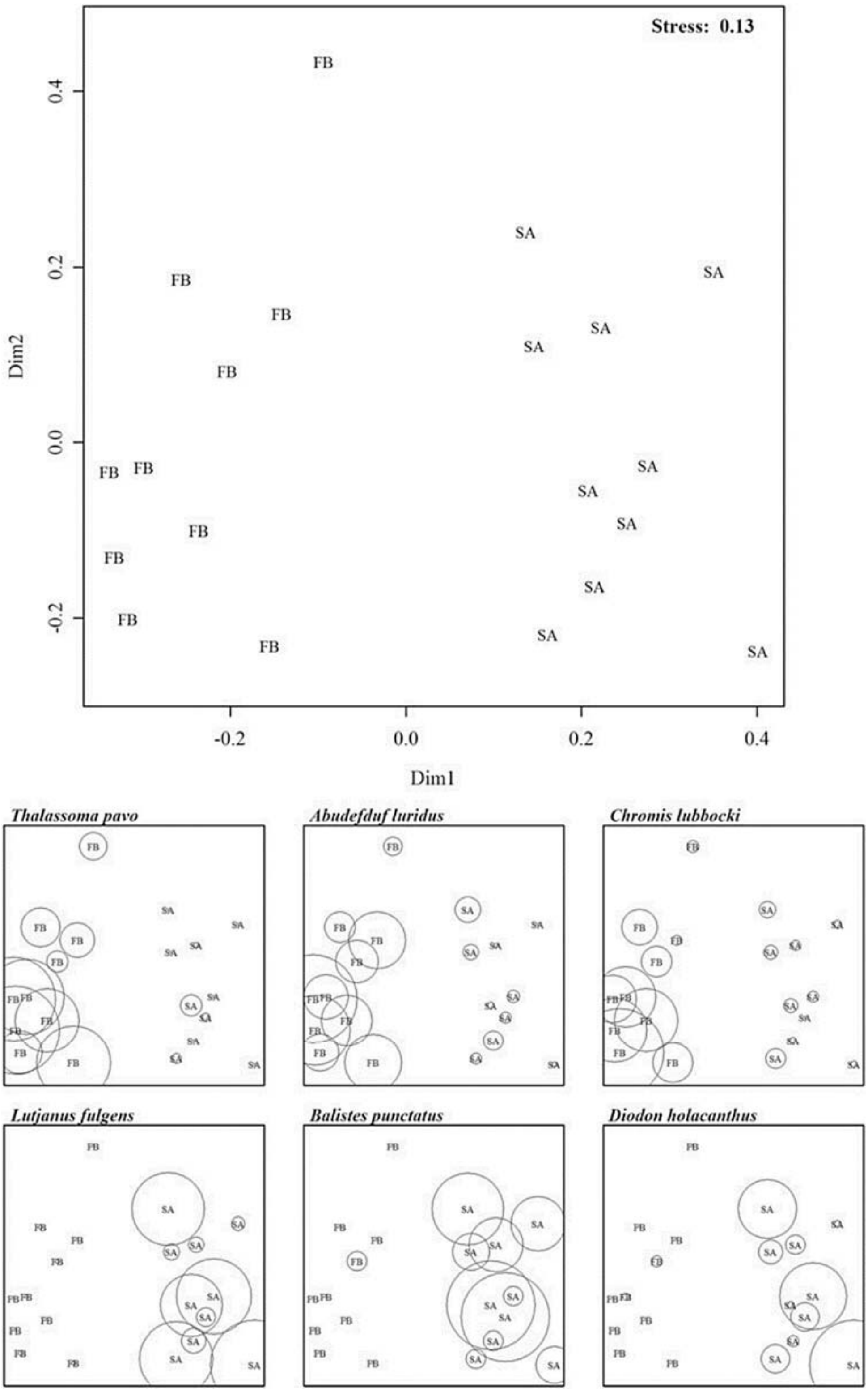

Figure 2.9. Non-metric multidimensional scaling plot of the fish community data from low depth sites at Santa Maria Bay. FB, 'Farol Baixo' (NR); SA, 'Santo Antão' (AR). Bray–Curtis index of similarity using untransformed abundance data. Abundance data superimposed (bubble size) for species that contributed most to the differences between AR and NR (indicator species analysis).

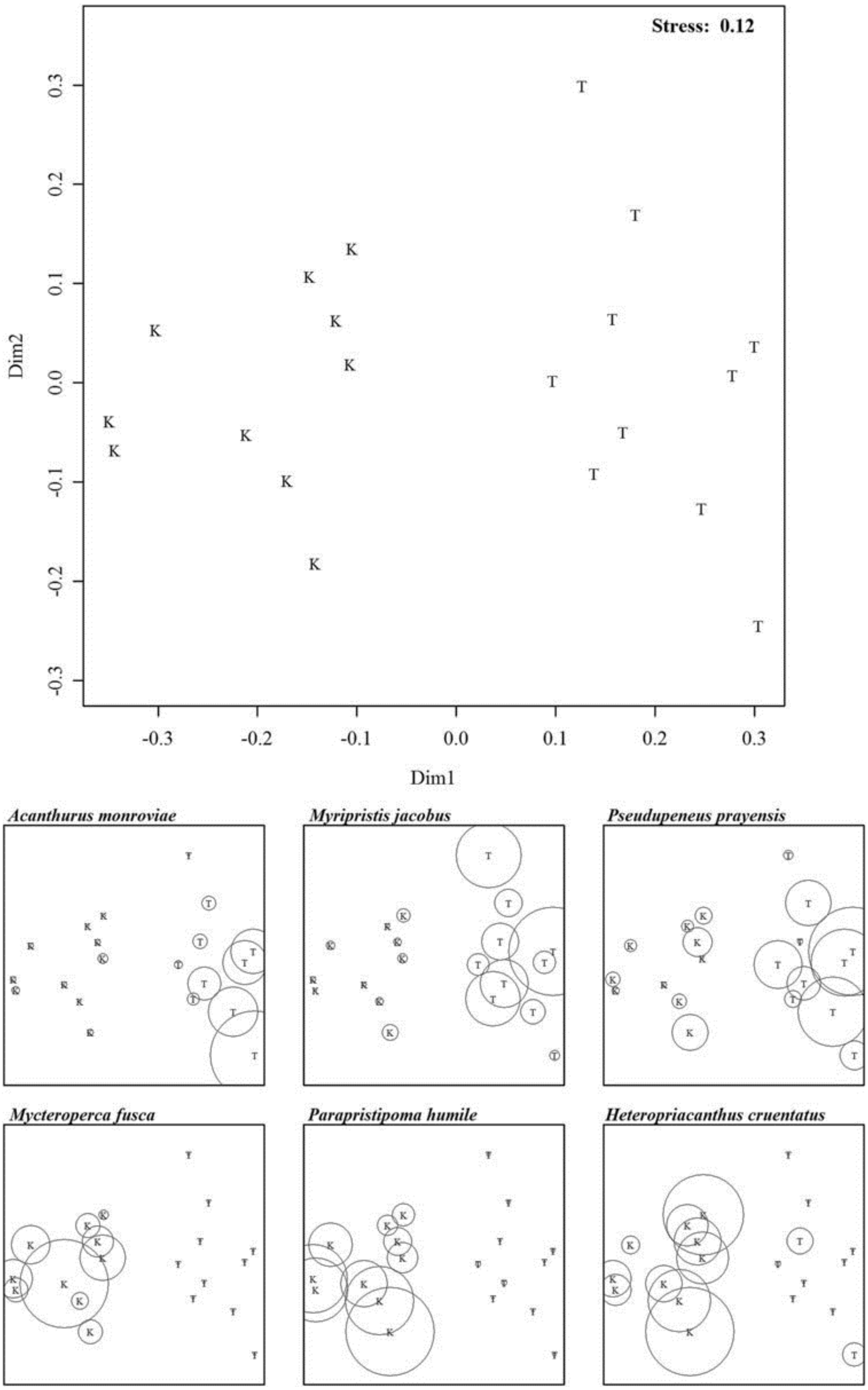

Figure 2.10. Non-metric multidimensional scaling plot of the fish community data from deep depth sites at Santa Maria Bay. T, 'Tchuklassa' (NR); K, 'Kwarcit' (AR).

Bray–Curtis index of similarity using untransformed abundance data. Abundance data superimposed (bubble size) for species that contributed most to the difference between AR and NR (indicator species analysis).

Most species showed similar size-ranges within the same depths. However, for larger-bodied species, a wider size-range was observed on the deeper sites. Most comparisons, in terms of the size distributions and respective median, showed significant differences between sites at similar depth. On the shallow reefs higher mean sizes and medians were observed at 'Santo Antão', while on the deeper reefs no clear pattern was noted (Table 2.4).

2.5 DISCUSSION

Artificial reefs are increasingly used as a tool to mitigate the human impact on NRs and to promote a higher biodiversity. Thus, as mentioned by Thanner *et al.* (2006) it is important to understand the extent to which the ARs can effectively provide similar habitats on NRs areas. Furthermore, the degree to which the fish assemblages on the ARs become similar to those on NRs has not been well demonstrated. Most studies involving the comparison of the fish assemblages from NRs and ARs do not control reef size, age and degree of isolation, because the man-made reefs are typically much smaller, younger, and more isolated than their natural counterparts (Carr and Hixon, 1997). In the present study we could only overcome one of the above mentioned constraints, by choosing sites with a similar degree of isolation and vertical relief, as there are no NRs of similar size or age to the ARs off Santa Maria Bay. This comparative study provides the first insight on the potential use of ARs (shipwrecks) to mimic, at some level, NRs in Cape Verde coastal waters, allowing similar fish assemblages to establish.

Table 2.4. Results of the statistical tests (U, Mann–Whitney; KS, Kolmogorov–Smirnov) used for the inter-site comparisons related to size distributions for the most numerically abundant species at the shallow (‘Farol Baixo’ and ‘Santo Antão’) and deep reefs (‘Tchuklassa’ and ‘Kwarcit’). ns, non-significant; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

Species	‘Farol Baixo’			‘Santo Antão’			*U*	*P* level	KS	*P* level	‘Tchuklassa’			‘Kwarcit’			*U*	*P* level	KS	*P* level
	Mean	SD	Median	Mean	SD	Median					Mean	SD	Median	Mean	SD	Median				
Abudefduf luridus	10.0	2.57	11.0	13.1	2.79	12.5	19643.5	***	0.38	***	10.5	2.39	11.0	11.4	1.97	11.0	3428	***	0.33	***
Abudefduf saxatilis	10.0	7.36	9.0	18.5	3.92	20.0	7136.5	**	0.62	***	18.3	2.36	23.3	14.0		20.2	6.5	ns	0.86	ns
Acanthurus monroviae	13.7	2.91	15.5	18.3	6.89	14.0	1119.5	***	0.30	ns	33.2	4.31	32.0	16.5	4.24	14.0	322293.5	***	0.90	***
Aulostomus strigosus	38.5	10.43	37.0	37.0	11.12	42.0	11062.5	ns	0.11	ns	46.8	10.31	42.0	44.5	11.61	42.0	39721	*	0.12	*
Canthigaster rostrata	5.6	1.69	5.0	6.2	1.54	5.0	1799	ns	0.18	ns	6.7	2.42	5.0	6.0	2.1	5.0	10003.5	*	0.18	*
Cephalopholis taeniops	17.0	5.48	14.0	16.6	4.89	14.0	2730	ns	0.04	ns	21.6	9	21.5	22.2	7.41	21.5	16189	ns	0.09	ns
Chromis lubbocki	9.0	2.46	9.0	10.3	1.32	11.0	382420.5	***	0.29	***	10.4	3.41	11.0	10.8	2.52	11.0	2597395	*	0.10	***
Coris atlantica	10.5	2.92	9.0	14.5	5.65	14.0	2138	***	0.55	***	12.9	4.32	11.0	14.0	3.65	14.0	6598	**	0.20	*
Diplodus fasciatus	27.7	5.01	27.0	30.4	6.26	32.0	2576	*	0.23	ns	28.2	7.22	27.0	29.7	5.47	32.0	15418	**	0.22	***
Diplodus prayensis	24.3	3.83	29.5	20.5	3.77	20.0	12144.5	***	0.45	***	22.1	5.41	20.0	22.5	4.47	20.0	4640.5	ns	0.10	ns
Heteropriacanthus cruentatus	22.9	4.31	21.5	20.1	3.58	20.0	9022	***	0.31	***	19.9	2.9	21.5	19.3	3.01	20.0	1824.5	ns	0.13	ns
Lutjanus fulgens	14.8	3.15	17.0	15.7	3.42	17.0	6293	ns	0.46	**	9.9	1.84	9.0	23.8	4.27	27.0	37.5	***	0.98	***
Lutjanus goreensis	5.9	3.44	8.3	16.2	1.77	23.8	340	***	0.92	***	15.6	4.5	15.5	20.4	5.73	20.0	719	***	0.40	*
Mulloidichthys martinicus	16.3	3.9	17.0	24.4	7.01	20.0	64387	***	0.65	***	28.8	6.08	32.0	29.6	6.98	32.0	113235.5	**	0.09	*
Myripristis jacobus	17.7	5.24	20.0	20.1	5.1	20.0	34447	***	0.21	***	19.3	3.65	20.0	18.3	3.56	20.0	426983.5	*	0.11	***
Parapristipoma humile	12.7	4.49	12.5	17.6	5.43	14.0	3952	***	0.62	***	15.5	5.44	17.0	23.1	4.83	20.0	15450.5	***	0.48	***
Pseudupeneus prayensis	16.5	5.47	21.5	14.8	2.94	14.0	2160.5	*	0.32	**	17.4	4.87	20.0	18.9	6.19	21.5	7094	ns	0.19	*
Sargocentron hastatus	17.5	3.2	17.0	20.4	4.23	21.5	915	***	0.29	*	19.8	4.3	20.0	20.3	3.1	20.0	29201.5	ns	0.13	*
Sparisoma cretense	18.0	6.07	21.5	20.7	5.65	21.5	6054.5	***	0.19	*	24.5	5.67	27.0	24.6	6.64	27.0	31830.5	ns	0.06	ns
Thalassoma pavo	7.3	3.85	7.0	8.5	2.8	9.0	3447.5	ns	0.31	*	7.8	2.76	7.0	7.3	2.59	7.0	32384.5	*	0.21	***

The present study showed that the Santa Maria Bay reefs support diverse fish assemblages, including both coastal and oceanic species. Most of these species were characteristic of infra-littoral habitats, have broad distributions and are readily found on rocky bottoms of the Cape Verde archipelago (Franca and Vasconcelos, 1962; Lloris *et al.*, 1991; Reiner, 1996; Monteiro *et al.*, 2008). Several of these species can also be found in the Canary Islands (Bortone *et al.*, 1994; Herrera *et al.*, 2002) and São Tomé and Príncipe Islands (Debelius, 1997). Furthermore, some of the recorded species are thought to have quite distinct origins (e.g. amphi-Atlantic, cosmopolitan or Atlantic–Mediterranean). Monteiro *et al.* (2008) suggested such findings might have two reasons: (i) Lloris *et al.* (1991) identified the Cape Verde Islands as the frontier between the Lusitanian province and the tropical West African sub-region; and (ii) the archipelago is located in the vicinity of the North Equatorial Current and the southern part of the Canary Current, which is part of the clockwise ocean current system of the North Atlantic Ocean (Zhou *et al.*, 2000). The list of species identified in this study should not be considered exhaustive, as sampling was limited in time and the visual census methods used does not favour the observation of small sized cryptobenthic species. The total number of species recorded was, however, greater than those previously reported by Monteiro *et al.* (2008) for two Cape Verde seamounts: 'Northwest' (27 species) and 'João Valente' (46 species). Furthermore, we observed 25 species that have not been reported before on the seamounts. Interestingly, 12 species recorded by the previous authors on the seamounts were not observed in the present study, seven of which were pelagic species. The seamounts found in this area have similar geological characteristics to those of the adjacent islands, which are in general composed of basalt rock (Mitchell-Thomé, 1972). The latter seamounts are commercially unexploited (Monteiro *et al.*, 2008), which is not the case of the Santa Maria Bay, whose fish assemblages are mostly (60%) composed of economically important species that are fished regularly by the local artisanal fleet. The slightly higher number of species found on the deeper reefs were due mostly to highly mobile, pelagic species (e.g. *Caranx crysos*, *P. dentex*, *Seriola dumerili* and *S. rivoliana*), which are not characteristic of the reefs, but often visit such habitats while foraging for preys (M.N. Santos, personal observation).

The present study demonstrates that the total number of species and mean fish densities at the ARs were similar to that of the NRs. These may be due to some level of similarity in terms of habitat complexity (namely at the deeper sites) and a result of the relative isolation of the

ARs, which favour the 'oasis' effect suggested by Santos *et al.* (2005). In Santa Maria Bay the scarcity and the discontinuity of hard substrata may be the cause of the high number of fish species found. Several authors have suggested that species richness and abundance associated with ARs may be related to the degree of isolation (Gascon and Miller, 1981; Walsh, 1985; Bohnsack *et al.*, 1991; Ody and Harmelin, 1994; Herrera *et al.*, 2002). On the other hand, as suggested by Gratwicke and Speight (2005), possible explanations for the higher number of fishes in rugose areas include increased refuge from predators and/or increased primary productivity (or availability of other food resources) on the hard surfaces that can support more fishes. Rocky biotopes located in the neighbourhoods of the ARs may serve as source areas, facilitating colonization.

The local NRs have a higher rugosity and structural complexity (more holes and crevices) than the wrecks, but the ARs showed higher values for the investigated ecological indices (mean species richness, mean diversity and mean equitability). Similar results have been previously reported by Rilov and Benayahu (2000), but are in contrast with those found in other studies carried out in tropical waters where high-relief structures were used (Carr and Hixon, 1997; Rooker *et al.*, 1997).

The similar assemblage's composition at the ARs and at the NRs (differences were mainly due to rare species) suggests that these ARs may have already reached an equilibrium point. But species composition can also change in the future depending on the succession of other colonizers (benthic epifauna and epiflora), as shown by other authors (Ardizzone *et al.*, 1997; Santos *et al.*, 2011). The differences found between ARs and NRs in this study were mainly due to a few particular species. In the case of the shallow NRs, the higher abundance of macrofauna (unpublished data) may favour the presence of *T. pavo* and *A. luridus*, while at 'Santo Antão' *B. punctatus* and *D. holocanthus* may be using the surrounding soft bottom to prey. In fact, the latter species was frequently observed feeding at 'Santo Antão'.

With regards to the deeper reefs, large shoals of *P. humile* were commonly observed around the ARs (M.N. Santos, personal observation), whereas *M. fusca* were found to swim frequently near the bottom in small shoals of two to five specimens. According to Bustos *et al.* (2009) the latter species is characteristic of rocky and sandy–rocky seabeds from the shore down to a depth of 150 m and is most frequent in dips and bays, where it swims around large rocks at middepths, most frequently alone but sometimes in small shoals. *Parapristipoma humile* and P. cruentatus, which mostly feed on benthic invertebrates, were found to be more abundant at 'Kwarcit'. At 'Tchuklassa', *M. jacobus* were seen to benefit from the greater availability of small crevices and holes, while *A. monroviae* forms large shoals concentrated on the sheltered part of this rocky reef.

The habitat rugosity and complexity records from all study sites were within the range of what has been reported for similar habitats. Differences observed between the two reef types reflected the greater heterogeneity of the NRs in contrast to the ARs which have fewer micro-habitats available. Several studies which analysed fish assemblages at local scales demonstrated that the less complex habitats (ARs) can support higher fish density than more complex ones, but more complex habitats generally support a higher number of fish species (Luckhurst and Luckhurst, 1978; Roberts and Ormond, 1987; Gorham and Alevizon, 1989; Ferreira *et al.*, 2001; Gratwicke and Speight, 2005). However, the present study showed no fish density differences between sites, but higher mean species richness at the lower complex artificial reefs. No explanation for such contradictory results could be found. However, the positive relationships found between habitat rugosity and number of species and fish density was in accordance to what has been commonly observed (Rooker *et al.*, 1997; Gratwicke and Speight, 2005). In the present case such relationships were mostly a consequence of the presence of a high number of species with medium-amplitude vertical movements and more-or-less important horizontal movements, but also due to a few highly mobile, gregarious, pelagic species. However, several other environmental and ecological factors can strongly influence fish assemblages.

The results related to the size structure of the most abundant species do not allow a detailed understanding of the role of the study sites for the different species. Although, based on our in situ observations during data collection, it appears both reef types are providing some common uses.

These include sheltering, growth and nursery areas for juveniles and spawning/mating areas for adults (the latter particularly for the wrasses, genus *Abudefduf*, for which nests were commonly observed). Therefore, further investigations are required, to better understand if these ARs can mimic NRs as essential fish habitats (see definition by Benaka, 1999).

2.6 CONCLUSION

The present study provides the first comparative study of fish assemblages of NRs and ARs in Cape Verde waters, and has demonstrated that decommissioned vessels can mimic the local NRs by supporting diverse fish assemblages similar to those from nearby natural habitats. Furthermore, such affects were noted across the depth-range studied (10– 30 m). These facts justify the potential of using ARs to attract a wide range of eco-tourists, from shallow to deep sites (IPIMAR, unpublished data). These findings might be particularly useful for local managers, because the Cape Verde Archipelago is under increasing pressure from the local fishing and ecotourism industries, therefore exposing natural reefs and their associated fish assemblages to higher vulnerability.

In a country which is highly dependent on tourism and has excellent conditions to develop ecotourism activities, it is important to promote local fish biodiversity (and associated fauna), as a strategy to support sustainable development of other marine related activities. A decline in the number and abundance of local fishes had been reported (Anon, 2004a; personal communications from local diving operators and environmental managers). Thus, by creating new habitats that resemble natural reefs in areas where the occurrence of hard substrate is limited, ARs may play a major role on the management of local environmental and ecotourism issues. These man-made structures may allow human pressures over the NRs to be reduced (as more diving sites are available) and the local development of ecotourism activities (e.g. diving, snorkelling and reef sightseeing on bottom glass boats). A lower pressure over the NRs will contribute positively to the natural rehabilitation of deteriorated habitats. However, the deployment of decommissioned vessels should only be considered within the scope of a programme aiming to manage the local coastal activities. Furthermore, the use of such structures should not be limited to decommissioned vessels, as more complex structures could possibly support the establishment of more species and providing them a wide range of uses. On the other hand, the use of ARs should not be promoted indiscriminately, and a management plan involving all the stakeholders should be developed to avoid conflicts and maximize their potential.

CHAPTER III

The importance of small scale artificial reefs for the biodiversity of macrofaunal communities in Cabo Verde

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The importance of small scale artificial reefs for the biodiversity of macrofaunal communities in Cabo Verde

3.1 SUMMARY

Coastal ecosystems are among the most productive ecosystems in the world. Reef-based tourism, one of the multiple uses of coastal zones, has become more important in terms of magnitude and contribution to national economies, as well as to the wellbeing of local communities. Tourism is a growing activity in Cape Verde and it can lead to more intensive and uncontrolled fishing and diving activities, affecting the quality of marine habitats. To mitigate this biodiversity problem, a private diving operator, supported by the local authorities, decided to deploy the first artificial reefs (ARs) in the Archipelago, just off Santa Maria Bay (Sal Island). To evaluate the ARs capacity to promote benthic biodiversity in Santa Maria Bay, the benthic communities within Santa Maria Bay were characterized and compared to those from nearby natural reefs (NRs), located at the same depth (9 and 25 m). All study sites were randomly sampled in 2008 and 2009. A total of 204 operational taxonomic units (OTU) were identified, distributed by 177 OTU of non-colonial fauna and 27 OTU of colonial fauna, mostly consisting of the Amphipoda, the Sipuncula and the Polychaeta (representing 80.8%) and *Balanus amphitrite* (representing 80.5%) respectively. The structure and composition of the macrobenthic assemblages varies within Santa Maria Bay - samples collected at low depth presented more heterogeneity than the deeper ones. The analysis of shallow sites clearly shows that both NRs and ARs present different assemblages regarding structure and composition while in deeper sites, a greater difference was observed, indicating a clear separation of both reefs. Both lower depth sites present a steep increase in the number of OTUs, considering that abundance values are relatively low, with the NR presenting more species than the AR but also higher variation. Both sites presented low dominance as indicated by the high values of Shannon Evenness values (J). Regarding moderate depth sites, the NR and the AR, presented high species richness. The rarefaction curves showed that both sites present a steep increase in the number of species and diversity is higher in the NR than in the AR (higher diversity at the NR regarding ES 50 and H' diversity indices). Both assemblages show high equitability.

These results suggest that the use of relatively small ARs for specific purposes, namely nature-based sustainable tourism, as long as properly monitored and managed, seems to be a good alternative, removing pressure from natural areas and eventually enhancing local populations and biodiversity.

Keywords: Natural and artificial reefs, macrofauna, diversity, diving tourism, Santa Maria Bay, Sal Island (Cape Verde).

3.2 INTRODUCTION

Biodiversity loss is a major issue concerning marine ecosystems, being particularly important for marine conservation (e.g. Sala and Knowlton, 2006; Worm *et al.*, 2006; Stachowicz *et al.*, 2007; Hooper *et al.*, 2012). Biodiversity can be expressed and quantified at several levels, but traditionally it is partitioned into local (α) and regional (γ) diversity (Magurran, 2004). The variation in species composition along a determined scale is denominated β diversity but until recently has received little attention concerning marine communities (Gray, 2000; Koleff *et al.*, 2003; Bevilacqua *et al.*, 2012). β-diversity quantifies the turnover (or complementarity) in species across space, time and environmental gradients, therefore providing a way to scale diversity (Leaper *et al.*, 2011; Bevilacqua *et al.*, 2012). It is also essential in estimating and mapping diversity, identifying scales of change and understanding ecological processes (Vellend, 2010; Leaper *et al.*, 2011; Bevilacqua *et al.*, 2012) and consequently it is essential for marine biodiversity conservation (Gering *et al.*, 2003; Leaper *et al.*, 2011; Kraft *et al.*, 2011), namely regarding the design of representative networks of marine reserves (Hewitt *et al.*, 2005; Winberg *et al.*, 2007; Bevilacqua *et al.*, 2012).

Cabo Verde has been recognised as a marine biodiversity hot-spot (Roberts *et al.*, 2002). However, it ranks in the top ten centers of endemism most threatened by species extinction (Roberts *et al.*, 2002). The archipelago presents a large number of endemic species, namely several Conus species (47 out of the 50 species present in the archipelago are endemic), representing 10% of the total number of Conus species (Cunha *et al.*, 2005; Duda and Rolán, 2005). In Cabo Verde, the vulnerability of marine resources and biodiversity reported by the national authorities lead to a series of governmental efforts to reduce the pressure on the species and their habitats, aiming towards the sustainable development of the country (Anonymous, 2004b; Andrade, 2004). The recent increase in the demand for fishing products in Cabo Verde has been followed by an increase in the captures of fish, crustaceans and molluscs since 2005 (Anonymous, 2007a), mostly supported by an intensive and uncontrolled local fishing activity (Andrade, 2004). What is more, biodiversity loss has been reported as a major environmental issue for the archipelago due to increasing human pressure in the coastal areas (Anonymous, 2004b, 2009b).

Human activities in coastal areas associated to tourism development such as scuba diving can have detrimental effects on the ecosystems, especially in tropical waters (see Davenport and Davenport, 2006, for a review). It has been proved that scuba divers are responsible for a large number of impacts on coral reefs (Rouphael and Inglis, 2001; Zakai and Chadwick-

Furman, 2002; Barker and Roberts, 2004; Davenport and Davenport, 2006). In Sal Island, the scuba diving market has increased recently as a result of the increased tourism but depends largely on natural reefs (NR) located in the Baía de Santa Maria where 6 companies operate. The concern regarding local biodiversity loss but also the need to diversify and increase the number of diving sites in this bay led one scuba-diving company to propose the creation of artificial reefs (AR) in the area using sunken ships, a commonly used strategy to enhance the scuba diving market at the local level (Morgan *et al.*, 2009, and references therein). Two of the main objectives of implanting ARs is to promote (or maintain) local biodiversity, offering refuge for rare and endangered species and to mitigate environmental impacts, by diverting human activities from natural areas (Abelson, 2006). Even though ARs proved to be successful in mitigating impacts, namely in coral reefs (Seaman, 2007), in order to be an effective tool for restoration purposes, their ecological performance needs to be proved locally with data from monitoring assessments (Seaman, 2007). In recent years a lot of information has been gathered regarding artificial reefs, namely their role in the surrounding habitats and contribution for restoration initiatives (Carr and Hixon, 1997; Perkol-Finkel *et al.*, 2006; Seaman, 2007; Burt *et al.*, 2009) with considerable debate regarding their effects, for example, in the enhancement of fish populations (Svane and Petersen, 2001; Brickhill *et al.*, 2005; Perkol-Finkel and Benayahu, 2009). Even though the patterns of species richness concerning ARs and NRs have been commonly studied (e.g. Perkol-Finkel *et al.*, 2005; Moura *et al.*, 2007; Santos *et al.*, 2013), the contribution of ARs in the variation in species diversity (β-diversity) has been largely neglected.

In the present study the macrobenthic communities in natural (NR) and artificial reefs (AR) are compared at two different depths in order to assess the role of sunken vessels (AR) for the development of fouling communities, with special emphasis on their contribution to local biodiversity. The main objectives of the present study are to 1) briefly characterize the benthic communities within Baía de Santa Maria and 2) to analyse the patterns of benthic biodiversity (α) and its variation within the area (β). Regarding the second objective, the main hypotheses to be tested is that ARs present similar benthic diversity to NRs at depths of 9m (1) and at 25m (2).

3.3 MATERIAL AND METHODS

3.3.1 Study area

This work was undertaken Sal Island, Cabo Verde, more specifically in the Baía de Santa Maria (Figure 3.1) where there are NRs and ARs (two submerged ships). The two ARs present several differences, namely the time of submersion at sampling (2.5 years for ”Kwarcit” and 42 years for ”Santo Antão”), the size (25m vs 50m) and finally site depth (≈25m vs ≈9m).

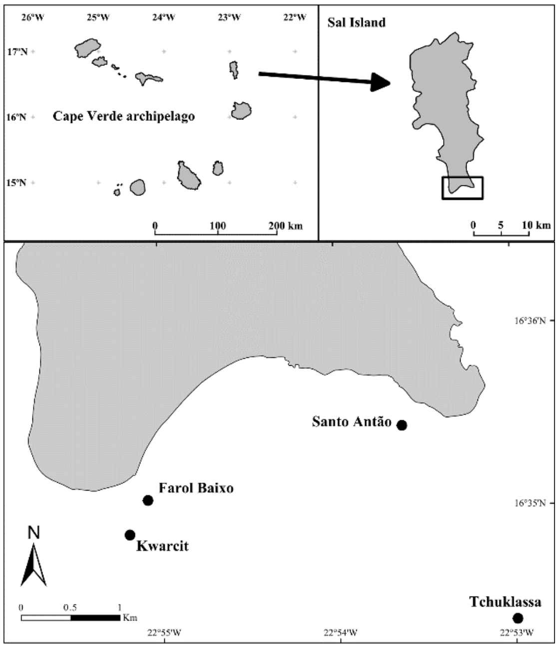

Figure 3.1: Map of the Baía de Santa Maria, Sal Island, Cabo Verde with sampling sites marked in the larger map. Farol Baixo and Tchuklassa represent natural reefs (NR) and Santo Antão and Kwarcit are artificial reefs (AR; sunken vessels).

Two locations at low depth (≈ 9m) were sampled, an AR (SA -”Santo Antão”) and a NR (FB - Farol Baixo). The latter is located in the westernmost area of the bay (Figure 3.1) at a depth of 9-12m but all the samples were taken in the inner part of the bay as the outer part may suffer from different oceanographic conditions. This site is dominated by corals, with limited algal cover, presenting a large diversity of fish (damselfish and butterflyfish species, sparids, Santos *et al.*2013). ”Santo Antão” (SA) was a former 53m long freight ship that sunk in 1966, at a depth of 9m in a soft bottom area and now forms a wreckage that extends for an area of approximately 100m by 20m, presenting a rich fish assemblages (Santos *et al.*, 2013).

Two other locations at deeper depth (≈ 25m) were sampled, an AR (”Kwarcit”) and a NR (Tchuklassa). Tchuklassa (T) is one of the natural reefs in Sal, located 2 miles offshore at the eastern part of the bay, in the middle of the channel that separates Sal and Boavista islands. This NR is characterized by its morphology, displaying a plateau area at 16m and a large overhang with vertical walls that extends from 16 to 40m depth, but also by its strong currents, making it a common way-point for large pelagic fish such as tuna, saw-fish, shark species and manta rays. The plateau comprises rocks of several sizes and some larger boulders, with small vertical relief, but presenting crevices where fauna can find refuge. The overhang is mainly characterized by corals that densely populate its vertical walls and ceiling, specifically *Tubastrea aurea* with the sea urchins *Diademma antillarum* and *Eucidaris* *tribuloides* also presenting high densities. “Kwarcit” (K) was a former soviet trawler that was sunk in 2006 in order to create the first “intentional” artificial reef in the Baía de Santa Maria. This AR was created mainly for recreational purposes (new dive spot), being located in the westernmost part of the bay, laying at 28m depth over a plateau-like large rocky area that, most of the times, is covered with sand.

3.3.2 Sampling

At each site 6 quadrats (25 cm × 25 cm, internal area of 0.0625m^2) separated by a few meters were randomly placed for sampling. All the samples were collected in vertical surfaces, and with similar vector (facing North). The vertical surfaces were scraped with chisels and the material was collected with the help of an airlift (Moura *et al.*, 2007). The samples were sieved through a 0.5mm square mesh and the material retained in the mesh was fixed using a buffered 4% formalin seawater solution stained with rose bengal. The samples were sorted under binocular microscopes and the fauna identified to species level whenever possible (operational taxonomic unit OTU). The abundance of non-colonial fauna was determined by counting the number of individuals for each species. For the colonial fauna and barnacles (the latter because they are destroyed by sampling procedures) biomass was used as the abundance measure for each taxon (Moura *et al.*, 2008). For simplification, colonial fauna and barnacles will be hereafter referred as colonial fauna. The biomass of each OTU was obtained for biological samples dried to a constant weight at 70°C (usually for at least 24-48h). The ash-free dry weight (AFDW) was determined by burning the animals at 450°C for 4h in a muffle furnace, and was calculated by subtracting the ash weight from the dry weight (Moura *et al.*, 2008).

3.3.3 Benthic communities within Baía de Santa Maria

Multivariate methods were used to detect differences in the composition and structure of the macrofaunal communities (both for non-colonial organisms and for colonial fauna), namely non-metric multidimensional scaling (n-MDS) and PERMANOVA using abundance data for non-colonial organisms and biomass data for colonial fauna.

Data was transformed ($\sqrt{}$ or $\sqrt[4]{}$) in order to reduce the weight of the most abundant taxa (OTUs) in the analysis (Clarke and Warwick, 2001), and a distance matrix was built using the Bray-Curtis dissimilarity index. The composition of macrofaunal communities was assessed using the Jaccard's coefficient using presence/absence data (Legendre and Legendre, 1998). Indicator species analysis (ISA) (Dufrêne and Legendre, 1997) was conducted on macrofauna data to assess macrofaunal associations to sampling sites by calculating an indicator value (ranging from 0 to 1) that takes into account the frequency and the abundance of each taxon on the defined groups. ISA allows for the examination of common and rare taxa within a community rather than focusing solely on common species, with high indicator values reflecting both high abundance and prevalence of a taxa within a group. Significance of indicator values was assessed using Monte Carlo simulations with 999 randomizations with p-values representing the probability of a similar observation using randomized data. For this analysis only the OTUs that presented a total abundance of more than 5 individuals were selected to prevent false positives. OTUs with a total abundance less than or equal to 5 individuals (0.1% of the total dataset) are considered uncommon.

3.3.4 Diversity patterns within Baía de Santa Maria

The local diversity (α) for each sample was evaluated using the number of species (S), Hulbert's estimated number of species (ES) and the Shannon index of species diversity (H'). Equitability was estimated using Pielou's evenness index (J'). Because some of the samples presented low abundance, Hulbert's estimated number of species was estimated for a sample of 50 individuals (ES 50). Rarefaction curves were also used to assess the diversity patterns of each site (Gotelli and Colwell, 2001). Differences in local diversity between sites (AR and NR) within low (LD - 9m) and moderate (MD - 25m) depths were tested using analyses of variance (ANOVA). When the assumptions of ANOVA were not met (homogeneity of variances, Levene test; normality, Lilliefors (Kolmogorov-Smirnov) test), appropriate transformations were used (Underwood, 1997). If the assumptions were still not met non-parametric tests were used (Kruskal Wallis).

Species turnover (β diversity) was assessed using four different indices: the classic Whitaker index (βw), the Jaccard index (βj), and two indices proposed by Lennon *et al.* (2001), the z index (βz) and the sim index (βsim). All these indices are presence/absence indices and were calculated according to the formulas presented in Koleff *et al.* (2003). The use of several indices is justified by their characteristics as they reflect different aspects of species turnover. Three of them measure the continuity of species among habitats, namely βw, βj and βz. βw reflects the difference in α diversity of two areas or more areas relative to the regional (γ) diversity (Koleff *et al.*, 2003; Magurran, 2004). βj reflects the differences in species composition between assemblages (Magurran, 2004), whereas βz is dependent on species/area relationships, therefore measuring the species turnover related to the accumulation of species with area (Koleff *et al.*, 2003; Magurran, 2004). The βsim index is more related to the gain and loss of species between assemblages and is less influenced by local species richness (Lennon *et al.*, 2001; Magurran, 2004). The total turnover between assemblages was also calculated using the pooled samples of each group to be compared, FB and SA and T and K . To look more on the variation of the species turnover within and between groups, the indices were calculated for all possible pairs of samples for each hypothesis and analysed using boxplot graphs. β diversity was also measured using multivariate dispersion (Anderson *et al.*, 2006).

All the analyses were conducted in the open source statistical software R v2.15.0. (R Development Core Team, 2005). β diversity indices were calculated using the package Vegan (Oksanen *et al.*, 2013). For the ISA, the package indicspecies was used (Caceres and Legendre, 2009).

3.4 RESULTS

In the present work, a total of 204 OTU were identified. For the non-colonial fauna, 4835 individuals were analysed, distributed among 177 OTU. The main faunal groups represented in the samples were the Amphipoda, the Sipuncula and the Polychaeta, representing 80.8% of the total abundance (with 18, 4 and 70 OTU, respectively). Other faunal groups included Bivalvia (367 individuals; 14 OTU), Decapoda (237 individuals; 9 OTU), Gastropoda (83 individuals; 32 OTU) and Echinodermata (52 individuals; 6 OTU) and several other groups with low abundance.

Concerning the colonial fauna, 27 OTU were discriminated, with eight OTU attaining 98.4% of the total biomass, namely *Balanus amphitrite* (80.5%), *Hydrozoa sp.*E (8.9%), *Schizoporella cf. errata* (3.8%), *Hydrozoa sp.*I (2.3%), *Bugula neritina* (1.0%), *Scrupocellaria scruposa* (0.9%), *Leuconia sp.* (0.7%) and *Crisia sp.* (0.4%).

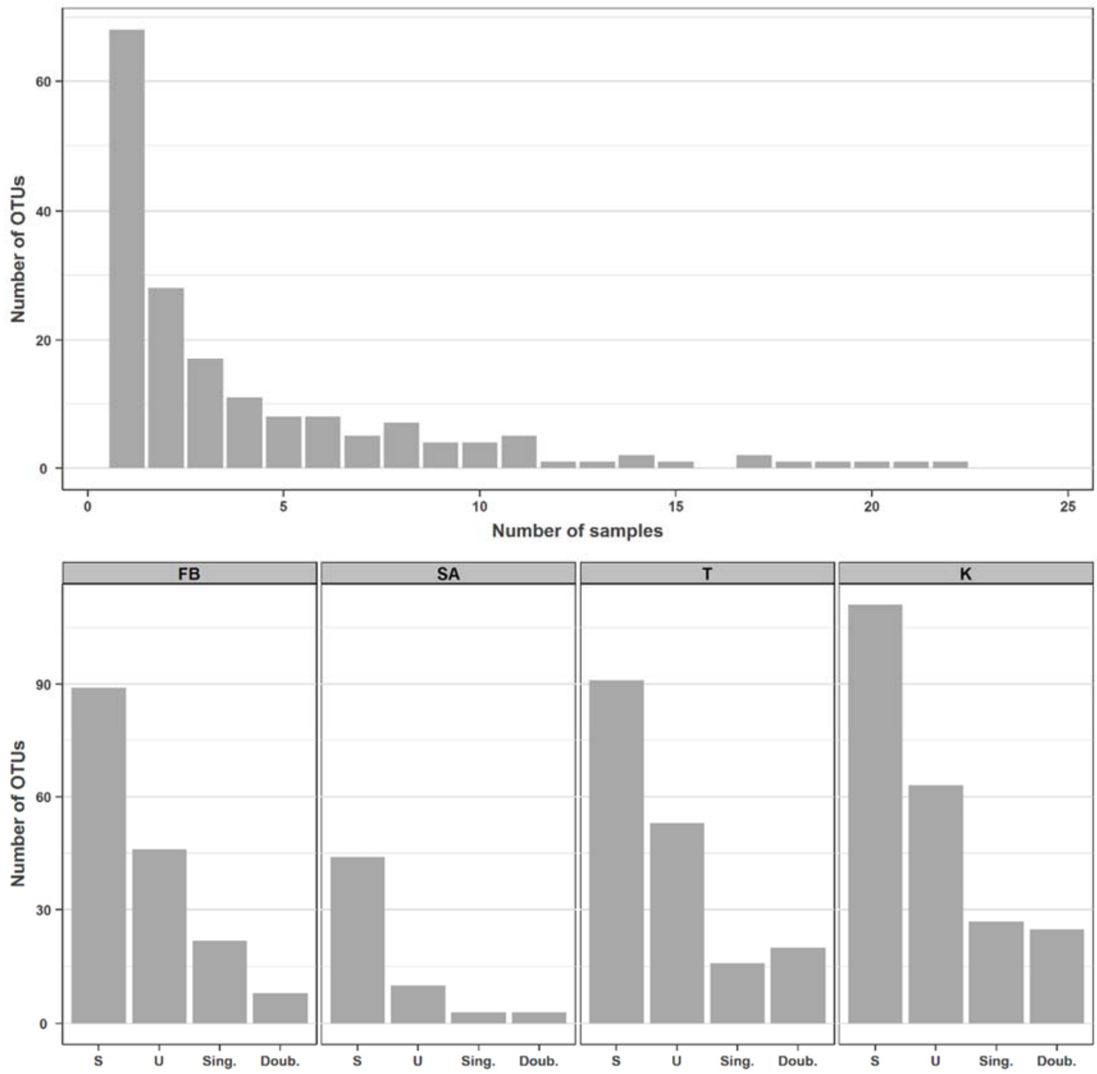

Figure 3.2: Distribution of OTUs according to their frequency in samples. Total number of OTU (S) and number of OTU which are uncommon (U - OTU total abundance in the dataset is less than or equal to 5 individuals), singletons (Sing.) and doubletons (Doub.) for natural reefs (FB - Farol Baixo; T - Tchuklassa) and artificial reefs (SA - Santo Antão; K - Kwarcit).

A large proportion of the species that compose the benthic communities at Baía de Santa Maria are rare, occurring in one or two samples (Figure 3.2). With the exception of the AR at low depth (SA), the proportion of OTUs that present low abundance (less than or equal to 5 individuals, 0.1% of the total abundance) is high (Figure 3.2), most of them singletons (single individual or species occurring at one sample only) or doubletons (species occurring at only two samples). In fact, samples included several rare species, with 56 OTU presenting only one individual. Only 11 (6.2%) of the OTUs occur at more than half of the samples, but account for 2361 individuals, comprising 48.8% of the total abundance.

3.4.1 Community patterns

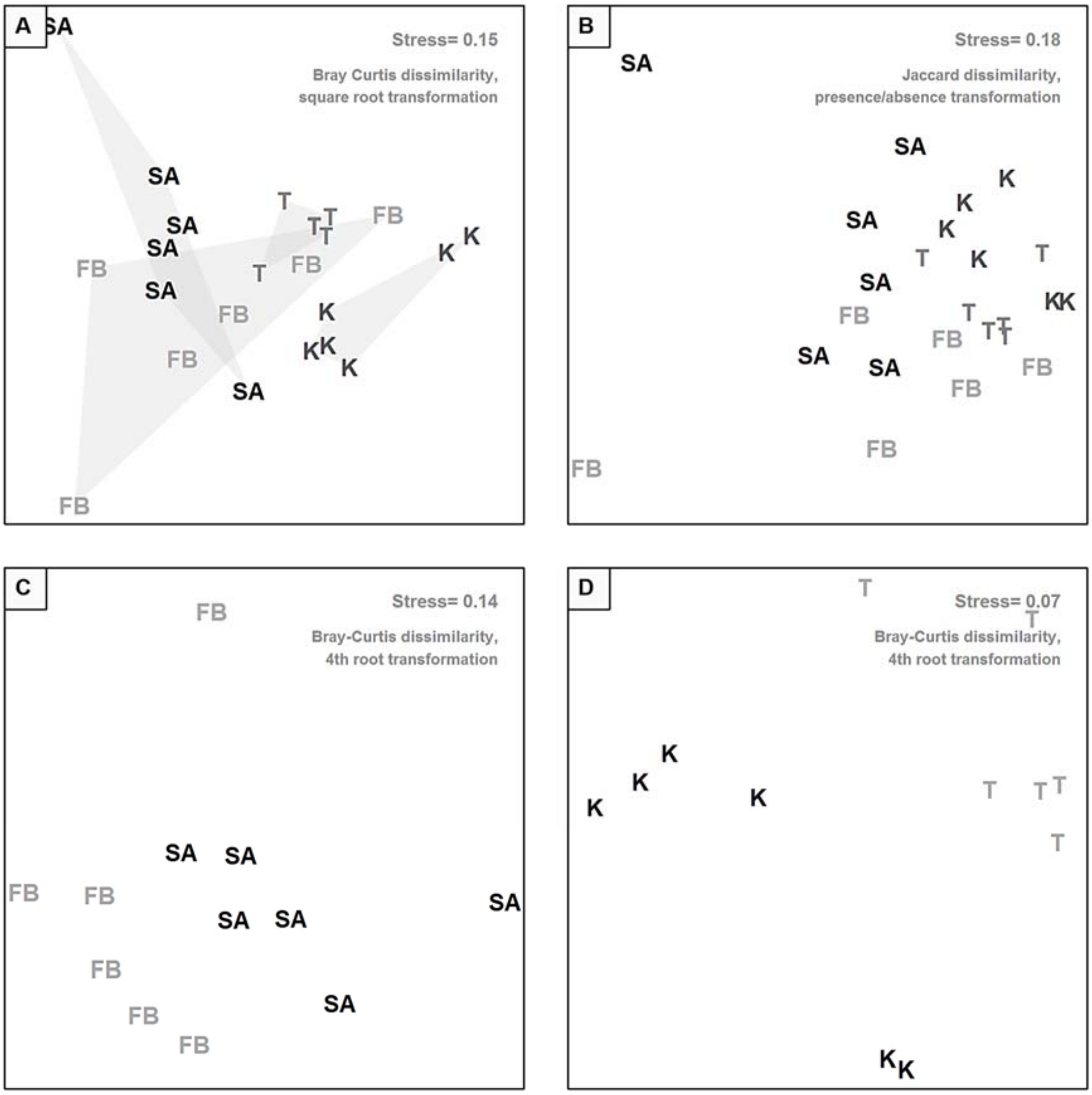

Figure 3.3: Non-metric multidimensional scaling diagrams of the benthic macrofauna data (non colonial fauna). a) abundance, all sites b) presence/absence, all sites c) abundance, low depth (≈ 9m) sites and d) abundance, moderate depth (≈ 25m) sites. FB - Farol Baixo (NR); SA - Santo Antão (AR); T - Tchuklassa (NR) and K - Kwarcit (AR).

The structure and composition of the macrobenthic assemblages varies within Baía de Santa Maria. Samples collected at low depth presented more heterogeneity than the deeper ones. This is evident in multidimensional scaling ordination diagrams when the structure of the community is analysed using abundance (Figure 3.3a) and in terms of faunal composition (Figure 3.3b). Furthermore, the multidimensional dispersion is greater at shallow depth

(F=8.39, p=0.008) but not significantly different between NR and AR at both depth ranges. Generally, the samples from deeper sites form a large cluster and the samples from the shallow sites disperse out of this cluster in the multidimensional space (Figure 3.3a and b), indicating a depth related pattern that is supported by differences in the mean total abundance between depth ranges (LD=61.9, MD=341.0; ANOVA, F=15.77, P=0.0006) but also in the structure and composition of the communities (Permanova, F=3.41, P<0.001). Samples from the deeper sites (T and K) form two different clusters (Figure 3.3a) evidencing differences in the structure of the assemblage. A similar and consistent pattern can also be found at lower depth even though it is less clear due to dispersion.

The separate analysis for the samples from the shallow sites clearly shows that the two reefs present different assemblages regarding structure and composition (Figure 3.3c; Permanova, F=1.80, P=0.005). One of the samples from the NR (FB) showed low abundance (6 individuals) and only 3 species and therefore is separated in the n-MDS ordination diagram (Figure 3.3c).

Concerning the samples from deeper sites, there is a clear separation of both reefs (Figure 3.3d) and significant differences were observed regarding the structure and composition of the communities (Permanova, F=3.94, P=0.003). Two samples from the AR (K) presented high total abundance values (1845 and 944 individuals) and are clearly separated from the remaining (Figure 3.3d). Similar patterns were also observed concerning the colonial fauna (data not presented).

Table 3.1: Indicator species (OTUs) for the Baía de Santa Maria (α=0.05, 999 permutations). The abundance and number of occurrences (in brackets) of the indicator species are presented for each site. The OTUs are arranged according to the site combination that obtained the highest correlation, and the value of the correlation (IndVal). The P values for the statistical significance of the associationare also presented.

	Abundance				IndVal	P	
	FB	**SA**	**T**	**K**			
Site T							
Leptocheirus cf. *guttatus*	–	–	12 (4)	-	0.816	0.015	*
Vermiliopsis cf. *infundibulum*	–	–	16 (4)	1 (1)	0.792	0.010	**
Site K							
Photiidae und.	–	–	–	176 (6)	1.000	0.005	**
Stenothoe sp.	14 (4)	–	–	666 (6)	0.990	0.005	**
Ostracodea	–	1 (1)	1 (1)	15 (6)	0.939	0.005	**
Arbaciella sp.	–	–	–	13 (5)	0.913	0.005	**
Autolytinae spp.	1 (1)	–	1 (1)	78 (5)	0.901	0.010	**
Caprella spp.	8 (2)	15 (4)	12 (3)	122 (6)	0.882	0.015	*
Filograna sp.	–	3 (1)	–	31 (5)	0.872	0.010	**
Demonax sp. B	3 (1)	–	–	11 (4)	0.724	0.010	**
Branchiomma sp.	–	–	–	27 (3)	0.707	0.020	*
Streptosyllis sp.	–	–	–	13 (3)	0.707	0.020	*
Odontosyllis sp.	3 (1)	–	–	42 (3)	0.683	0.050	*
Sites SA + T							
Diogenidae spp.	–	5 (4)	10 (4)	–	0.816	0.020	*
Sites T + K							
Ericthonius sp.	18 (4)	1 (1)	95 (6)	124 (6)	0.959	0.005	**
Chone spp.	2 (2)	1 (1)	42 (6)	18 (4)	0.891	0.005	**
Kellia sp.	–	1 (1)	23 (5)	29 (3)	0.809	0.020	*
Sites FB + T + K							
Jassa sp.	49 (5)	3 (2)	48 (6)	87 (6)	0.964	0.005	**
Liljeborgiidae und.	8 (4)	–	7 (4)	22 (4)	0.816	0.020	*

The indicator species analysis showed that some species are clearly associated with thesampled sites. There are no species associated exclusively to shallower sites. On the other hand, some species are characteristic of deeper sites, namely the polychaete *Vermiliopsis* cf. *infundibulum* and the amphipod *Leptocheirus* cf. *guttatus* which are frequent in the deeper NR (T) but absent or rare in the other sites. However, the recently sunken vessel (K) had a few species which are extremely abundant and frequent at this site and much less abundant and frequent elsewhere, namely some amphipods (*Stenothoe* sp., *Photiidae* und. and *Caprella* spp.) and some polychaetes (*Filograna* sp., Autolytinae spp., *Streptosyllis* sp. and *Demonax* sp.B) but also the sea urchin *Arbaciella* sp. and the ostracods. Some OTUs such as *Pilumnus* sp., *Phtysica* spp. and *Ericthonius* sp were found to be more frequent and abundant at deeper sites, even though commonly found at all sites. The amphipods *Lilleborgiidae* und. and *Jassa* sp. were commonly found at the two NR (FB and T) and the deeper AR (K) showing high frequencies of occurrence and similar abundance (Table 3.1). A single species is pointed out as being indicator of the natural reefs, the crab *Alpheus macrocheles*, but this species was only found in two of the six samples in FB.

3.4.2 Diversity

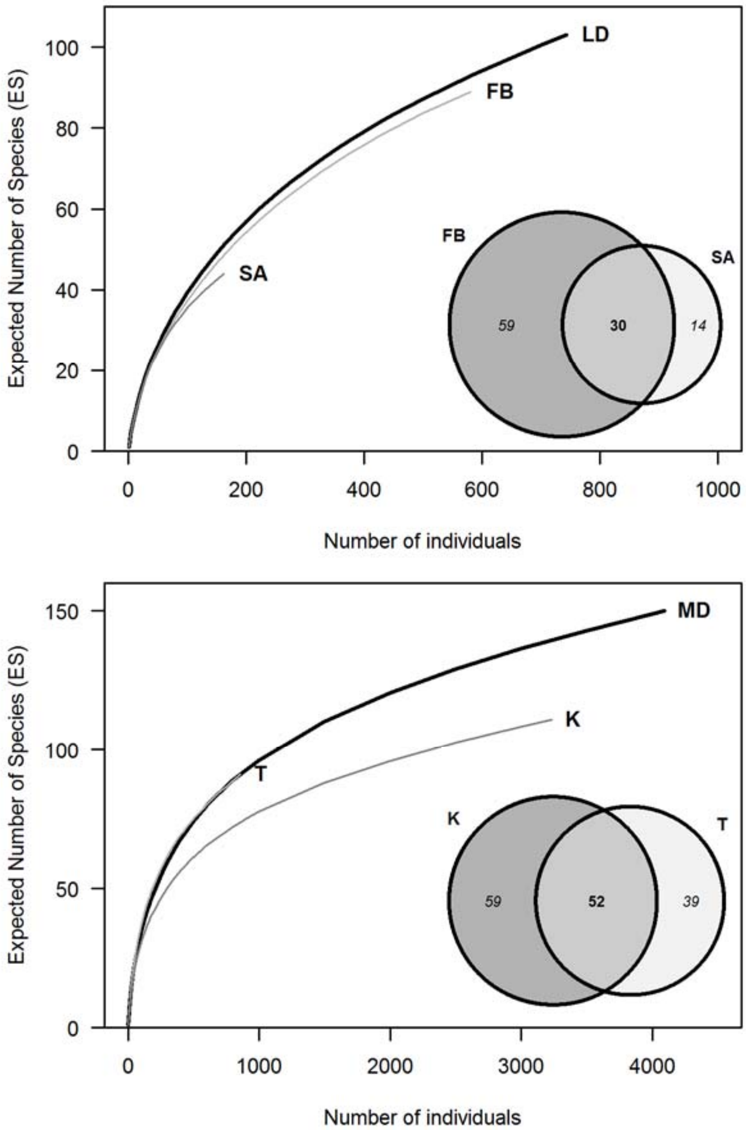

Figure 3.4: Hulbert's estimated number of species (ES) for the sampled sites at (top) 9m depth (LD) and (bottom) 25m depth (MD). Venn diagrams are used to present the number of OTUs that are exclusive of NRs and ARs and those shared between them. FB - Farol Baixo (NR); SA - Santo Antão (AR); T - Tchuklassa (NR) and K - Kwarcit (AR). Different axis ranges are presented to improve the definition of the ES curve.

LOW DEPTH (9M DEPTH)

Both sites present a steep increase in the number of OTUs considering that abundance values are relatively low (Figure 3.4). Of the 103 OTUs identified at these two sites (macrofauna OTUs, not macrofauna and colonial) only 30 of them were present at both sites, with the NR (FB) presenting many more species than the AR (SA) but also higher variation (Figure 3.4 and Table 3.2). The same pattern was found for the α diversity indices H' and ES_{50} with higher values in the NR (FB) (Table 3.2). Both sites presented low dominance as indicated by the high values of Shannon Evenness values (J) which agrees with the general low abundance values observed at these samples.

Table 3.2: Macrofaunal community diversity in Baía de Santa Maria. Mean alpha diversity values (macrofauna abundance data) are presented for each site for the number of species (S), Hulbert's Expected number of species (ES50), Shannon Wiener diversity index (H') and Pielou's evenness index (J). Statistics are compared for reef effects at a) low (FB x SA) and b) moderate (T x K) depth using parametric (ANOVA; F) or non parametric (Kruskal Wallis; χ2) tests. Natural reefs: FB - Farol Baixo; T - Tchuklassa. Artificial reefs: SA - Santo Antão; K - Kwarcit.

a) low depth

Site	S	ES_{50}	H'	J
FB	25.7±21.19	16.3±8.71	2.51±0.846	0.89±0.068
SA	14.3± 5.35	14.3±5.35	2.27±0.554	0.89±0.074
between FB and SA	χ^2=0.33	F=0.04	F=1.15	F=0.09
	P<0.001	P=0.846	P=0.291	P=0.762

b) moderate depth

Site	S	ES_{50}	H'	J
T	39.2± 8.35	23.9±2.31	3.12±0.160	0.86±0.029
K	42.7±28.16	18.8±2.25	2.83±0.221	0.80±0.095
between T and K	χ^2=1.66	F=50.97	F=23.74	χ^2=4.67
	P=0.197	**P<0.001**	**P<0.001**	P=0.031

Table 3.3: Beta diversity of macrofaunal communities in Baía de Santa Maria (macrofauna and colonial presenceabsence data; see text for details). Data is presented for site pooled data (a) and for individual samples (b). Beta diversity (value or value ± SD) values were calculated using the classic Whitaker index (βw), the Jaccard index (βj), the z index (βz) and the sim index (βsim). Multivariate dispersion tests are presented for reef effects (FB x SA at low depth; T x K at moderate depth). The average distance to group centroid (dC) for each group of samples being compared is also presented.

a) Beta diversity (macrofauna and colonial data pooled for each site)

	β_w	β_j	β_z	β_{sim}
between FB and SA	0.512	0.678	0.597	0.316
between T and K	0.489	0.657	0.575	0.443

b) Partition of beta diversity (macrofauna and colonial data)

	β_w	β_j	β_z	β_{sim}
Low depth reefs (9m)				
within FB	0.69 ± 0.126	0.81 ± 0.090	0.75 ± 0.108	0.42 ± 0.174
within SA	0.61 ± 0.093	0.75 ± 0.072	0.68 ± 0.083	0.49 ± 0.105
between FB and SA	0.71 ± 0.083	0.83 ± 0.056	0.77 ± 0.070	0.54 ± 0.154
Multivariate dispersion	F=0.556	F=0.543	F=0.552	F=0.405
	P=0.466	P=0.478	P=0.475	P=0.539
$\overline{d}C_{FB}$	0.438	0.519	0.481	0.250
$\overline{d}C_{SA}$	0.391	0.485	0.440	0.303
Moderate depth reefs (25m)				
within T	0.45 ± 0.096	0.61 ± 0.101	0.53 ± 0.100	0.38 ± 0.099
within K	0.47 ± 0.124	0.63 ± 0.117	0.56 ± 0.122	0.25 ± 0.070
between T and K	0.61 ± 0.066	0.76 ± 0.051	0.69 ± 0.059	0.49 ± 0.093
Multivariate dispersion	F=0.268	F=0.183	F=0.215	F=4.489
	P=0.612	P=0.678	P=0.652	P=0.060
$\overline{d}C_T$	0.285	0.392	0.339	0.246
$\overline{d}C_K$	0.311	0.413	0.362	0.152

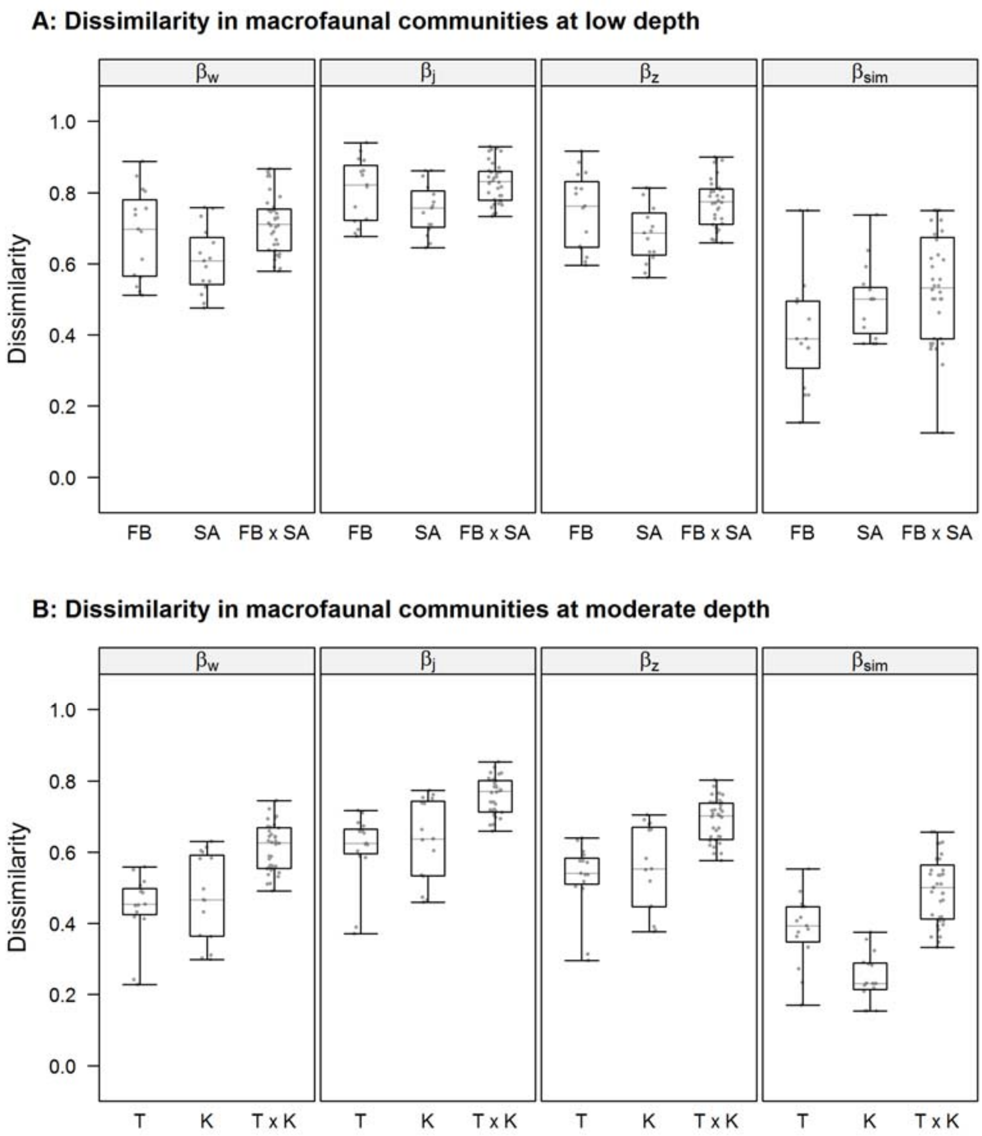

Figure 3.5: Distribution of the β diversity dissimilarities (β_w, β_j, β_z and β_{sim}) within and between groups of samples for a) low depth sites (9m; FB - Farol Baixo, NR; SA - Santo Antão, AR) and b) intermediate depth sites (25m; T - Tchuklassa, NR; K - Kwarcit, AR). The horizontal line represents the median value, the box the interquartiles (25 and 75 quantiles) and the bars the minimum and maximum dissimilarity values.

Pooled samples for each site (macrofauna and colonial, presence/absence transformed) showed high β diversity regarding the indices β_w, β_j and β_z (Table 3.3a). These values indicate that continuity between faunal communities is reduced as they show different faunal composition (β_j), high turnover (β_z) and contribute to regional diversity (β_w; region scaled to shallow depth waters of Baía de Santa Maria). The β_{sim} index showed a lower value, confirming the local richness gradient (α) observed concerning species richness, H' and ES_{50}. Species turnover (β_w, β_j and β_z) was generally high (Table 3.3a; Figure 3.5) with higher dissimilarity between sites (FB x SA), and the NR (FB) showed higher variability than the AR (SA). β_{sim} also showed higher values when samples from both sites were compared but presented a slightly different pattern as dissimilarities were lower within the NR (FB) than within the AR (SA). This latter pattern is also confirmed by the average distance to group centroid at both sites, which presented higher values at the AR (SA). The multivariate dispersion of the four β diversity indices was not significantly different between groups, suggesting that species turnover is similar at both sites.

MODERATE DEPTH (25M DEPTH)

Both the NR (T) and the AR (K) presented high species richness (Table 3.2). The two assemblages share 52 species (macrofauna data only) representing 51% and 47% of the total species richness of NR and AR, respectively. The rarefaction curves showed that both sites present a steep increase in the number of species and suggests that diversity is higher in the NR than in the AR (Figure 3.4). Such a pattern is supported by the higher diversity at the NR (T) regarding ES_{50} and H' diversity indices (Table 3.2). Both assemblages show high equitability even though Shannon J evenness values are lower in the AR (K) due to the high abundance values of some OTUs in some of the samples.

The high β diversity values of the pooled samples (Table 3.3a), especially β_j, suggest a high species turnover between NR and AR supporting the biotic distinctness of the assemblages previously observed in the n-MDS diagram (Figure 3.3d). High species turnover measured by β_w, β_j and β_z was also evident within sites (Figure 3.5) with similar average values between NR (T) and AR (K) but higher dispersion in the latter (Table 3.3, average distance to centroid; Figure 3.5b). β_{sim} presented lower values at the AR (K) than at the NR (T) (Figure 3.5b; Table 3.3, average distance to centroid, P=0.060). All four indices presented higher values of dissimilarity when pairs of samples from the two reefs were compared (T x K).

3.5 DISCUSSION

Marine benthic communities are extremely complex as their dynamics are shaped at different scales with continuous replacement of species in space and time. Benthic assemblages within Baía de Santa Maria present different structure and composition between artificial and natural reefs but also between depth ranges. At 9m depth the communities are characterised by low abundance and high species turnover, both within and between ARs and NRs. At 25m depth the assemblages showed higher abundance and species richness and generally presented lower species turnover (β diversity) within each site. These differences form a complex mosaic adding complexity to the benthic communities of the area, namely in what concerns the species pool or diversity.

3.5.1 Patterns of communities at 9m depth: long colonization period

The macrobenthic assemblages of the AR and the NR presented similar high species turnover within and between reefs, i.e. species are continuously replaced by others at each reef over time. However, benthic assemblages of both reefs presented different faunal composition and diversity was higher in the NR, implying that the processes shaping the benthic assemblages are either different or occur at different scales.

At low depth, physical disturbance such as strong currents, fishing and siltation shape the macrobenthic communities, and if frequent they can limit the succession of the communities, reducing the diversity of the area (Guerra-García, 2001; Balata *et al.*, 2007; Wernberg and Connell, 2008; Scheibling *et al.*, 2009; Constantino *et al.*, 2009).

The strong winds, characteristic of Baía de Santa Maria, lead to frequent and sometimes severe disturbance events. The effects of such events (high loads of sediment being re-suspended, ripple marks and some fauna and flora being washed away) were observed both at the AR (SA) and at the NR (FB), with higher magnitude in the former. It has been previously suggested that physical disturbances in the Baía de Santa Maria, such as storm damage, possibly prevent competitive interactions between coral species having an important role in their distribution (Morri and Bianchi, 1995). Theoretically, when disturbance occurs at several scales (fractal), species' extinction thresholds increase in a habitat consisting of a block (the AR) compared to habitats with patches of different sizes and higher frequency or availability (the NR, extended over a much larger area), especially for species with short or moderate dispersal rates (Kallimanis *et al.*, 2005). The geomorphology of the NR, with higher rugosity and complexity than the AR, can reduce the overall effects of physical disturbance by providing areas with lower exposure. Because the AR is relatively isolated in a sandy bottom, habitat fragmentation may explain why the AR communities are poor as it has been proved that, whenever the space separating the habitat from source populations is not appropriated, the distance between habitats strongly affects the colonization of fragmented habitats (Goodsell and Connell, 2008). After a disturbance event, extinction threshold is lower where habitat connectivity is higher, as the probability of propagules falling into unsuitable habitat is reduced by the fractal arrangement of suitable patches (Hill and Caswell, 1999). The high species turnover at both sites is consistent with frequent disturbance (β_w, β_j and β_z; all combinations), even though in the case of the NR they may be inflated due to differences in species richness between samples, as the β_{sim} values are lower (Lennon *et al.*, 2001). This indicates that the NR is more stable than the AR resulting in lower rates of species turnover. Therefore, it seems reasonable to assume that disturbance effects are higher in the AR, leading to the detected differences in abundance, species richness, diversity, and explaining the dissimilarities between the AR and NR assemblages.

3.5.2 Patterns of communities at 25m depth: recent colonization

The benthic assemblages were markedly different in terms of species composition but also in abundance patterns, with the NR showing higher diversity (α) and evenness whereas the AR presented some OTUs with high abundance and therefore higher dominance. In fact, the early colonization process or artificial structures, even though highly variable, is generally characterized by the dominance of a few species, some of them numerically abundant, as observed in the present study. These early colonizers are able to rapidly colonize the area and are normally replaced by specialist species along the succession of the community (Perkol-Finkel and Benayahu, 2005; Moura *et al.*, 2007). The high abundance of some species and the high number of species in the AR (K) suggest that the recently sunken vessel encompasses strong competitor species for available resources (space and food?) which are numerically dominant but also some specialists (increasing the number of species). Availability of appropriate physical habitat but also of food are determinant factors in the fixation of macrobenthic species. The high abundance of some species in the AR may be explained by enhanced productivity, as some of the OTUs that dominate the community, such as the amphipods *Jassa* and *Stenothoe*, are also found in the initial phases of the colonization of ARs (Moura *et al.*, 2008) where there is evidence of increased deposition of organic matter (Falcão *et al.*, 2007). One of the most abundant taxonomic groups in the AR, the sipunculids, are known facilitators of the transport of organic matter (Shields and Kedra, 2009) and consequently can be numerically dominant and have an important role in the ecology and biogeochemistry of certain areas (Schulze, 2005). What is more, the higher abundance and biomass of fish in this AR (Santos *et al.*, 2013), also results in higher concentration of faecal pellets that can be enhanced by biofilms and ingested by detritivores or suspension feeders. The high abundance of some AR samples is clearly reflected in the lower values of alpha diversity measures, even though the number of species at each reef is similar. However, species richness is much more variable in the AR reflecting the high spatial variability of the early colonization process (Walker *et al.*, 2007). The observed differences in species composition leading to high complementarity between reefs (β diversity, T x K combinations) suggest that the processes involved in the succession of the assemblages present differences. At the AR, in an early colonization phase, competition between species is shaping the patterns of abundance and diversity presenting high rates of species replacement. On the other hand, the high complementarity at the NR, a more stable and mature assemblage, is probably due to the increased complexity and heterogeneity of the area forming a mosaic of patches with high spatial variability.

3.5.3 The importance of understanding local diversity patterns

In Baía de Santa Maria a high number of species was found for a limited set of samples, which can be partially explained by the differences between sampled sites: artificial and natural reefs at different depth, thus incorporating species with different ecological requirements. The present data supports that the benthic communities in NR and recent and old ARs at different depth are very different. Because there are new species at each assemblage, the local species pool is enhanced with an effective contibution of ARs at both depths analysed. The local species diversity is important for the biogeography of the area, especially because the Cabo Verde archipelago presents a fauna and flora with diverse origins. Coral fauna is associated to Caribbean species, especially at low depths where they are dominant (Morri and Bianchi, 1995); a large amount of species are commonly found in the North Atlantic; and some species are common from the South Atlantic coasts, namely the western coast of Africa. Some of the OTUs that were not possible to identify to the species level (*e.g.* many Syllidae) are possibly new records for the area and some of them might even be new species for science. This information corroborates other scientific works that suggest that Cabo Verde is an important area for marine diversity (Roberts *et al.*, 2002). In fact, several endemic species are present in the marine fauna of Cabo Verde, such as the fish *Diplodus prayensis*, *Chromis lubbocki* and *Similiparma hermani* and invertebrates, several species of *Conus*, the ascidean *Eudistoma santamariae*, the gorgonian *Leptogorgia capverdensis* and the nudibranchs *Flabellina arveleoi*, *Aldisa barlettai*, *Tambja fantasmalis* and *Tambja simplex*. With the exception of *Aldisa barlettai*, all the referred species were observed by the authors at the Baía de Santa Maria, many coexisting in natural and artificial reefs suggesting that man made structures may contribute for the preservation of local biodiversity.

The patterns of species diversity (α) were clear at both depths, NRs presented higher diversity than ARs. At low depth, the AR assemblage seems to be more affected by disturbance than the NR, resulting in lower diversity. However, the AR seems to enhance the local species pool as it showed several exclusive species and high complementarity (β diversity) to the NR. The high species turnover at both reefs (all comparisons) reinforce that a common factor (physical disturbance) is shaping species turnover at both reefs similarly. At 25m, the recent AR undergoing the initial phases of colonization/succession contributes with many exclusive species for the local species pool showing high complementarity with the NR.

The present data indicates that all the analysed reefs presented high beta diversity, i.e. high complementarity between samples within and between reefs. The high beta diversity within each site may arise from the fact that when sample size is small relative to the study area, even neighbouring sampling units may be very dissimilar due to high variability in species occupancies (Barton *et al.*, 2013). The use of several different sites produced an incomplete species list of each site (unsaturated accumulation curves) but as it included a wide range of rare species, provided a better assessment of the heterogeneity of species diversity (Gering *et al.*, 2003). The partitioning of diversity at a small spatial scale (comparing NRs and ARs at similar depth) provides a unique approach to understanding the factors shaping community diversity such as reef age, complexity and size (contrastingly different in the present study). Such information increases the probability and speed of identifying the processes that might be responsible for observed species diversity (Wagner *et al.*, 2000; Gering *et al.*, 2003). This is extremely valuable for management purposes focusing on biodiversity conservation, for example in establishing MPAs size and number; or the spatial extension of AR areas and AR types.

Using different alpha and beta diversity measures provide alternative and/or complementary ways to unveil diversity patterns (Gering *et al.*, 2003). For example, the patterns of β_w, β_j and β_z provide strong evidence on how beta diversity changes between (and within) reef types but the use of β_{sim} provides a way of detecting how local species richness (SAR) is affecting those patterns. What is more, the patterns of species turnover at different reefs using several presence/absence indices corroborated multivariate results providing strong evidence on the processes underlying those patterns. These procedures can be easily adapted for other studies and therefore useful to complement existent methods that provide statistical inference of such differences (e.g. Koleff *et al.*, 2003; Anderson *et al.*, 2006).

3.5.4 The use of artificial reefs in Baía de Santa Maria and other areas

The present data shows that ARs enhance local species pool, mostly because they are able to provide new niches for colonization, proving that they are complementary to the NRs. One of the major concerns regarding the introduction of ARs in the marine environment, especially in islands, is that these structures may facilitate the dominance of benthic communities by invasive species, which most of the times are strong competitors and early colonizers. In fact, generalist broad scale species with capacity to adapt and invade habitats have been pointed as triggering speciation depression and leading to marine biodiversity crisis in the fossil record (Stigall, 2010) and modern invasive species should be expected to have similar impacts in marine ecosystems. The high prevalence of invasive species in artificial structures has been reported for pontoons and pilings, which can be poorly utilised by native species but highly favourable to invasive species (Glasby *et al.*, 2007). Consequently, the rates and extent of artificial structures introduced to marine systems may also play an important role in the success of biological invasions (Glasby *et al.*, 2007) and therefore the indiscriminate use of ARs should be avoided. The use of relatively small ARs for specific purposes, namely nature based sustainable tourism, as long as properly monitored and managed, seem to be a good alternative, removing pressure from natural areas and eventually enhancing local populations and biodiversity. For example, at low depth, where benthic assemblages are so constrained by physical disturbance, the added effects of human activities can deteriorate the NRs and reduce species diversity. Therefore, existent ARs can be used to alleviate the NR, but the differences found between the assemblages even after a long period of time and the small size of the Baía de Santa Maria it is not recommended that more vessels should be sunken at this depth.

However, as the present data is a snapshot of the community at the time of sampling, it is impossible to know how the dynamics in terms of diversity will evolve with time. Will the ARs allow some species to persist by providing new niches and adding ecological roles to the community? Is community structure going to be stabilized or destabilized by the addition of these species (Ives *et al.*, 2000)? Further information is needed in the future to shed light on these issues and it is particularly important to focus on species traits as complexity of biotic and abiotic characteristics (and interactions between them) are important for diversity and abundance patterns in mature communities (NRs) (e.g. Harborne *et al.*, 2011; Graham and Nash, 2013). The fact that ARs can be sources of species does not necessarily mean that they provide additional complexity to the community. Species budgets should be systematically inferred from long-term data sets accompanied by experimentation, modelling and monitoring to evaluate the effects of ARs on local diversity in the long term (Jackson and Sax, 2010), especially because several factors that alter assemblage history lead to changes in alpha and beta diversity patterns (Martin and Wilsey, 2012).

3.6 CONCLUSIONS

A biodiversity conservation model has been proposed for Cabo Verde, with strong links to ecotourism activities (Benchimol *et al.*, 2009). However, these activities, closely dependent on the coastal and marine biodiversity can be developed only if management and administration are adequate, relying strongly on environmental education and scientific research (Benchimol *et al.*, 2009). The present work untangles some of the complexity of the local macrofaunal diversity within Baía de Santa Maria providing insights on different aspects of diversity, such as estimates on the number of species and which sites are more diverse (alpha diversity), but also how species are replaced within and between areas (beta diversity). Similar approaches can be used elsewhere to gain a full understanding of how diversity patterns contribute to overall regional diversity (Gering *et al.*, 2003; Carvalho *et al.*, 2013).

CHAPTER IV

The African Hind's (*Cephalopholis taeniops*, SERRANIDAE) use of artificial reefs off Sal Island (Cape Verde): A preliminary study based on acoustic telemetry

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The African Hind's (Cephalopholis taeniops, SERRANIDAE) use of artificial reefs off Sal Island (Cape Verde): A preliminary study based on acoustic telemetry

4.1 SUMMARY

The African hind *Cephalopholis taeniops* (Valenciennes, 1828) is one of the most important commercial demersal species caught in the Cape Verde archipelago. The species is closely associated with hard substrate and is one of the main attractions for SCUBA divers. In January 2006 a former Soviet fishing vessel - the Kwarcit - was sunk off Santa Maria Bay (Sal Island). Young *C. taeniops* are commonly observed in this artificial reef (AR). In order to investigate the species' use of the AR, 4 specimens were captured and surgically implanted underwater with Vemco brand acoustic transmitters. The fish were monitored daily with an active telemetry receiver for one week after release. Simultaneously, an array of 3 passive VR2 / VR2W receivers was set for 63 days, registering data that allowed an analysis of spatial, daily and short term temporal activity patterns. The results showed site fidelity to the AR, with no migrations to the nearby natural reef. The method used allowed to register a consistent higher activity during daytime and a preference for the area opposite the dominant current.

Keywords: *Cephalopholis taeniops*, Vessel reef, Cape Verde, Activity pattern, Acoustic telemetry.

4.2 INTRODUCTION

The African hind, Figure 4.1, is a demersal serranid (Serranidae, Epinephelinae) whose native range extends from Morocco to Angola, including the Cape Verde and the Sao Tome and Principe archipelagos (Heemstra and Randall, 1993). This species has recently been identified in the Mediterranean, in the Gulf of Syrte, Libya (Abdallah *et al.*, 2007), thus extending its northern distribution limit. The habitat for this species is of sandy and rocky bottoms at depths from 20 to 200 m (Heemstra and Randall, 1993) and it occurs mainly as solitary individuals associated with caves and other shelters (Monteiro *et al.*, 2008). There is very little biological information on this species (Pastor, 2002), although some recent studies have investigated the genetic diversity off the Cape Verde islands (Medina *et al.*, 2008). Nevertheless, this species is very important for local fisheries and is heavily exploited (Stobberup *et al.*, 2005).

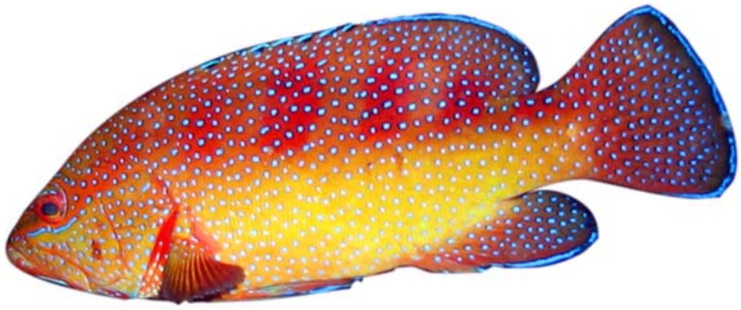


Figure 4.1. The African hind *Cephalopholis taeniops* (Valenciennes, 1828).

Sal Island in the Cape Verde archipelago has great potential as a tourist resort due to the favorable climate almost all the year round. Although there are some natural diving site locations around the island, the southern coast, which is more protected from local currents and winds, has few natural underwater attractions. This was one of the reasons behind the "Rebuilding Nature" project - the creation of some artificial hard habitats that would add to the underwater attractions, as well as contribute to the restoration of the fishery resources that had been heavily exploited in the past, by providing additional protected habitats. Two ships were, therefore, sunk in Santa Maria Bay. One of them, a former Soviet fishing vessel named Kwarcit, was sunk in 2006 on a sandy bottom at around 28 m depth.

This new habitat has been monitored since 2008 in terms of colonization (unpublished data). The information gathered has shown that among the abundant fish community observed around and within the Kwarcit, there is a large number of juvenile African hind. Since there is very little biological information on this species, its behavior in terms of migratory and daily movement is particularly important for the assessment of the standing stock from two perspectives: as an attraction for underwater tourism and as a sustainable fishery resource for the local population (hand-lining and spear-fishing).

Acoustic tags have been used in fresh water for monitoring fish movement since the 70's. However, the use of underwater acoustic monitoring in the marine environment has different limitations due to the increased conductivity (Reine, 2005). The increase in tag-battery capacity, which affects study duration and also the range of detection (by increasing power output), associated with a reduction of tag size and weight has, according to Reine (2005), led to the proliferation of electronic tag types, tracking equipment and expanded telemetry applications. Further, the use of automated receivers allows continuous tracking within the array's range for extended periods of time on spatial scales ranging from meters to kilometers (Voegeli *et al.*, 2001).

Therefore, according to Zeller (1999), acoustic telemetry is the ideal tool to address questions of fish movement and activity patterns. This technology has been used worldwide to study the behavior of demersal species, as regards habitat preferences and use (Lino *et al.*, 2009).

The present study is a part of the Rebuilding Nature project, which covers a wide range of aspects of the first ARs of the Cape Verde coastal waters. The main objective of this study was to assess the use of the AR habitat by *Cephalopholis taeniops* and to investigate possible movements to and from the nearby natural reefs.

4.3 MATERIAL AND METHODS

Study Area and Sampling Procedure

This study was carried out in the Cape Verde Archipelago, in the western part of the Santa Maria Bay off Sal Island (Figure 4.2). The marine habitat in the study area has a fine grain sandy bottom, which includes a shallow natural reef (NR), known as the "Three Caves" with a few small caves (at 15 to 18 m depth) and the artificial reef

(AR), a 28 m length vessel wreck, located on the deeper edge of the platform (30 m depth). Sampling of C. taeniops was carried out on the artificial reef, using SCUBA equipment and a hand line baited with chunks of fresh mackerel. After unhooking, each fish was examined to assess its general condition and placed for two days in a 1 m3 cage near the capture site, in order to guarantee that no damage was suffered during capture and handling.

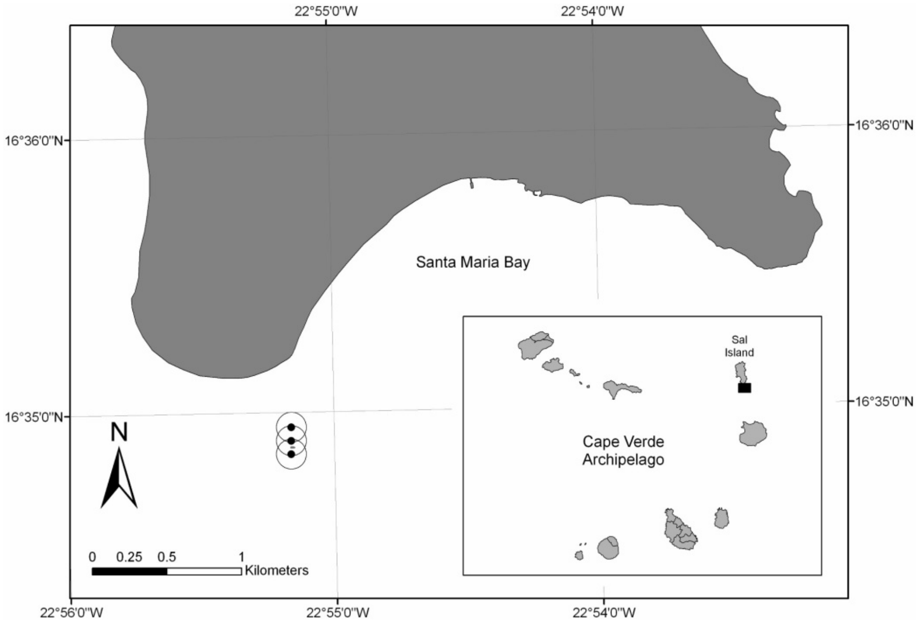


Figure 4.2. Location of the study site. The black square in the inset image indicates the enlarged area. The circles in the Santa Maria Bay show the area covered by the passive acoustic receivers.

Tagging

Acoustic tagging was carried out under water using a V-shaped berth. Fish were sedated by oral administration of 100 ml of a 120 ppm clove oil in saline solution and placed dorsally on the berth. The acoustic transmitter (V8SC-2L, Vemco) was inserted into the body cavity through a 1.5 to 2 cm incision on the linea alba, midway between the pelvic girdle and the anus. The incision was closed with a single suture of nylon monofilament (Braun Dafilon 3/0 DS19 45 cm) and cyanoacrilate adhesive (Histo-acril, B. Braun) was used to close the incision and consolidate the knots. Prior to surgery all fish were measured for total length (TL) to the nearest half centimeter. After the surgery the fish were returned to the cage for postsurgical recovery for 3 hours. The fish were then inspected to confirm their good condition, and released on the vessel reef's deck (Figure 4.3).

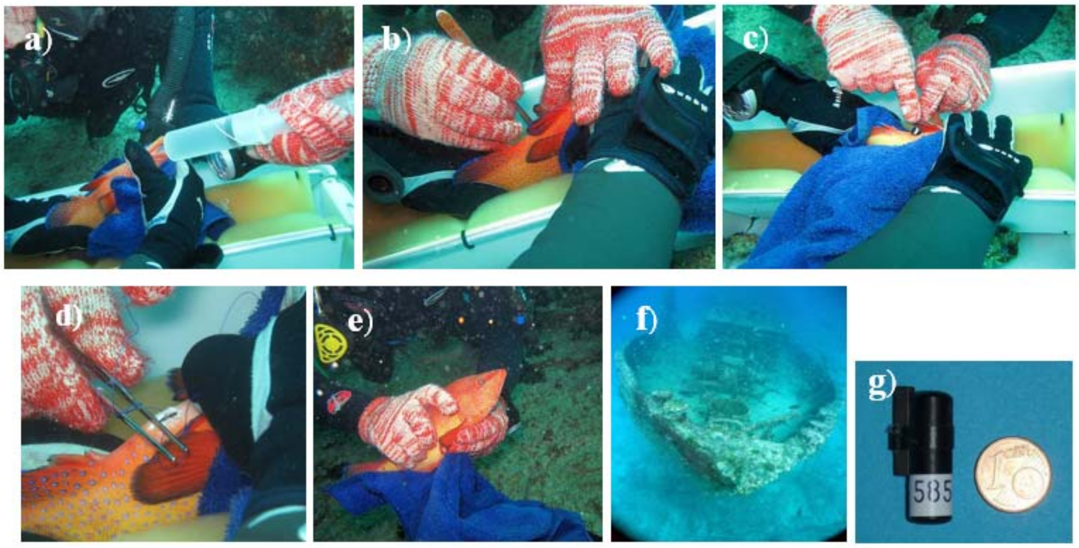


Figure 4.3. Acoustic tagging process: a) sedation by oral administration of 100 ml of a 120 ppm clove oil in saline solution; b) 1.5 to 2 cm incision on the linea alba, midway between the pelvic girdle and the anus; c) acoustic transmitter was inserted into the body cavity; d) single suture of nylon monofilament and cyanoacrilate adhesive; e) fish inspection; f) Kwarcit´s deck; g) VEMCO V8SC-2L tags used.

Experimental Design

In order to design the final experimental layout, preliminary field work was carried out to assess the acoustic transmission conditions *in situ*. The preliminary study was carried out at the exact location where the main experiment was to be carried out. An acoustic transmitter was moored at about 1m from the bottom, on a cable connected to a surface buoy, and simultaneous measurements were registered with a VR2 passive receiver and a VH100 active receiver connected to an omnidirectional hydrophone. Based on the preliminary results a theoretical maximum acoustic range was set to 100 m. Two acoustic receivers (VR2 / VR2W) were set on the bottom 40 m to port and 40 m to starboard of the bow of the vessel reef. A third acoustic receiver (VR2) was set on the nearby natural reef, nearly 200 m from the AR, in order to monitor this area for possible migrations.

Active Telemetry

Active telemetry was carried out using a VR100 active acoustic receptor connected either to an omnidirectional or a directional hydrophone. After the tagged fished had been released, acoustic monitoring of the study area was carried out on a daily basis by performing transects covering the area from the "Three Caves" natural reef to the outer edge of the shelf, beyond the vessel reef's position (Figure 4.4).

For each specimen the Residence Index (RI) was calculated. The RI is the ratio between the number of days the fish was detected and the total number of days the area was monitored. The relationship between the number of detections and water temperature was investigated using data recorded by a temperature sensor positioned on the AR.

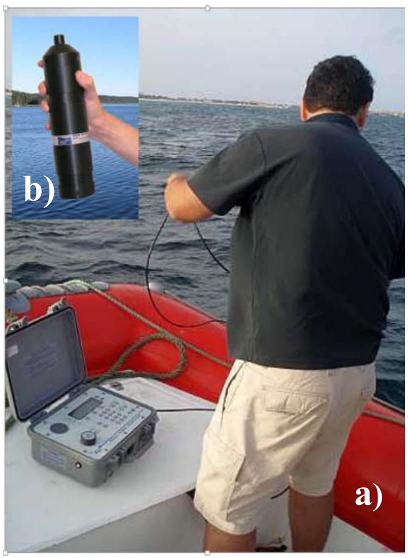


Figure 4.4. a) Active telemetry was carried out using a VR100 active acoustic receptor connected either to an omnidirectional or a directional hydrophone; b) VR2 and VR2W passive acoustic receivers.

4.4 RESULTS

The characteristics of the four fish captured using the underwater baited hand line are presented in Table 1. All four tagged specimens were young adults, in accordance with the size at first maturity of 18 cm TL described by Siau (1994). The fish had an average total length of 24.9 cm (±2.1cm, SD) and an estimated average weight of 219.5 g (±59.7 g, SD). Their weights were estimated using a weight-length relationship based on a sample of 310 specimens (later published on Oliveira *et al.* 2015a – Annex I).

The use of active telemetry allowed the detection of the presence of all the tagged fish on the AR. On several occasions it was necessary to lower the hydrophone several meters more to detect the fish. No fish migration was ever detected during active telemetry. The lack of the detection of any movement around the sunken vessel and the lack of any detection of fish in the nearby natural reef area determined the end of the active tracking. An additional active tracking survey was carried out before the passive receivers were recovered, and although the study area was covered, only two fish (ID913 and ID914) were detected near the artificial reef (Figure 4.5).

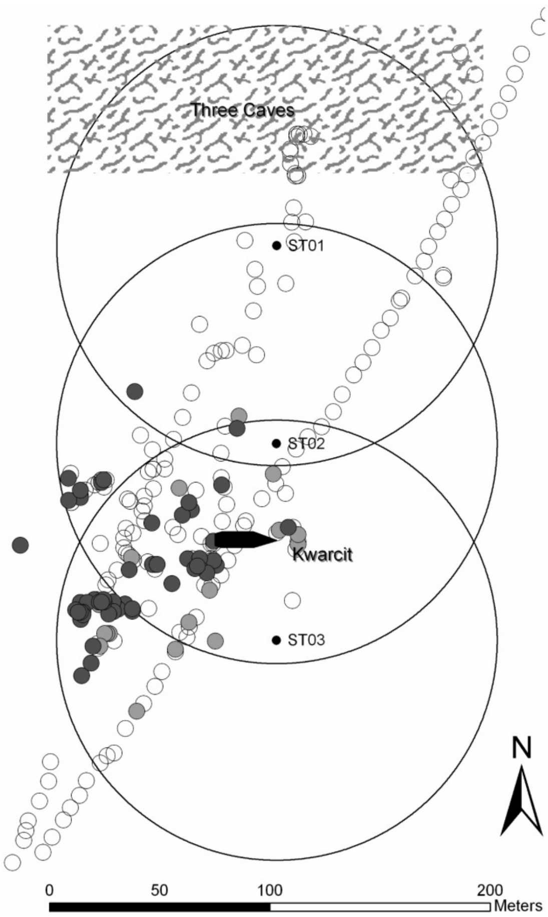


Figure 4.5. Results from active telemetry. The empty circles show the path taken by the survey boat. The lightly filled circles represent the surface position when a fish was detected. The dark filled circles represent a position with high acoustic intensity (Signal to Gain ratio > 1).

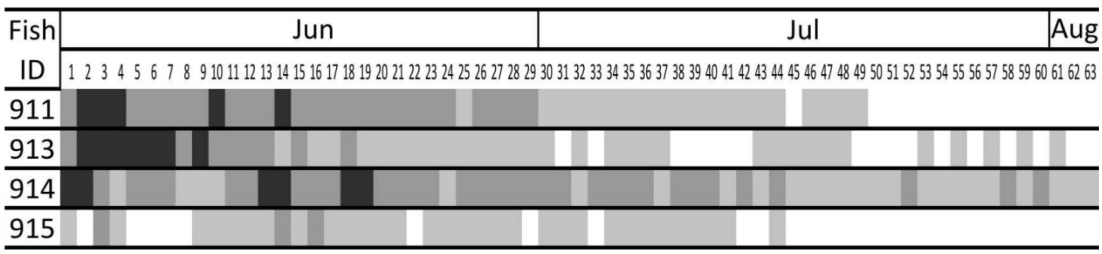


Figure 4.6. Activity pattern. Dark grey squares represents high detection (>100 detections/day); mid grey represents moderate detection (25 to 100 detections/day); light grey represents low detection (<25 detections/day). White squares represent days where the fish was not detected. Fish ID is the number reported by the acoustic tag to the acoustic receiver.

The general activity pattern as detected by the passive receivers (Figure 4.6) shows that the fish were more active during the first month and that by the 50th day after release only fish ID914 remained permanently within the study area. Fish ID915 was last detected in the study area 44 days after release, while fish ID911 was last detected 49 days after release. Fish ID913 was detected in the study area on the day before the receivers were recovered but had been absent for several intervals of a few days before then. This pattern can also be observed from the residence index (Table 4.1). Fish ID915 was present in the study area a little over half of the time (0.54), while fish ID911 and ID913 (0.76 and 0.73) were detected during nearly three-quarters of the study's duration. From a receiver perspective (Table 4.2), 31% and 69% of the detections were registered at Stations 2 and 3, respectively. All the fish were detected by these two receivers. Although the receiver at Station 1 registered 657 pings over the 64 days, there was not a single complete detection. The number of detections by the receiver at Station 2 (located to the port side of the ship) *versus* Station 3 (to the starboard side) show (Figure 4.7) that, on average, the fish were detected more than 69% of the time by the starboard passive receiver. The passive monitoring revealed a clear daily pattern (Figure 4.8), common to the 4 tagged specimens, with an increase in daily activity starting at daybreak and attaining a maximum a few hours before sunset. During the night, very little activity was detected, except for fish ID915 that had a peak of activity during the night of the third day of the experiment.

Table 4.1. Characteristics of the tagged fish. Total Length in centimeters was measured to the nearest half centimeter and Total Weight was calculated from a Weight-Length relationship. Fish ID is the number reported by the acoustic tag to the acoustic receiver; RI is the Residence Index.

Fish ID	Total Length (cm)	Total Weight (g)	# Days Detected	# of Detections	# of Receivers	RI
911	25.0	219	48	2521	2	0.76
913	27.5	299	46	1614	2	0.73
914	24.5	205	63	2671	2	1.00
915	22.5	155	34	257	2	0.54

Table 4.2. Results from the passive telemetry. ST01, ST02 and ST03 are the station numbers.

Stations	ST01	ST02	ST03
Detections	0	2182	4884
% of Total	0	31%	69%

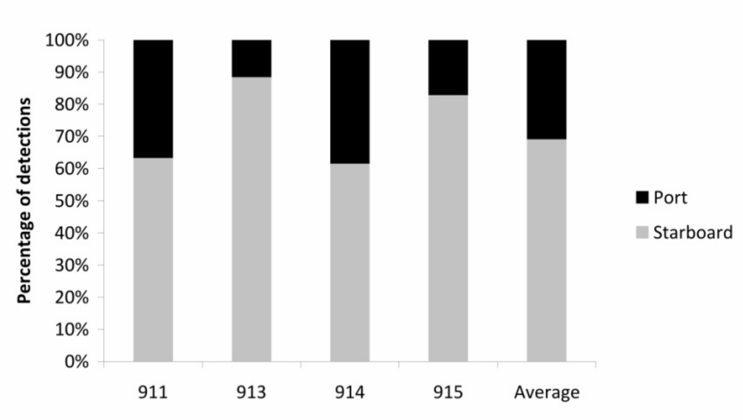


Figure 4.7. Detections of each fish by station. The grey bar represents the detections by the receiver in Station 3 (40 meters to Starboard from the bow of the vessel reef Kwarcit); the black bar represents detections by the receiver in Station 2 (40 meters to Port from the bow of the vessel). Columns identified by the fish ID; last column is the average for the 4 fish.

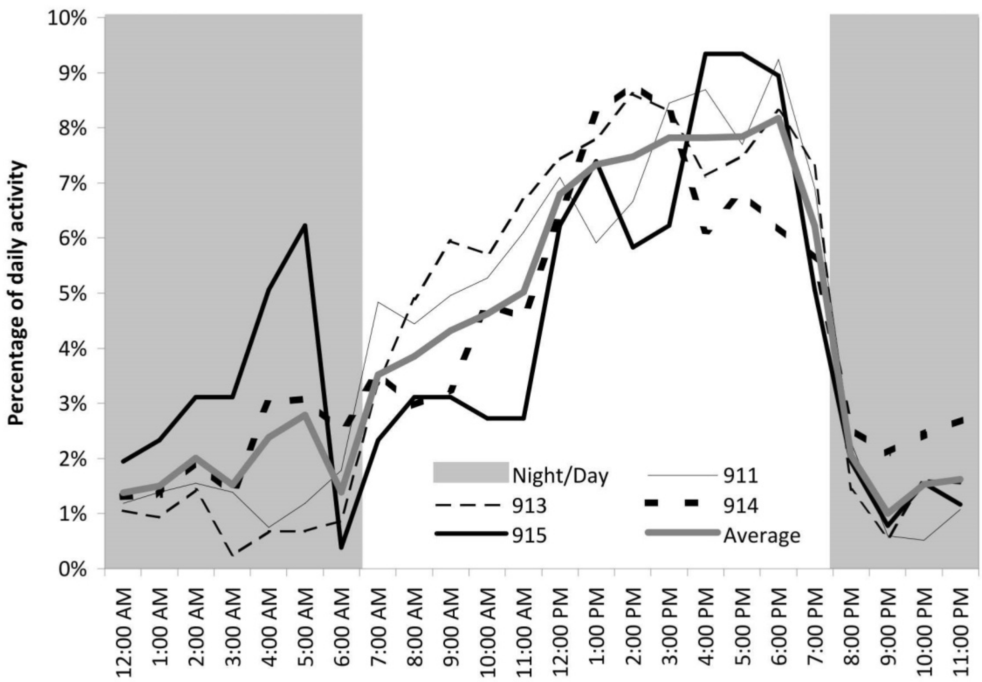


Figure 4.8. Detections of each fish by passive receivers. The grey area corresponds to the night time. The dark grey ribbon represents the average activity per hour.

4.5 DISCUSSION

The results obtained from active telemetry were similar to those later recovered from the passive receivers. The same fish were detected in the same areas by both passive and active receivers, which proves that the experimental design was appropriate and in accordance with the existing knowledge of the study area. However, although fish ID913 was detected with active telemetry in the study area on the day before the receivers were recovered, no register of this fish was made by the passive receivers. This means that the position in which it was detected was out of the range of the passive receivers but still within the same general area. This probably indicates that there is an uncharted hard substrate nearby to which the fish move.

During the study period no movement to the shallow natural reef was detected. However, the data collected during a parallel study, based on visual censuses, showed that there was a size distribution overlap between the shallow "Farol Baixo" natural reef area (where total length ranged from 9-32 cm), which is adjacent to "Three Caves", and the deeper vessel reef site (where it ranged from 11-37 cm). Further, there is a statistically significant difference between the mean fish size at the two locations (16.82cm±2.32SD and 22.67cm±2.64SD at Farol Baixo and at the AR, respectively). This means that there is a size gradient with depth and that although the fish living on the AR apparently do not migrate to shallow waters, it does not prove that large fish from the surrounding natural habitat do not visit the AR for feeding or reproduction. Daily migrations between the NR and the AR have been described for *Diplodus sargus*, a common demersal sparid (Lino et al, 2009). There might also be some migration of smaller specimens but current acoustic tagging limitations prevent their study using this methodology. Clearly, further investigation is required to determine the source and interchange of specimens between the two habitats.

All the fish remained in the study area for 44 days. In mid-July two fish were no longer detected and a third (ID913) was only detected randomly. Clearly the peak of activity within the study area, even ignoring the random activity registered on the first few days after release, which can be attributed to handling stress, occurred within the month of June, extending to mid-July. The posterior reduction in activity could be related to some reproductive migration since, according to Siau (1994) and Pastor (2002), the reproductive season occurs between

June and September in nearby Senegal and between June and October in the Cape Verde islands of São Vicente and São Nicolau.

The higher number of detections from the starboard receiver indicates that the tagged fish preferred the starboard side. This is to be expected from the lie of the boat which lists slightly to starboard with the bow facing the predominant easterly current. The vessel reef thus provides protection from the dominant current, creating a "shadow" area aft on the starboard side. This is corroborated by the active telemetry results, which showed that the most frequent detections were made near that position and by a parallel study on the AR fish assemblages (unpublished data). Stanley and Wilson (1997) have described a similar phenomenon by correlating the dominant current direction with higher counts of fish on the leeward side of a petroleum platform.

The fact that the vessel is leaning slightly to starboard means that the upper deck and superstructures are also protected from the dominant current. This not only increases the area protected but increases the number and complexity of available habitats as well as the abundance and diversity of benthic and demersal organisms available as food. These results seem to indicate that from a protection point of view it might be a better option, when deliberately sinking a vessel as an AR, to position it so as to list to one side, in such a way that the upper deck is to leeward of the dominant current. This will have both a positive effect on the fauna and create a protected area for recreational divers even in areas with bottom currents.

The fishes' daily activity showed more intense activity during the day for all the specimens, except for fish ID915 that was not detected during the second day, but had a high number of detections during the night of the third day.

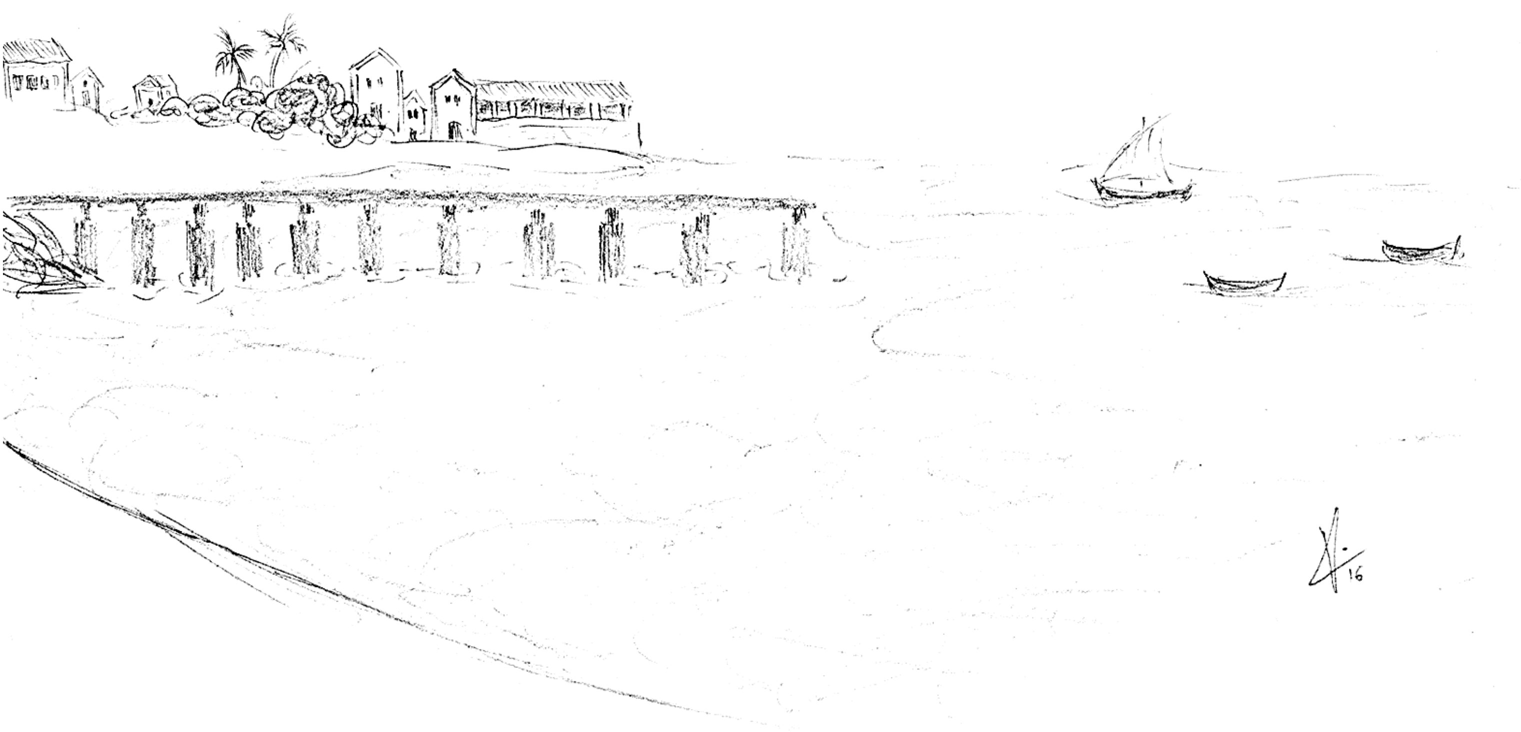
4.6 CONCLUSIONS

Since little is known about the biology of this particular species, this data could be interpreted as indicating that *C. taeniops* is a visual predator, actively seeking for food during the daytime period. This behaviour was observed *in situ* and allowed the authors to capture the fish with a hand line since they actively attacked the bait. Karlsen *et al.* (2009) also correlated greater activity of cod around shipwrecks with the diurnal activity of the major prey. However, the opposite behaviour has been observed by Popple and Hunte (2005) for *Cephalopholis cruentata* using acoustic telemetry in a marine reserve on St. Lucia, West

Indies. This species showed greater activity at night, which reinforces the need for species specific study of habitat use.

The results obtained in this study call for further study of the movements of *C. taeniops* both in terms of area, using a larger array of receivers, and time, covering a whole year if possible to investigate seasonal patterns. Studies should also concentrate on other species, such as the island grouper *Mycteroperca fusca*, which is also quite abundant locally but listed as endangered by the IUCN. This continued study will clarify the role of vessel reefs in the life cycle of these species but also ascertain the importance of ARs in the protection and restoration of local biodiversity.

3ND PART: SOCIAL AND ECONOMICAL ASPECTS



CHAPTER V

Stakeholder perceptions of decision-making process on marine biodiversity conservation on Sal Island

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Stakeholder perceptions of decision-making process on marine biodiversity conservation on Sal Island

5.1 SUMMARY

In Sal Island (Cape Verde) there is a growing involvement, will and investment in the creation of tourism synergies. However, much of the economic potential of the island can be found submerged in the sea: it is its intrinsic 'biodiversity'. Due to this fact, and in order to balance environmental safety and human pressure, it has been developed a strategy addressing both diving and fishing purposes. That strategy includes the deployment of several artificial reefs (ARs) around the island. In order to allocate demand for diving and fishing purposes, we have developed a socio-economic research approach addressing the theme of biodiversity and reefs (both natural and artificial) and collected expectations from AR users by means of an inquiry method. It is hypothesized a project where some management measures are proposed aiming marine biodiversity conservation. Using the methodology named as analytic hierarchy process (AHP) it was scrutinized stakeholders' perception on the best practice for marine biodiversity conservation in the Sal Island. The results showed that to submerge obsolete structures in rocky or mixed areas have a high potential, but does not gathers consensuality. As an overall conclusion, it seems that limitation of activities is the preferred management option to consider in the future.

Keywords: Marine biodiversity conservation, artificial reef project, Sal Island (Cape Verde), underwater tourism, Analytic hierarchy process (AHP).

5.2 INTRODUCTION

Many island microstates develop tourism activities as an alternative form of economic development, assuming that international tourism continues to grow (Wilkinson, 1989). One type of tourism that has grown dramatically in recent years is related to wildlife and biodiversity watching. Many tourism companies operate in this segment and promote products with a view to satisfying their clientele. This activity, also related to ecotourism, is based on management procedures intended to supply conservation services whereby the natural and cultural heritage should be preserved. According to Tapper (2006), these services usually involve local communities both in their planning and operation, and contribute to their wellbeing through the creation of jobs (e.g., as guides to visitors). Ecotourism enterprises imply strong, lasting and equitable partnerships with local communities and also protect the environment. In this field of activity there are several examples of highly successful projects (Parker and Khare, 2005).

Bourdet (2000) observes that Cape Verde has several structural development constraints (e.g., poor location and inadequately developed physical infrastructure). This small country has some agricultural products (e.g., bananas, sugarcane and coffee, among others) and some natural resources (e.g., fish and salt). There are also some industries producing fish and fish products and ship-building and repairing. But the main economic potential of the country is to be found in the sea. Cape Verde has a low per capita Gross Domestic Product (GDP) (McElroy and Morris, 2002), but in 2003 the UN Economic and Social Council recommended that Cape Verde should be upgraded from the list of Least Developed Countries (LDC), mainly due to increases in its per capita GDP. The country is preparing a National Strategic Development Plan for Tourism and is establishing a national school for hotel and tourism activities (Loper *et al.*, 2005). This means that the tourism sector is becoming the most important in Cape Verde and is the most promising (Alves *et al.*, 2000; Christie and Crompton, 2001). For instance, Sal Island is becoming very popular for underwater tourism and is able to take advantage of the international airport located on the island (Irwin and Wilson, 2009).

In the Cape Verde archipelago, the island shelf, of limited extent, is associated with a relatively low primary production and consequently the biodiversity is apparently lower than that of the African continental coast (Menezes *et al.*, 2004). The ichtyofauna is of tropical type. As Cape Verde is an archipelago there are a few dozen endemic *taxa*, probably due to speciation related to isolation and thermal stability (Brito *et al.*, 2007). In Cape Verde in recent years there has been a perceptible decline in the biodiversity of local marine life, especially due to increasingly intensive and unregulated fishing practices. As a result, underwater tourism may be affected by virtue of there being ’less to see’. However, increasing diving tourism may also jeopardize marine biodiversity if it continues to grow uncontrolled. Due to these threats and well aware of the need to contribute positively to providing quick answers to the issues mentioned, a local diving operator, with the agreement of Cape Verde’s Ministry of the Environment, took the first step in this direction when it launched the *Rebuilding Nature Project - Artificial Reefs in Cape Verde* (www.rebuildingnature.org).

The first record of benefits arising from artificial reefs comes from Japan, where in the Kansei Era (1789-1801) a fisherman caught an immense quantity of large sea-bream near a ship wreck. When the wreck vanished the fish stopped shoaling there. Thus did the relationship between sunken structures and increased catch come to light. The construction of devices to attract shoals and increase the wealth of fishermen and their families then spread to fishing communities throughout Japan (Mottet, 1985). By virtue of this empirical knowledge and further experience, there emerged the idea that by placing suitable long-lived, stable and environmentally safe materials (usually steel or concrete) in an area of the sea bottom selected *a priori*, marine life would be attracted and biodiversity of all kinds promoted. It has been demonstrated that ARs have a relatively higher potential than does empty space (Grove and Sonu, 1985). Seaman Jr. and Jensen (2000) observe that any AR exercises an influence not only on the biological context, but also on the physical and socio-economic processes related to living marine resources. In many places worldwide, ARs have been deployed for the purpose of stimulating commercial or recreational fishing activity, or simply as a protection for fish and the marine habitat (Milon, 1989a, b). It is now generally accepted that AR purposes may vary or be combined. Various social and economic methods have been proposed for the appraisal of ARs (Milon *et al.*, 2000). For instance, within that purpose it is possible to find studies on the demand for vessels-reefs generated by diving activities, which is one example of economic opportunity created by underwater tourism (Leeworthy *et al.*, 2006; Morgan *et al.*, 2009).

Biodiversity management presupposes both the desire to enhance the tourist experience and also to protect the local fauna and flora. For this it is necessary to discover how tourists see proposed biodiversity management arrangements. The scrutiny of tourist preferences for biodiversity management is thus essential (Semeniuk *et al.*, 2009). However, this decision-making question may pose some difficulty in terms of accurately quantifying people's preferences as regards management alternatives.

In order to adjudge demand for sustained diving and fishing purposes, we have developed a socio-economic research strategy for Sal Island. It is presupposed that there is funding available to support an environmental project, in terms of social responsibility, aiming at marine biodiversity conservation. In accordance with that purpose, four management measures, related to the motivation for reef diving, are proposed. However, due to the limitation of financial resources, it is necessary to choose the best practice in terms of the allocation of money. By using the analytic hierarchy process (AHP), stakeholders' perceptions as to the best practice for marine biodiversity conservation were investigated.

Study Area

Cape Verde is an archipelago of ten main islands and some islets located in the North Atlantic off West Africa. Sal Island is one of the most easterly islands of the windward group. It is relatively flat and arid, with sparse vegetation. However, its flat terrain led to its choice as the site for the country's main international airport in 1939. The island was almost uninhabited, but that development triggered some immigration from the neighboring islands (mainly S. Nicolau). The saline marshes found on Sal gave the island its name.

Until the 1980s the main economic activity was the production of salt for export. In recent decades tourism has supplanted the production of salt as the main activity (Pinto and Almeida, 2005). During this period the population has increased greatly, due basically to the development of modern tourist resorts, based mainly on the town of Santa Maria on the southern tip of the island which has become the main tourist centre of the archipelago. Also on the bay on the southern coast there are long white beaches, of great interest to tourists, formed of the sand carried thither from the Sahara desert by the wind. Other places of aquatic tourist interest include the foaming lagoon of Buracona (Irwin and Wilson, 2009).

According to Morri *et al.* (2000), knowledge on Cape Verde's marine biodiversity concerning both sessile and motile species is very limited. Even so, the synergies between different bodies on Sal Island have resulted in 'an environmental project with a social conscience' aiming to promote biodiversity. The project so far consists of the deployment of two ARs in Santa Maria bay (Kwarcit - a former soviet fishing vessel sunk in January 2006 and Sargo - an obsolete Cape Verdean navy patrol vessel sunk in April 2008).

These ARs have diversified diving options between Tchuklassa (natural sanctuary of underwater fauna), the accidental shipwrecks (Santo Antão - carrier sunk in the 1960s) and other sites such as: natural reefs (Farol Fundo), caves (Três Grutas) and mixed (Farol Baixo - natural reef and a 1920s shipwreck) (see Figure 5.1).

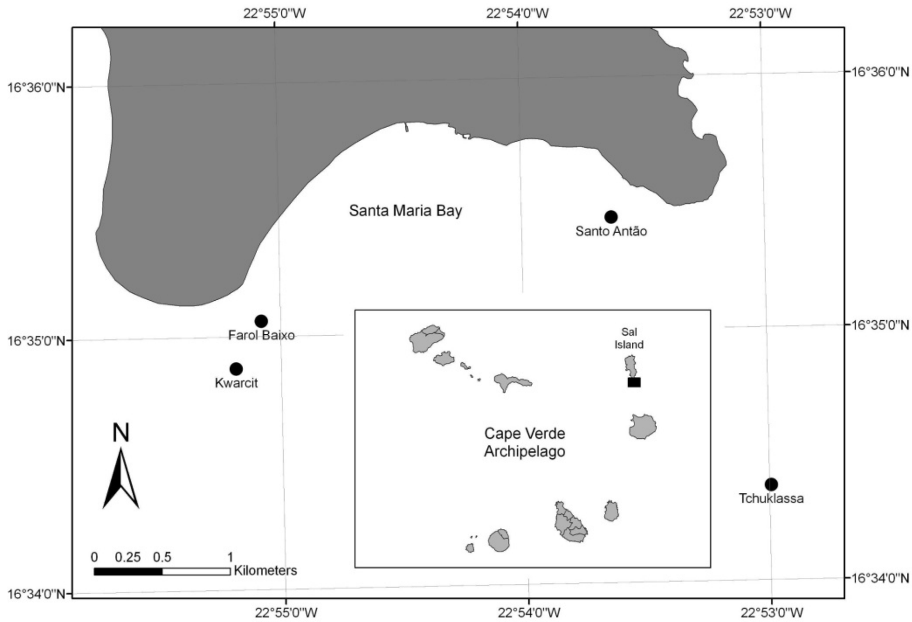

Figure 5.1. Map showing study location in Sal Island (Cape Verde archipelago).

5.3 MATERIAL AND METHODS

Data Collection and Stakeholders

The present study to examine perceptions concerning the management of marine biodiversity on Sal Island was carried out basically by means of two instruments of data collection: a questionnaire using the AHP and secondary data. People were invited to answer a questionnaire taking into consideration some aspects of diving, and express their opinion accordingly. Respondents were informed about the creation of ARs on Cape Verde. They were asked to give their opinions, by means of a simple AHP methodology, about a future project aiming at marine biodiversity conservation on Sal Island and their preference regarding the allocation of money for each type of diving site, in the light of four different management options. Respondents were then asked to rank their preferred management measures. Respondents were subdivided into five stakeholder groups: 1) Biologists, 2) Diving operators (DOs), 3) Non-governmental organizations (NGOs), 4) Managers, and 5) Recreational divers (RDs). All those aware of local marine biodiversity issues were considered to be biologists. Diving operators were all those commercial enterprises located on Sal Island or elsewhere who had already organized diving activities on the island. All those stakeholders who had an interest in and were involved in biodiversity and management on Sal Island and represented local, national or international institutions were taken to be NGOs. All those who had any sort of involvement in environmental, tourism or fisheries management on Cape Verde were considered as managers. Finally, recreational divers were all those people that had been diving on Sal Island with independent tourist activities. Stakeholders' influence on a project's outcome may vary, as, on the other hand, may the impact of the project on each stakeholder group. However, for the purpose of the present study, each individual independent stakeholder group was considered to have the same weight in the decision making process. Secondary data included information on the general development of tourism on Cape Verde and more specifically that focused on AR deployment projects. The internet sites of those diving operators working on Sal Island were also consulted.

The Analytic Hierarchy Process (AHP) Methodology

The AHP technique was developed by Thomas Saaty in the mid-1970s (Saaty and Rogers, 1976) and has been used in a wide range of disciplines (Saaty and Vargas, 2001). The potential of AHP is enormous and it is possible to use it in multicriteria decision-making, planning, conflict resolution, forecasting and in nearly all areas of knowledge (Saaty and Alexander, 1981; Triantaphyllou and Mann, 1995; Ananda and Herath, 2003; De Steiguer *et al.*, 2003). In the social sciences the AHP can be used to quantify and derive measurements for intangibles. It can also be used to link hard measurements to human values, by interpreting what the measurements mean. The technique has been applied to a range of problems involving natural resource management (Herath and Prato, 2006), in a few instances to fisheries and aquaculture (Leung *et al.*, 1998; Mardle and Pascoe, 2003a,b; Whitmarsh and Wattage, 2006) and in reef diving choices (Ramos *et al.*, 2006). One study of site selection for artificial reefs (Tseng *et al.*, 2001) has been made using the AHP. The AHP is essentially, basically a mathematical approach to decision making using pairwise comparisons. The technique considers both qualitative and quantitative aspects of related decisions. It reduces complex decisions to synthesized results thus making the decision-making process easier. The process consists of modelling a problem by using a hierarchical structure. In its essence, the AHP consists of a sequence of distinct steps (Saaty, 1990): (1) the definition of the problem, (2) the definition and selection of the elements for evaluation, (3) the selection of a set of alternative outputs, (4) the definition of a set of relevant criteria by which the alternatives are judged, (5) the construction of the hierarchical structure, (6) the gathering of information and choice of priorities, and finally (7) the preparation of recommendations for action. Usually the AHP model is represented by a schematic tree. Level zero is for the goal sought by the decision, level one establishes the criteria, and the lowest level of the tree is represented by the alternatives to the decision or other options (Figure 5.2).

After organizing all the criteria and alternatives, the selection process begins. To make the pairwise comparisons, a 9-point scale was used by the convention of which the value of one was chosen to indicate that two items were of equal importance, while nine indicates that one item was absolutely more important than the other (Table 5.1).

Then a number of pairwise comparisons were made in order to establish factor weights and the following assessment. Paired comparisons were made between n criteria and alternatives. In our case six comparisons were made for each level of the tree, as both the criteria and the alternatives were four (Table 5.2). In the end, the alternative with the highest total weight score was selected as the best one.

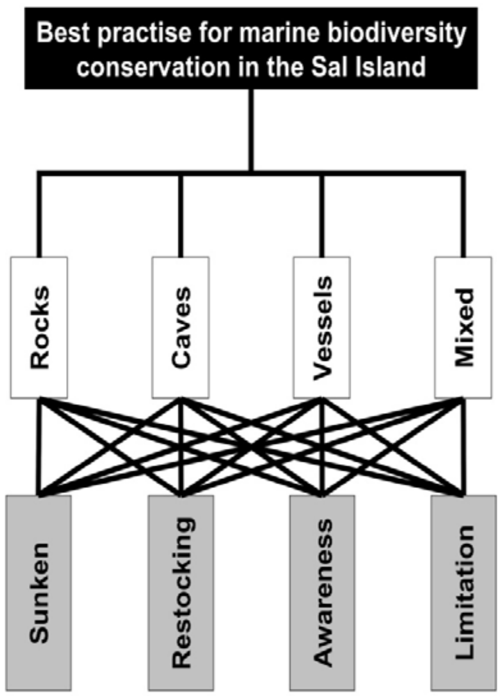

Figure 5.2. The AHP tree model (goal, diving spot types and management alternatives).

Table 5.1. The AHP scale represents an intensity of importance.

Score	Pairwise comparison	Explanation
9	Significantly more important	One item is favoured in the highest possible way
7	Much more important	Dominance of one item in relation to another
5	More important	One item is strongly favoured to another
3	Moderately more important	One item is slightly favoured in relation to another
1	Equally important	Two items contribute equally to the goal
2, 4, 6, 8	Intermediate values	Used to compromise between two comparisons

Table 5.2. Criteria, alternatives and their number of paired comparisons.

Level	Description	Number of paired comparisons
Criteria	Rocks, Caves, Vessels and Mixed	6
Alternatives	Sunken, Restocking, Awareness and Limitation	6

The aggregation of individual preferences was made by assuming that the group wants to act together though as separate individuals. The method used is called ’aggregating individual priorities’ (AIP). By this method the aggregation of each individual’s resulting priority weights is computed using the geometric mean and the Pareto principle is not violated.

Forman and Peniwati (1998) state that *"The Pareto (unanimity, agreement) principle essentially says that given two alternatives A and B, if each member of a group of individuals prefers A to B, then the group must prefer A to B"*. A consistency ratio of 20% or less was used to consider the answers as reliable. If the consistency ratio was below 10%, the answers were considered consistent. This also meant it was unnecessary to make much adjustment to the actual values of the eigenvector entries.

AHP Evaluation: Diving Spot Types (Criteria)

Incentives were given for the deployment of ARs on Sal Island. After preliminary studies carried out by specialists, the best locations were selected and the task of sinking the vessels was carried out. Prior to the survey some basic information related to the diving activities on Sal Island was provided. Having in mind the preservation of marine biodiversity in the Santa Maria Bay, the respondent should consider the most important diving spot types (criteria) on the island, according to the following distinctions: (1) *Rocks* were natural reefs characterized by being essentially rocky intrusions. (2) *Caves* were natural reefs that correspond to narrower or wider cavities with one or more openings. (3) *Vessels* were artificial structures accidentally or deliberately sunk. (4) *Mixed* were places that present both natural and artificial reefs within the same area. In terms of use, it was intended to minimize the first and second, to maximize the third and to maintain the last.

AHP Evaluation: Management Measures (Alternatives or Options)

The following management measures (alternatives) were also considered: (1) *Sunken*, the sinking of artificial structures (e.g. vessel-reefs) to widen the spectrum of diving sites and mitigate the damage caused to fragile habitats; (2) *Restocking* of living organisms including corals in order to maintain biodiversity and sustainability of diving activities; (3) *Awareness* on the part of the local community for the importance of the preservation of marine living organisms in the areas of diving interest; (4) *Limitation* of activities considered to be a threat to diving sustainability and marine biodiversity.

AHP Sensitivity Analysis

Different values were attributed for each of the variables analyzed, according to the respondent's judgment. However, it was important to know where each of the criteria and management options that had been evaluated by respondents was positioned. Thus a sensitivity analysis was carried out in order to ascertain the range of variation of each variable. Variable changes (i.e. diving spot type and management alternatives) show the range of preferences chosen by respondents. The objective of a sensitivity analysis is to identify the critical variables of the AHP model and show how the variability of each of the inputs will contribute to the best decision.

5.4 RESULTS

Stakeholder Characteristics

The collection of data by means of the questionnaire survey took place between June 2009 and February 2010. Respondents were mostly required to answer a questionnaire delivered *in situ*. A total of 59 questionnaires were collected (Table 5.3). Each individual was considered as belonging exclusively to one stakeholder group.

Table 5.3. Survey response rate by stakeholder group.

Stakeholder group	Participants surveyed	Usable responses	Usable response rate (%)
Biologists	7	6	86
DOs	4	3	75
NGOs	4	3	75
Managers	6	4	67
RDs	38	26	68
Total individuals	**59**	**42**	**71**

The biologists questioned were responsible for studying local marine biodiversity and were usually engaged in projects in that field. Four out of the six DOs in Santa Maria Bay responded to the questionnaire. There were few NGOs on the island and they mostly represented international schemes (e.g., *SOS Tartarugas*). Managers were people who have some knowledge and expertise in terms of local fisheries and environmental management. Finally, RDs were usually non-residents who went to Sal Island for tourism and/or diving purposes, due to the attractiveness of this tropical resort. Apart from DOs and managers, around two-thirds of the respondents were male, mostly non-residents (the majority being EU citizens). In terms of age, almost half the respondents were between 26 and 40 years old. Their level of education was usually high (4/5ths of the respondents had the equivalent of a university degree). The tourists' stay on the island usually varied from a few days to two weeks and for most of them it was their first visit to Sal Island. The majority of them dive just a few times a year, had less than fifty recorded dives, and only a few of them often travel abroad to dive.

Eliciting Respondents' Priorities and Sensitivity Analysis Using the AHP

The results of the sensitivity analysis were represented by a boxplot and whiskers diagram (Figure 5.3). The y-axis of the diagram showed the range of variation each management option has concerning the different criteria on the result, where the most sensitive variable is the largest box, which means that it had the maximum impact on the result. The horizontal line in each boxplot (i.e. the median) showed the base case answer for each of the variables (i.e. management options).

In rocky areas, the most preferred management alternative was the deployment of obsolete structures (e.g. derelict vessels). It was also the most sensitive one (the eigenvalue varied between 0.170 and 0.480). In rock intrusion areas, restocking was viewed as an option that did not make much sense. In diving spots based on caves, the most sensitive management option - i.e. restocking - did not attain a consensus among the stakeholders, revealing many doubts or a lack of information such as would facilitate a decision (the eigenvalue varied between 0.120 and 0.450). On the other hand, the limitation of activities was the alternative that achieved the greatest consensus, it being considered very important to limit destructive practices in cave areas (its eigenvalue varies between 0.300 and 0.380). As in the case of caves, it was perceived by respondents that in areas where there were sunken vessels, intensive fishing activities should be minimized. Sinking more vessels as reefs had high preference, but this variable was somewhat sensitive (0.200 to 0.410). Restocking did not achieve a high preference, but is highly sensitive (i.e. not consensual). Mixed areas showed high sensitivity for sunken structures (0.130 to 0.440).

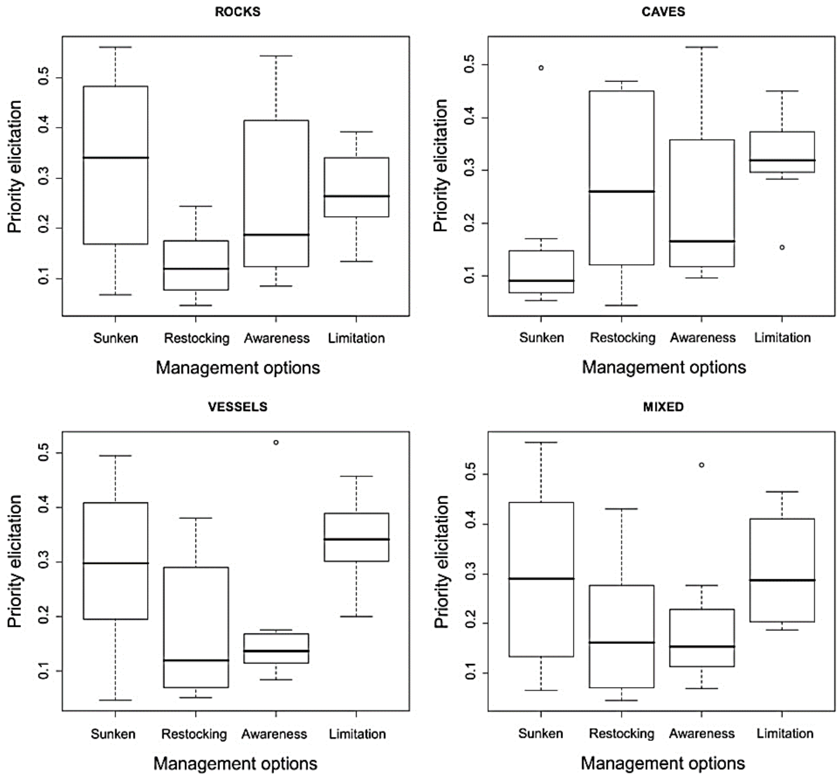

Fig. 5.3. Sensitivity analysis for diving spot types and management alternatives.

AHP Evaluation and Decision to Make

So far we have used AHP to evaluate the options with regard to each of the criteria. What the decision makers (DMs) also need to do is establish the relative importance of the management measures proposed (alternatives). Through the AHP procedure followed, the paired comparisons in respect of the four management alternatives (Sunken, Restocking, Awareness and Limitation), generated the priority weighting. The results of the sensitivity analysis were represented by a boxplot and whiskers diagram as shown in Figure 5.4. The y-axis of the diagram shows the range of variation each stakeholder group presented concerning the variables in the result. The horizontal line in each boxplot (i.e. the median) shows the base case answer for each stakeholder. Sinking an obsolete structure is a management alternative that is not consensual, i.e., its choice is somehow dependent on the stakeholder group. It is the option preferred only by diving operators, half of whom prefer this option (the eigenvalue is over 0.500), but managers also strongly support the idea (they rank this option as their second preferred choice, after limitation of activities considered dangerous to diving sustainability and to local marine biodiversity). This management option is probably one of the most sensitive ones as there is a wide variety of opinions among stakeholders. Restocking, despite being the option that gathered fewest supporters (usually the eigenvalue lies between 0.050 and 0.200), was the most consensual. Only managers saw this option as having some potential, but it was considered sensitive. On the other hand, NGO representatives see no reason for restocking. Among the four management options assessed, restocking was also seen as the least sensitive. Awareness was a management alternative that did not achieve much of a consensus, i.e., its choice was highly dependent on the stakeholder group concerned. The eigenvalue lay over 0.600 in the case of NGOs and under 0.100 for managers. It was a sensitive variable among both biologists and NGOs (they show a large range of variation). NGOs see this option as by far the most important one concerning the best practice for marine biodiversity conservation on the island. None of the other groups considered this option as sensitive. Limitation is a management alternative that was in some measure consensual, i.e., its choice was not dependent on the stakeholder group. All stakeholder groups considered this variable as usually one of the most deserving of consideration. As well as the sinking of obsolete structures, this management option presented a wide range of variation among stakeholders, thus denoting great sensitivity. Recreational divers showed a high preference for the limitation management option (they present an eigenvalue of between, approximately, 0.200 and 0.600).

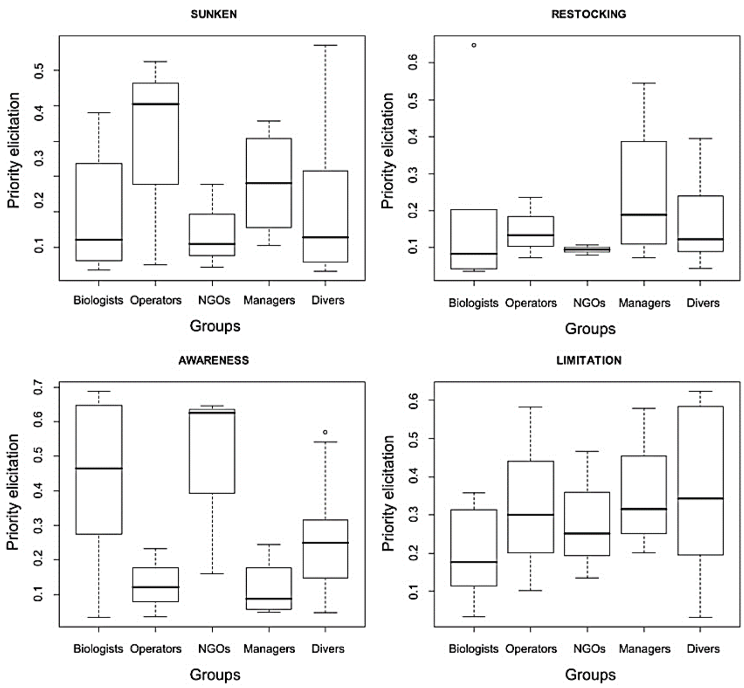

Figure 5.4. Sensitivity analysis for the best management decision according to stakeholder group.

5.5 DISCUSSION

With the aid of the AHP, people were able to express their preferences regarding management options aiming at biodiversity conservation, according to the different diving spot types. In a first phase, when the overall individual choice was considered, the results of the present study showed that the most sensitive diving spot type was restocking in cave areas. This result denoted some ambiguity because it might be interpreted either as being regarded as very important to take into account in a near future restocking of some species in somewhat sheltered areas (i.e. caves), or as an option that should not be taken very seriously. The second most sensitive variables were reefing structures in rocky and in mixed diving spots. The least sensitive variable was awareness of vessel diving spots. Notwithstanding the above considerations, these results enabled us to understand the dynamics of the diving spot type variables and consequently gave some clues as to how to decrease the overall risk of the project.

The main focus should, however, be on the management options. Overall, of the management alternatives presented to represent the best practice for marine biodiversity conservation on Sal Island, the results presented in this paper suggest that, although there is no clearly defined management alternative consensual among all stakeholders, there was a higher priority call for limitation. This attitude expressed by the questionnaire survey respondents may reflect some perception amongst stakeholders that the limitation of potentially damaging activities should safeguard diving sustainability and mitigate the alleged risk of biodiversity loss at diving spots. The second preferred choice was not so easily perceived because it was dependent on the stakeholder group. A somewhat opposite view was expressed when comparing the sinking of obsolete structures with the awareness of the local community concerning the preservation of marine species. The least preferred choice was restocking. Probably stakeholders thought that there was no need to introduce species produced under controlled conditions because they perceived that there was no serious risk of biodiversity loss. It is interesting to note that the DOs' priority goes to the sinking of more derelict structures as reefs. This attitude may presume operators' interest in diversifying diving spots. Their interest in participating in and promoting projects related to marine biodiversity through using sunken vessels as reefs with a view to promoting underwater tourism is understandable. This result supports the idea that the that the demand for 'non-natural' habitats (where structures such as derelict vessels are included) is potentially high, as suggested by Leeworthy *et al.* (2006) and Ramos *et al.* (2006). Another interesting, noteworthy finding was that both biologists and especially NGOs accorded high priority to awareness, which reflects their concern for biodiversity conservation and recognition of the importance of sustainable and adequate use and practice of marine resources.

5.6 CONCLUSION

On Sal Island the effort to contribute to the reconstruction of nature through the deployment of ARs is seen as protecting marine biodiversity from damaging fishing practices and simultaneously as widening the range of diving options by diverting diving from natural to artificial reefs. This action is believed to be an important preliminary step towards adequate management of marine biodiversity on the island. By creating better diving conditions, not only through diversifying diving spots, but also by assuring higher sustainability of its practice, it is supposed that more tourists can be attracted to and become particularly involved in diving activities. These activities create jobs and contribute to the social acceptability of such projects, involving an increasing number of local people who would otherwise be redundant or unemployed. Thus it is possible, through a synergistic effort, democratically and effectively to point to the right choices for the allocation of funds for a given project.

In terms of recommendations for action, the decision regarding the ’best practice for marine biodiversity conservation on Sal Island’ would be for the promotion of greater protection for the rocky type diving spots and to facilitate the process of sinking obsolete or man-made structures in order to diversify diving spots. These results support a preliminary approach whereby divers would be diverted from natural to artificial structures. Since there is some fishing activity that has a certain economic and social impact in Santa Maria Bay, it is important to consider and understand the use of ARs not only for diving purposes, but also for the enhancement of fishing resources, since this affects the performance of the fisheries as a whole (Ramos *et al.*, 2006). There is no clear preference regarding the definition of a management plan, probably due to the lack of available information concerning the different aspects of the project (e.g., the availability of continuing funding resources and the tangible, longer-term objectives to be sought). This aspect of the question means that further studies should be commissioned.

CHAPTER VI

Valuing marine biodiversity conservation in Sal Island (Cape Verde) using the contingent valuation method

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Valuing marine biodiversity conservation in Sal Island (Cape Verde) using the contingent valuation method.

6.1 SUMMARY

In the present study, we estimated the value of marine biodiversity off Sal island (Cape Verde) through a contingent valuation methodology, where tourist divers, who had recently dove off Sal island, were asked about their willingness to pay (WTP) for the protection of local marine biodiversity through donations, fees, or other forms for the creation of a trust fund. Of 347 respondents, 32% stated they were unwilling to contribute (protest bidders). Of those respondents who said they would be willing to contribute, 50% chose “fee” as the option where they were willing to pay less, whereas the “combined” option (i.e. including “donation”, “fee” and “souvenir”) was the one where respondents were willing to pay more, with around €1-7 and €0-800, respectively. We discuss the potential of trust funds as potential revenue sources to support marine biodiversity conservation and improve resilience of both local diver operator businesses, other tourist enterprises, and the local community as a whole.

Keywords: Artificial reefs, Diving tourism, Exploratory contingent valuation, Marine biodiversity conservation, Sal island (Cape Verde).

6.2 INTRODUCTION

Marine biodiversity is often put at risk when there is misuse of resources without the simultaneous action to conserve and replace those resources (Roberts *et al.*, 2002; Carpenter *et al.*, 2008). Different sources of funding for the protection of marine biodiversity are available and their effectiveness depends upon several circumstances - e.g. public policies, private or public organization commitments (Williams *et al.*, 2010). One such funding source is the establishment of trust funds, which are already established in several places worldwide (e.g. Subade, 2007; Peters and Hawkins, 2009). The economic value associated with marine biodiversity conservation has been studied in different places around the world, with particular emphasis in tropical waters. There are several studies in this area of research, most of them dealing with diving in MPAs, coral reefs or both. For example, the consumer surplus for the diver is often related to the increased chance of finding more corals, turtles or fish (e.g. Parsons and Thur, 2008) and eventually facing less pressure from divers (e.g. Schuhmann *et al.*, 2013). Divers usually tend to maximize utility, which is obtained if their expectations at a dive site are fulfilled (Semeniuk *et al.*, 2009). Diving tourist enthusiasts (eco-tourists) are keen to preserve marine habitats that offer a different experience (Uyarra *et al.*, 2010). Indeed, "uniqueness" is often a keyword used to describe a diver's favourite site (Parsons and Thur, 2008). Eco-tourists are typically interested in visiting dive spots that house rare or endangered species (Ramos *et al.*, 2006), as well as those that protect or mitigate a negative agent (Stamieszkin *et al.*, 2009). Malpractices, habitat loss and other phenomena expose marine biodiversity to risks (Wielgus *et al.*, 2009), and to counteract these effects, conservation measures are needed (Airoldi *et al.*, 2008). In that sense, divers can be involved in the process of evaluating marine biodiversity and demonstrate their willingness to pay (WTP) for underwater biodiversity (Sorice *et al.*, 2007). Stakeholders in general and eco-tourists in particular find that they need to contribute to the protection of coastal and marine spots (Pomeroy *et al.*, 2007). Several national marine parks have developed different financing mechanisms in order to achieve self-sustainability (e.g. Gallegos *et al.*, 2005), such as entrance fees to marine reserves (Arin and Kramer, 2002).

For some sites, particularly marine protected areas (MPAs), funding from fees, grants, and donations are usually not enough to cover operational costs, and the involvement of local communities in the activities of the marine parks brings additional revenues from tourists to the local tourist industries (Dygico, 2013). The local economy, e.g. souvenir shops, also benefit from biodiversity conservation namely by selling protected area-related clothing and daily use objects (Ross and Wall, 1999). The objective of this paper was to determine eco-tourists' WTP for the creation or maintenance of certain divesites off Sal island. To achieve this goal, we developed an online survey to ascertain the factors that influence WTP.

Literature Review

The need to attribute values to environment preservation has been in existence since the middle of the last century (Smith, 2009). Typically, studies on the valuation of non-market resources use indirect methods (e.g. travel cost) and direct methods (e.g. contingent valuation) (Adamowicz *et al.*, 1994; Kopp and Smith, 2013). The contingent valuation method (CVM) was first proposed by Ciriacy-Wantrup as a survey-based economic technique (Ciriacy-Wantrup, 1947).

People take advantage of the availability of natural resources (utility), but the majority of the time, those resources are not sold in markets. Consequently, their value is uncertain, because there is no market price for them (Zhang and Li, 2005). Contingent valuation focuses on social choice (McFadden, 1994), and single or multiple instruments can be used to measure the above mentioned problem, i.e., to preserve certain public goods (Green *et al.*, 1998; McComb *et al.*, 2006) or to accept natural or environmental losses (Andersson, 2007). The instruments used to collect elicitations from people vary (Welsh and Poe, 1998). Surveys, whether face-to-face, mail, telephone (Holbrook *et al.*, 2003; Mitchell and Carson, 2013) or more recently web-based (Thurston, 2006; Heiervang and Goodman, 2011) are commonly used to gather information for the CVM. Comparisons of both instruments have also been tested (Berrens *et al.*, 2003; Canavari *et al.*, 2005; Lindhjem and Navrud, 2011). Basically, whatever the instrument used, people are asked to choose their preference, ideally in a single and straightforward way, by stating how much money they are willing to pay to preserve a given natural feature such as marine biodiversity (Kahneman and Sugden, 2005).

Within economics the standard CVM makes use of different formats to elicit a response based upon a hypoThesised contingency, with the dichotomous choice and/or the payment card amongst the most commonly used. The stated preference methods used to measure WTP are usually based on the combination of several economic values associated for the use, option, and existence of natural and environmental resources (Freeman, 2003). Thus, in CVM surveys, it is common to find protest bidders and the ways to deal with them may vary (Meyerhoff and Liebe, 2006; Jacobsen and Thorsen, 2010). According to Halstead *et al.*

(1992), protest bidders are not only those that give a value of zero to the commodity being offered (protest zero bids), but also disagree with or do not like the format of payment being used in the survey instrument.

Diving surplus value is commonly expressed in monetary terms (Table 6.1). For instance Brander *et al.* (2007) collected information from 166 worldwide studies on the recreational value of coral reefs and standardized it in US$/visit.

Table 6.1. – Selected studies valuing access and quality change for diving.

Author(s)	**Location**	**Resource**	**Methodology**	**Year of study (YoS)**	**Value per diver in 'YoS US$'**
Arin and Kramer (2002)	Phillipines	Marine park	CVM	1997	$3.40–5.50/day (WTP)
Tongson and Dygico (2004)	Tubbataha (Phillipines)	Marine park	CVM	1999	$41.11/trip (WTP)
Oh *et al.* (2008)	Texas (USA)	Marine sanctuary	CVM	2007	$101–171/yr (WTP)
Parsons and Thur (2008)	Bonaire	Marine park	CVM	2001	$45–192/yr (WTA welfare losses)
Asafu-Adjaye and Tapsuwan (2008)	Similan islands (Thailand)	Marine park	CVM	2004	$27.07–62.64/yr (WTP)
Nuva *et al.* (2009)	West Java (Indonesia)	Marine park	CVM	2004	$0.82/day (WTP)
Yacob *et al.* (2009)	Malaysia	Marine parks	CVM	2007	$1.92–2.79/yr (WTP)
Casey *et al.* (2010)	Yucatan (Mexico)	Coral protection	CVM	2005	$42–58/yr (WTP fees)
Thur (2010)	Bonaire	Marine park	CVM	2002	$61–134/yr (WTP fees)
Ransom and Mangi (2010)	Mombasa (Kenya)	Marine park	CVM	2007	$2.2–8/yr (WTP)
Schuhmann *et al.* (2013)	Barbados	Marine biodiversity	CVM	2007-09	$41–62/two-tank dive (WTP)

Sal Island (Cape Verde)

Cape Verde is an island country spanning an archipelago of ten volcanic islands in the central Atlantic Ocean (Figure 6.1). Located 570 kilometres (350 miles) off the coast of Western Africa, the islands cover a combined area of 4,033 square kilometres (1,557 sq mi) (Anonymous, 2005). Cape Verde has few significant natural resources beyond fisheries, suffers frequent drought (Anonymous, 2007b) and was recognised as one of the marine biodiversity hot-spots most threatened by species extinction (Roberts *et al.*, 2002). Nevertheless, Cape Verde hosts more than 300 fish species, with 6.3 % endemism (Wirtz *et al.*, 2013), five marine turtle species (Santos *et al.*, 2009) and a large number of macrofaunal endemic species (Cunha *et al.*, 2005; Duda Jr. and Rolán, 2005) in clean, pristine waters attracting more than half a million tourists annually (INE, 2013b).

Diving is one of the main tourist attractions, with Sal Island and Boavista being the two most visited of the archipelago (INE, 2013b). Despite the recent competition from the new airport built in 2007 on Boavista Island, Sal Island still attracts an increasing number of tourists (Duarte and Romeiras, 2009). The main tourism attraction in Sal is diving due to the pristine waters and as a tropical destination it offers a high diversity of warm-water marine species.

Job opportunities in Sal have risen in recent years. As a consequence many deprived people from other islands moved to Sal seeking a tourism-related job, which resulted in a rapid population growth (Simão and Môsso, 2013). The tourism sector has been one of the main reasons that poverty has attenuated on Sal (Rocha and Ferreira da Silva, 2014). Job opportunities are both directly and indirectly linked to the expanding tourism industry, where small-scale fisheries play an important role in the chain by supplying fresh fish and shellfish to the food and beverage businesses (Fidalga *et al.*, 2014). Fishermen have seen their catches achieving a higher price, because of the rising demand of high quality fish for restaurants and hotels (Barros, 2007) and a few studies on diving have already been carried out, such as the first attempt to characterize the Sal diver profile (Ramos *et al.*, 2011).

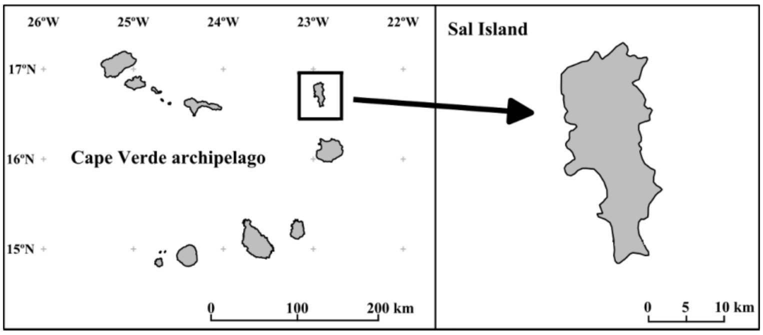

Figure 6.1 – Cape Verde archipelago: Sal Island location.

6.3 MATERIAL AND METHODS

Questionnaire and data collection

The survey instrument was pre-tested on a sub-sample of five divers in October 2012. After some adjustments a questionnaire survey was placed online. A covering letter introducing the purpose of a CVM survey about the value of marine biodiversity conservation off Sal island and a link to a survey, was emailed to 7,434 addresses drawn from a list of divers who had visited Sal island and went out with a local dive operator. The questionnaire was active between February 18th and March 18th, 2013. Because it was aimed to reach a wide audience, both the cover letter and the questionnaire were presented in English. The expected average time to complete the questionnaire was 15-20 minutes and it consisted of 29 questions: 26 multiple choice and 3 open-ended. The survey included questions about the geographic origin of respondents and some of their personal characteristics (e.g. age group, gender, marital status, job occupation group), holiday and tourism choices (e.g. season of the year to go on holidays, number of visits to Cape Verde, staying time, accommodation type), diving characteristics (e.g. dive expertise, dive avidity, preferences), and specific questions related to marine biodiversity (perceived status of marine biodiversity, perceived diving impact).

A hypothetical conservation scenario was posed where respondents were invited to state their preferences in terms of willingness to pay for the status of marine biodiversity. Respondents were asked if they were in favor, against or indifferent to the contingent valuation question. Some follow-up questions were included to differentiate protest bids and other bidders. Those who were favorable or indifferent were asked to state their preferential options to contribute for the potential creation of a trust fund, namely a donation, buying a souvenir, a diving fee, or a combination of the above. Respondents were asked to choose one of eight donation amounts (< €1, €1-5, €6-10, €11-20, €21-50, €51-100, €101-200 and > €200). Following Brander *et al.* (2007), the valuation results were standardized in a single unit of monetized values in the currency (euros €), for the year 2013, for the entire island (Sal), per visitor (diver), during a certain time period (usually one week). Variables were used in statistical analysis (Table 6.2).

Table 6.2. Selected variables used in the contingent valuation method and their description.

Variable	Description
Individual characteristics	
ORIGIN	Country where respondent lives most of the time (= 1 if Portugal, = 0 otherwise)
GENDER	Gender (= 1 if male, = 0 if female)
AGE	Age group (coded 1 to 4: 1 = under 26 yr old, 2 = 26 to 40 yr old, 3 = 41 to 60 yr old, 4 = over 60 yr old)
EDUC	Last years at school / university completed (coded 1 to 3: 1 = under 9 yr, 2 = 9 to 12 yr, 3 = over 12 yr)
MA_STATUS	Marital status (= 1 if married or living together, = 0 if single, widowed or divorced)
Trip characteristics	
SAL_VISIT	Number of Sal Island visits (coded 1 to 4: 1 = once, 2 = twice, 3 = three to five times, 4 = more than five times)
MO_VISIT	Month of last visit to Sal Island (=1 if summer: June, July and August, = 0 otherwise)
TOT_COST	Proxy for income: total costs estimated (i.e. travel and lodgement costs)
Diving characteristics	
DIVE_EXP	Diving experience (= 1 if less than fifty dives, = 0 otherwise)
DIVE_YR	Number of dives per year (= 1 if less than ten dives, = 0 otherwise)
FUND	Willingness to contribute for a fund (coded 0 to 2: 0 = 'no' to WTP, 1 = 'maybe' WTP, 2 = 'yes' to WTP)
HELP	Availability to participate and help in Sal conservation project (coded 0 to 2: 0 = 'no', 1 = 'maybe', 2 = 'yes')

There are different ways of dealing with protest bids (Freeman, 2003). Halstead *et al.* (1992) refer that there are three commonly used approaches: (1) simply dropping them from the data set, (2) including protest bids in the data set, (3) assigning protest bids a mean WTP according to some characteristics of other respondents. In this study protest bids are included in the data set.

Econometric model approach

According to Train (2009) the utility (*u*) derived by an individual (*i*) from a particular alternative (*j*) comprises a deterministic value component (v_{ij}) and a random component, where the latter is unobservable to researchers (ε_{ij}). Utility can be expressed as:

$$u_{ij} = v_{ij} + \varepsilon_{ij} \tag{1}$$

when it is accepted that when the individual chooses an alternative (*k*) over another alternative (*j*), it is implied that the utility received from the former outweighs that from the latter as follows:

$$u_{ik} > u_{ij} \tag{2}$$

Following Oh *et al.* (2008), Asafu-Adjayea and Tapsuwan (2008) and Casey *et al.* (2010), we used a random utility econometric model to verify if the responses to the hypothetical change to promote biodiversity conservation through the potential establishment of a trust fund. Respondents (*i*) were asked to compare their personal utility based on the current state or status quo (u_{ij}) with the establishment of a fund used to create artificial reefs and other mitigation measures to protect marine biodiversity at a given cost represented as (u_{ik}). We assume that utility is a function of a proxy of income (M_i) (i.e., based on diver's accomodation costs estimation and staying time plus the approximate standard flight cost according to the distance from the country of origin), individual socioeconomic characteristics of the respondent (S_i) and the WTP to contribute for a biodiversity fund (F_{ik}) which has two possible states (1 if the respondent is willing to contribute and 0 if is not), and unobservable elements that contribute to respondent's decision (ε). A diver (*i*) is willing to pay from a payment card a given amount (A_{ik}) (i.e., answer type ‘‘Yes’’ or “Maybe”) only if:

$$u_{ik}(F_{ik}, M_i - A_{ik}, S_i) + \varepsilon_{ik} > u_{ij}(0, M_i, S_i) + \varepsilon_{ij} \tag{3}$$

WTP is calculated based either on supportive ("Yes" and "Maybe") or protest ("No") bids to the statement. It is assumed that the error terms are independently and identically distributed with mean zero and variance $\pi^2/3$ (the multinomial logistic distribution function or multinomial logit), and the probability that the respondent gives a supportive answer is represented by:

$$Pr(\text{"maybe" or "yes"} = 1) = 1 / (1 + e^{-z}) \tag{4}$$

where z can be expressed by:

$$z = \alpha + \beta F_{ik} + \gamma S_i + \delta M_i \tag{5}$$

where α, β, γ and δ are coefficients to be determined.

6.4 RESULTS

Of 7,434 e-mails sent out, we received 347 replies (4.67%). Of those, only 292 surveys were filled out completely; these were used for subsequent analyses.

Descriptive statistics

Respondents' characteristics were allocated in three sections (Table 6.3). One related to individual characteristics, a second one connected to the diving trip to Cape Verde, and a third one linked to diving. Regarding man-made structural reefs, most respondents like this type of reef (76.5%) or are indifferent (19.3%), while few divers do not prefer man-made structures (5.2%).

Table 6.3. Dive tourists sample characteristics. NR stands for Natural Reefs, AR stands for Artificial Reefs, Indiff stands for divers with no preference for dive site, ALL stands for aggregated divers.

	ALL (n = 292)		NR only (n = 16)		AR (n = 225)		Indiff. (n = 51)	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Individual characteristics								
ORIGIN	0.705	0.456	0.709	0.455	0.704	0.457	0.704	0.457
GENDER	0.692	0.462	0.688	0.464	0.691	0.463	0.690	0.463
AGE	2.421	0.655	2.440	0.647	2.423	0.657	2.422	0.658
EDUC	2.822	0.433	2.830	0.421	2.821	0.434	2.819	0.437
MA_STATUS	0.651	0.477	0.656	0.476	0.649	0.478	0.652	0.477
Trip characteristics								
SAL_VISIT	1.534	0.938	1.553	0.950	1.536	0.940	1.544	0.945
MO_VISIT	0.336	0.473	0.337	0.473	0.333	0.472	0.338	0.474
TOT_COST	2,505	1,041	2,515	1,048	2,509	1,040	2,510	1,049
Diving characteristics								
DIVE_EXP	0.606	0.489	0.603	0.490	0.605	0.490	0.610	0.489
DIVE_YR	0.651	0.481	0.635	0.482	0.636	0.482	0.641	0.481
FUND	0.795	0.629	0.805	0.638	0.801	0.634	0.801	0.636
HELP	0.966	0.682	0.965	0.684	0.966	0.684	0.965	0.684

Estimates of WTP

The multinomial logistic regression model for WTP was fitted (Table 6.4). The *p* values were calculated using Wald tests. For better consistency in results, we dropped two predictor variables (i.e., MA_STATUS and MO_VISIT). The outcome variable was fund type (FUND).

Table 6.4. Summary of results for the WTP applied to Sal island divers using the multinomial logistic regression model.

Fund type	Combined		Donation		Fee		Souvenir	
Variable	Coefficient[1]	SE	Coefficient[1]	SE	Coefficient[1]	SE	Coefficient[1]	SE
(Intercept)	-2.4255***	0.414	1.1150***	0.0396	-1.0692***	0.0319	-5.5413***	0.0461
ORIGIN	0.2714*	0.1562	0.7127***	0.0643	0.1727	0.2619	1.8967***	0.0478
GENDER	0.2489*	0.1430	0.5617***	0.0348	0.2003	0.2246	-0.2934***	0.0382
AGE	-0.3898*	0.2073	-0.8772***	0.1644	0.1403	0.1706	0.4182**	0.1292
EDUC	0.1684	0.1854	-1.3954***	0.1518	-0.4624**	0.1689	0.3514*	0.1393
SAL_VISIT	0.3144	0.1612	0.3932*	0.2068	-0.0607	0.1537	0.4140*	0.1809
TOT_COST	0.0000	0.0002	0.0005*	0.0002	0.0004	0.0002	-0.002	0.0004
D_EXP	0.0002	0.0009	0.0027*	0.0013	0.0011*	0.0008	0.0028*	0.0017
DIVE_YR	0.0107	0.0085	-0.0117	0.0147	-0.0048	0.0081	-0.0292	0.0214
HELP	1.1448***	0.2381	0.1020	0.0969	1.0600***	0.2063	0.2316**	0.0800

[1]Significance levels of 0.1, 0.05, and 0.01 are represented by *, **, and *** respectively.

Residual deviance: 719. AIC:819.

The aim was to use the multinomial logit to model fund type choices (Figure 6.2). Based on the assumption of independence of irrelevant alternatives (IIA), it can be stated that the odds of preferring one type of fund over another do not depend on the presence or absence of the alternative "other" which was chosen by only few respondents. So, based on IIA it is assumed that the relative probabilities of choosing "fee" or "souvenir" do not change if the alternative "other" is added as an additional possibility.

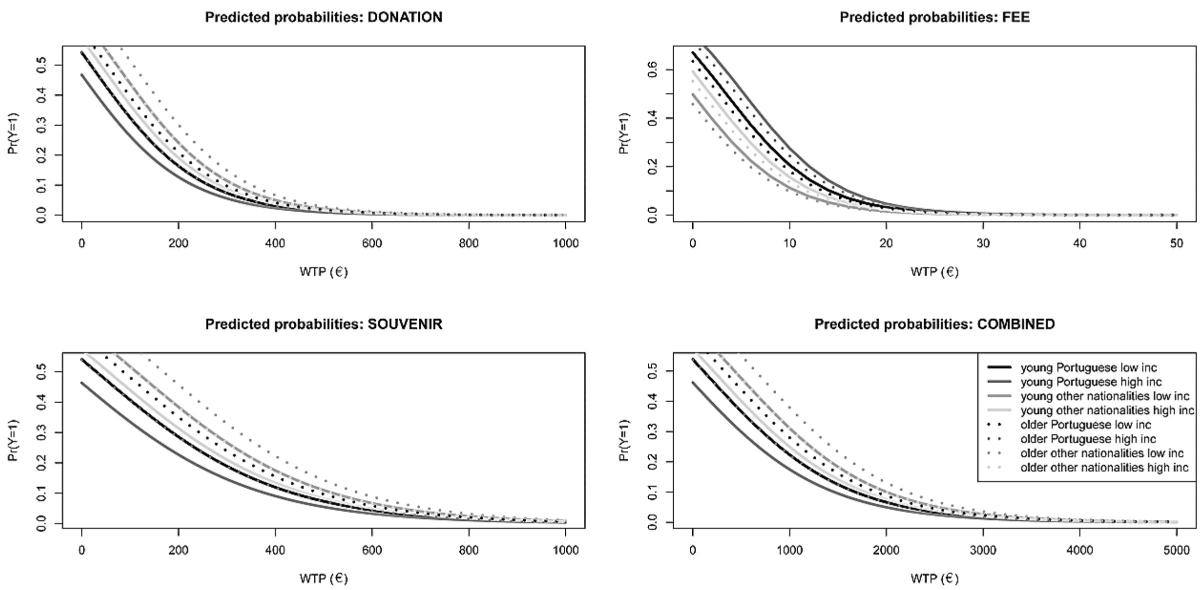

Figure 6.2 – Multinomial logit distributions for each of the alternative choices of WTP (in euros).

Protest bids

Protest bids were included in the multinomial logit models (Figure 6.2). There were 94 respondents (i.e. about 32%) that were not willing to pay for a marine biodiversity conservation fund, even though more than half of those said they would be willing to participate in a conservation project in Sal Island. This suggests that 52 (out of 292 bids) appeared to be protest zero bids.

6.5 DISCUSSION/POLICY IMPLICATIONS

Preferences for marine biodiversity may vary according to different cultural backgrounds (Ressurreição *et al.*, 2012). However, a higher value is attributed for visiting a place where there is a strong conservation culture. The origin of the diving tourists may vary according to the destination, but certain patterns can be found, namely with regard tropical destinations (Hu and Wall, 2005; Dicken and Hosking, 2009; Vianna *et al.*, 2012), perhaps due to the pristine waters and higher biodiversity of marine species (Asafu-Adjaye and Tapsuwan, 2008).

The question of biodiversity conservation seems to be highly relevant to divers when considering value attribution (Cruz-Trinidad *et al.*, 2011). If tourist divers are concerned that certain species are at risk, the value given to marine biodiversity conservation is lower; but in contrast, actions to stimulate the preservation of certain species can be very valuable for local economies (Barker *et al.*, 2011; Clua *et al.*, 2011).

People seem to give their answers according to their feelings and beliefs and as such they put a value on the marine biodiversity that can be found. (Bess and Rallapudi, 2007; Pascual *et al.*, 2011).

Here, we found that tourist divers tend to have higher WTP if a combined range of mechanisms to finance biodiversity exists, as was described by Terk and Knowlton (2010), Halkos and Jones (2011). It seems that establishing fees garnered support from those willing to pay a small amount. This finding is in accordance with what has been described in both the Philippines (Arin and Kramer, 2002) and in MPAs worldwide (Peters and Hawkins, 2009).

Previous CVM studies have expressed WTP by dive/trip or annually (Depondt and Green, 2006). Sometimes the WTP is related to the establishment of an access fee or a similar financial measure (Dharmaratne *et al.* 2000).

6.6 CONCLUSION

In the present study, we developed a CVM in order to obtain divers' WTP according to different scenarios. In terms of fees, it seems that our results are in accordance with other studies presented in Table 1, but may diverge in terms of donation amount (Rivera-Planter and Muñoz-Piña, 2005; Parsons and Thur, 2008).

When it comes the question on funding some caution is needed. For example, divers' WTP for such a fee is a matter of analysis because it assumes several premises from both the demand and the supply side (Subade, 2007). From the demand side, eco-tourists seek clean waters, special features, or certain species or individuals of a certain size or behaving in a certain way (Ramos *et al.*, 2006) and are WTP a certain amount to maintain or improve a preferred dive site (Grafton *et al.*, 2011). From the supply side, dive-operators and biodiversity project promoters have to guarantee what is aimed to achieve by the Rebuilding Nature Project.

When considering the promotion of biodiversity through buying a souvenir, we feel the simplest way is by promoting natural and biological iconic ex-libris that are painted or embossed directly in daily clothing, toys and other objects that people want to use and consequently promote their attention and eventually their preservation. People seem to be WTP through this process (Seenprachawong, 2002). Donation seems to be sometimes used as an equivalent to fee (Rivera-Planter and Muñoz-Piña, 2005; Thur, 2010).

Funding biodiversity will need to be assessed on a case-by-case basis, and the surveys such as the one presented here will be important to determine the factors affecting WTP at different sites. The implementation of trust funds can be used to promote and manage biodiversity conservation, because they stimulate both directly and indirectly other tourism activities such as accommodation and transportation (Mustika *et al.*, 2012).

Finally, protest bids may have diverse reasons: the fee is too high, the belief that money to preserve biodiversity should come from taxes instead of donations, biodiversity is not worth anything to that person, or biodiversity is important for that person, but the person refuses to place a value on it (Halstead *et al.*, 1992; Meyerhoff and Liebe, 2006)

A caveat of this study is that our survey did not include how a biodiversity conservation trust fund would be used, as already carried out elsewhere (e.g. Peters and Hawkins, 2009). The specification of such entities seems of fundamental importance to provide additional information to tourist divers who were willing to respond to this inquiry.

CHAPTER VII

An approach to the economic value of dive sites: artificial versus natural reefs off Sal Island (Cape Verde).

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An approach to the economic value of dive sites: artificial versus natural reefs off Sal Island (Cape Verde)

7.1 SUMMARY

In the present paper there was a twofold hypothesis, i.e., that the deployment of artificial reefs adds some value to natural features by diversifying diving sites and that there must be a certain propensity concerning the type of value added (either non-extractive direct use value or indirect use value). Two vessels were deployed as artificial reefs off Sal Island (Cape Verde) in 2006 and 2008 aiming to bolster the local economy through ecotourism. The additional economic value expected was to: 1) enhance fish aggregation as well as other marine organisms and; 2) mitigate human pressure from natural reefs by diverting divers. Here, the supply-sided view of dive trips was tested and analysed for a 4-year period (2008 to 2011) in terms of choice by divers among natural and artificial reefs and reef attributes such as reef depth, reef distance from main pier in Santa Maria bay, year, season and combinations of these reef features. Also, the data were analysed to determine if the deployed reefs off Sal Island had a complementary or substitute function. It was observed that the presence of artificial reefs creates diving users, but divers who use these reefs were not deterred from diving on natural reefs. This resulted in a low-diversion effect (low substitutability). Thus, dive operators can offer additional spot options to divers (moderate to high complementarity). Distance to diving sites was the most influential factor in the diving decision (results from the linear model indicated 15 more divers at closer distances to Santa Maria bay than elsewhere). From the log-linear model the number of divers would expect to change according to distance as the most influential factor (11.7 times higher at closer sites), whereas reef type and depth were less influential (0.2 times less divers for artificial reefs and 2.3 times more divers at shallower waters). It was also apparent that reef depth was fundamental in diver niche allocation throughout seasons.

Keywords: Artificial reefs; direct use value; diversion effect; diving; economic analysis; indirect use value; Sal Island (Cape Verde).

7.2 INTRODUCTION

Principle economic considerations

For the past several years, there has been an increase in the use of sunken decommissioned ships and other stable structures as artificial reefs to enhance local fish diversity and abundance in support of the fishing industry (Milon, 1989b; Jørgensen *et al.*, 2002), angling (Scarborough-Bull *et al.,* 2008) and ecotourism either for snorkelling or scuba diving (Van Treeck and Schuhmacher, 1999; Pendleton, 2005; Ammar, 2009). The purposes of such supply driven decisions may vary but, as referred by Shani *et al.* (2012), one of the main purposes is to alleviate pressure on natural reefs. These deployments can be evaluated through additional economic value that is created in a given area (Pendleton, 2004). However, despite the large economic value created by artificial reefs already put in place, there is the risk that too many artificial reefs in an area may lessen their individual value (Johns *et al.*, 2001). One important question is: how many of these structures are needed to obtain full benefits without leading to diminishing returns on expenditures? In terms of economic value or other socio-economic aspects, the creation of artificial reefs is not always a consensual issue (Sutton and Bushnel, 2007). However, supporters of artificial reefs' deployments argue that they benefit local economies and the sustainable use of resources and biodiversity (Pickering *et al.*, 1999; Tunca *et al.*, 2012). Artificial reefs also provide additional incentives to divers (Musa and Dimmock, 2013), which subsequently have a cascading effect on the local economy (e.g. dive shop revenue, services provided by the dive operator), as suggested by MacCarthy *et al.* (2006). However, in this evaluation some additional aspects may have to be considered. Especially appropriate are considerations as to whether one is looking at demand - or supply - side contributions to a local economy and/or to the influence artificial reefs may have on natural ones. Scuba diving tourists visiting Sal Island can also be part of the local marine conservation effort - about 32% of scuba divers are willing to pay for the protection of local marine biodiversity through donations (Oliveira *et al.*, 2015b). Longland *et al.* (2007) indicated that special attention should be given when considering the economic value of reefs deployed for diving purposes. For instance, it may become fundamental to determine which economic values are important in a given area. Specifically, an examination should include tangible market values such as: line-and-hook fishing (Grossman *et al.*, 1997) or recreational diver participation (Ryan and Clarke, 2005); and intangible non-market values such as: primary production by kelp beds (Ambrose, 1994; Terawaki *et al.*, 2003) or water filtration due to the presence of sessile organisms (La Peyre *et al.*, 2012). In terms of reef management, decisions must be made regarding the relative cost-benefit impact of each activity. Klein *et al.* (2008) stated that each reef feature contributes to the balance between the main economic and long-term ecological sustainability.

Our objective is to ascertain to what extent artificial reefs deployed off Sal Island (Cape Verde) are contributing to local economic value by specifically providing alternative sites for recreational divers. The expression 'alternative' is further explored in terms of investigating the propensity that reef deployment has in matters such as its complementarity towards natural reefs, by providing additional dive sites (non-extractive direct use value), or its substitutability by diverting diving trips from natural reefs (indirect use value).

Potential benefits derived from artificial reefs

Artificial reefs have been used for a variety of purposes other than the improvement of commercial harvest. In fact, applications of artificial reefs are broad and include fisheries programs, recreational and environmental projects, and their use as both natural and man-made materials (see reviews by D'Itri, 1986; Seaman and Sprague, 1991; Jensen *et al.*, 2000; Bortone *et al.*, 2011). Several authors (e.g. Grove *et al.*, 1994; Feary *et al.*, 2011; Bennett and Dearden, 2012) showed that increased fish abundance at artificial reefs sites attract commercial fishermen who then gain an additional source of income (extractive, direct-use value). The coexistence of human activities depends on the ecosystem services sought and the values provided. However, there are other direct-use values associated with artificial reefs with great importance, such as ecotourism (Figure 7.1).

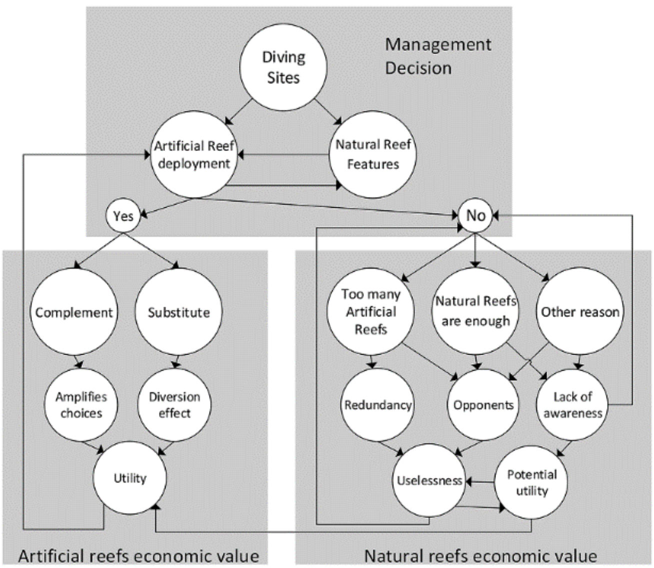

Figure 7.1 – Conceptual diagram for the decision of artificial reef deployment based on expected utility for the ecotourism industry. Top shaded area represents manager´s decision when confronted with increasing diving demand. Two possibilities are possible, either maximizing diver allocation within available diving site choices ('No' option – attributes higher economic value to the natural formations), or promoting the deployment of artificial structures either to amplify diving sites available or to mitigate damages on the natural counterparts ('Yes' option – attributes additional economic value to the artificial structures).

Direct use value

Polak and Shashar (2013) demonstrated that alternative artificial reef sites if adequately planned may create additional value for divers (non-extractive direct-use value). It has been found that historical wrecks have a certain demand from the diving community around the world (Edney, 2012). Divers often prefer sites with a higher number of species or abundance of particular organisms (Rudd and Tupper, 2002; Ramos *et al.*, 2006) and those artificial reefs sites with such attributes have an obvious increased value. The presence of these features may have low importance in the dive experience (in terms of demand), but are considered noteworthy alternatives for dive operators that tend to treat artificial reefs as complementary to natural reefs choices by widening the range of sites (i.e. diversifying supply).

Indirect use value

Comparisons between both types of reefs are then very important (Carr and Hixon, 1997). In general the deployment of artificial reefs occurs in areas where a number of natural reefs are presumed to be associated with a limiting factor or factors for aquatic species. Considering that there may be a number of different factors being provided by a natural reef, the purposes for artificial reefs deployment may vary (Baine, 2001), for example, artificial reefs may benefit species' colonization or serve to create new dive sites.

There is some evidence that artificial reefs may influence the reduction of pressure on natural reefs, particularly corals (Zakai and Chadwick-Furman, 2002; Perkol-Finkel and Benayahu, 2004). The size of the artificial reefs is also important to reduce diving pressure, with smaller ones having an almost negligible contribution (Polak and Shashar, 2012), while larger ones promote a higher effect (Morgan *et al.*, 2009).

The use of natural materials in artificial reefs serves to mimic natural structures and it has some positive acceptability (Moberg and Rönnbäck, 2003). The deployment of artificial reefs to deter or divert human activities, that can cause damage to natural reefs, is an important ecosystem function/service. Thus the artificial reefs provide an indirect-use value (Whitmarsh *et al.*, 2008). Artificial reefs can serve to alter environmental pressure on natural reefs by diverting divers from natural reefs (Leeworthy *et al.*, 2006; Stolk *et al.*, 2007). Davis and Tisdell (1996) indicated there has been considerable destruction of natural reefs due to the presence of divers but there has been an absence of suggestions on how to reduce diver demand in local areas. Artificial reefs as substitutes of natural reefs, particularly coral reefs, are advocated by some authors (e.g. Wilhelmsson *et al.*, 1998; Van Treeck and Eisinger, 2008). Oh *et al.* (2008) highlight that despite the higher ecological value reported for natural reefs, the substantial economic value attributed by divers to artificial reefs may indicate their potential role as substitutes for conservation purposes.

Artificial reefs' utility

Both types of services referred above seek to maximize artificial reefs' utility through economic or conservation interests. Different types of artificial reefs can lead to different levels of enthusiasm according to the structures available for diving purposes - shipwrecks being one of the most popular (Kirkbride-Smith *et al.*, 2013). Lino *et al.* (2011) observed that artificial reefs' deployment off Sal Island can attract species with high site fidelity (e.g. African hind's grouper, *Cephalopholis taeniops*). Interestingly, the African hind's is one of the chief commercial species in the archipelago and is also of particular interest to recreational divers.

7.3 MATERIAL AND METHODS

Sal Island insights and dive sites

Sal Island is a windward island of the Cape Verde Archipelago. Sal Island is 30km long and 12km wide covering an area of 216km^2. It has a fast growing human population, increasing from approximately 15,000 residents as of 2000 (Duarte and Romeiras, 2009) to about 35,000 residents (according to the census 2010, as described by INE, 2013a). Local fisheries are predominantly small-scale and artisanal, aiming to supply the local markets and occurring mostly on near-shore reefs, as the continental shelf is narrow (Oliveira *et al.*, 2015a) however, just two decades ago, Sal Island underwent increasing socio-economic changes and the major source of income since then has been tourism (Brito, 2012; Simão and Môsso, 2013). Due to its geographic position, air temperatures are tropical and surrounding oceanic waters clean and pristine. From 1993 up to the new Boavista Island international airport's inauguration, in late 2007, Sal Island received more than half of the annual visitors to the Cape Verde islands and most of these were tourists (Table 7.1).

Table 7.1 – Total number of persons arriving to Sal Island and Cape Verde (2000-2011). Source: adapted from Brito (2012).

Year (yr)	***Sal (S)***	***Cape Verde (CV)***	***Ratio S/CV***
2000	75,016	145,076	0.52
2001	93,496	162,095	0.58
2002	93,783	152,032	0.62
2003	116,319	178,379	0.65
2004	129,608	184,738	0.70
2005	162,625	233,548	0.70
2006	167,222	280,582	0.60
2007	192,038	312,880	0.61
2008	190,137	333,354	0.57
2009	148,005	330,319	0.45
2010	154,115	381,831	0.40
2011	168,322	475,294	0.35

According to López-Guzmán *et al.* (2012), scuba diving off Sal Island is one of the chief tourist sub-activities and it has been experiencing a fast growth in the last decade. The presence of 10.2% endemic coastal reef fish (Freitas, 2014) and marine turtles serves as an attraction to the many tourists who visit Cape Verde to dive. However, the paradox is that the conservation of endangered species is commonly threatened by human activities such as fast growing tourism (Marco *et al.*, 2011).

Most of the dive sites are located inside Santa Maria Bay located at the southern tip of the island (Figure 7.2). Other important dive sites are found off the western side of the island. Despite the large availability of natural reefs, artificial reefs have been purposefully deployed to increase the diversity of dive sites and bring added economic value to the island, namely through the Rebuilding Nature Project promoted by Manta Diving Center, one of the oldest private diving operators on the island.

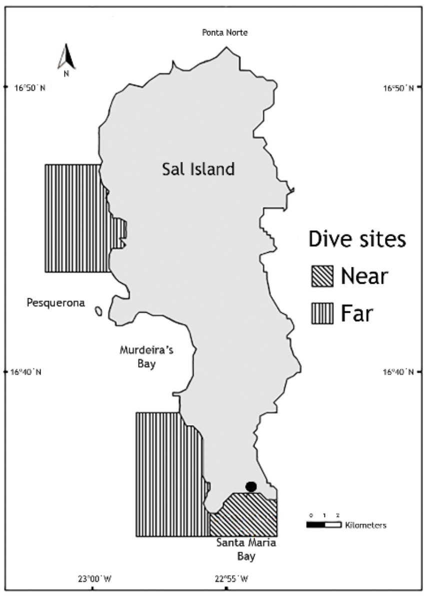

Figure 7.2 – Sal Island diving sites areas. Oblique shaded area corresponds to the Santa Maria Bay, whereas the vertical shaded areas on the west coast correspond to the location of other less visited dive sites.

In Santa Maria Bay there are several natural dive sites, most of them at depths ranging from 10 to over 50mts deep. There are also some caves and other natural features as well as sites where natural and artificial habitats merge. The artificial reefs consist of a few shipwrecks, such as the derelict *Santo Antão* sunk in the 1960s, *Kwarcit* and *Sargo*; the latter two ships deliberately sunk in January 2006 and April 2008, respectively. These latter two vessels were deployed, not only to diversify dive sites, but also to alleviate habitat degradation due to environmental pressure from human activities on nearby natural reefs (Ramos *et al.*, 2011; Santos *et al.*, 2013). Offshore of the Bay, and to the southeast there is a natural sanctuary (i.e., Tchucklassa), where a high biodiversity can be observed by more skilled divers. Off the west coast of the island near Santa Maria Bay, divers can visit deeper sites where particular fish species and other marine organisms are found. Further north, the caves of Palmeira and Buracona are also important dive sites.

There are six diving operators on the island. Although most dive sites are shared amongst operators, all of them have their own sites and attempt to keep them secret from other operators. Revenues generated by diving activities are increasing associated with an increase in tourism (Barros, 2007). The benefits brought by diving (ecotourism) are related to an increase of the economic value attributed to moderate weather, clean waters and high aquatic biodiversity (Santos Alves, 2009).

Demand and supply

On Sal Island, scuba diving is mostly a supply-driven market, where divers (consumers) largely take whatever (and as much as) they are offered by diving operators (suppliers). Operators have to choose which dive sites are the most adequate for each diver group. For example, inexperienced divers are better suited in shallower and closer dive sites. Often, however, a tourist’s “dive package” may offer several dives to a variety of sites with varying skill requirements, although the operators can easily adapt it to each group. During summer most divers are inexperienced. The majority of experienced divers come to the island during the winter season, mostly from norther European countries on organized diving trips (Oliveira M. T., personal observation), when they are able to visit deeper sites.

The data for the present study were gathered from diving records over a 4-year period (2008 to 2011) and were supplied by one of the first and most experienced dive trip operators in the country. These records allow insight into the tourist diving supply dynamics to determine if there is a perceived surplus of dive sites from diving in artificial reefs when compared to natural reefs, and to determine if artificial and natural reefs are complementary or substitutable.

Hypotheses to test

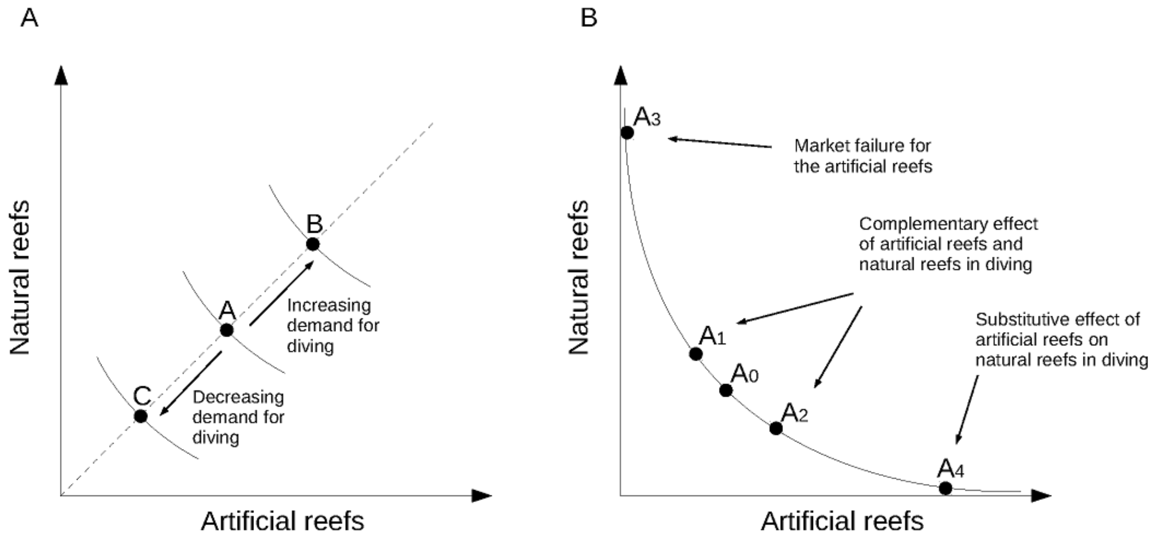

Figure 7.3 – Hypothetical views for diving supply of natural reefs and artificial reefs: Demand for reefs (Fig. 8.3A), A – Same demand, represents an equal allocation of natural and artificial reefs to divers; B – Increased diving demand for reefs; C – Decreased diving demand for reefs. Divers' choice is mostly determined by operator's sensitivity (Fig. 8.3B): operator decides to allocate similar number of diving trips to natural and artificial reefs (A0), or slightly more either to natural (A1) or to artificial (A2) reefs - complementary effect. Overwhelming supply of natural reefs (A3) - market failure for artificial reefs. Residual supply of natural reefs (A4) - diversion effect.

Considering a given demand for reefs (Figure 7.3A). Assuming that after the deployment of artificial reefs, supply possibilities for reefs vary from the starting point A, which represents an equal allocation of natural and artificial reefs to divers. Either an increase (the shift from point A to B), or a decrease (the shift from point A to C) in the diving demand for reefs, the supply possibilities for each reef type may diverge.

Divers' choice is mostly determined by operator's sensitivity (Figure 7.3B). Therefore, in the long run, if the operator decides to allocate similar numbers of diving trips to natural and artificial reefs (A0), or slightly more either to natural (A1) or to artificial (A2) reefs, then, a complementary effect of artificial on natural reefs is to be expected. However, if there is an overwhelming supply of natural reefs (A3), then a market failure for artificial reefs is expected. In opposition, if there is just a residual supply of natural reefs (A4), then a complete substitution effect of artificial over natural reefs (diversion effect) is expected.

Data analysis

It was assumed that dive tourism on Sal Island is a supply-driven activity, therefore a multiple regression econometric model was developed using qualitative and quantitative variables to test dive trip supply (DTS). The variables are defined in Table 7.2.

Table 7.2 – Variables used in the multiple regression analysis of reef diving trips from a Sal Island diving operator between 2008 and 2011.

Variable description	Variable name	Explanation
Dependent variable		
Diver trip supply	DTS	Number of divers occurring at a given location
Independent variable		***Use of dummy variables***
Type of reef	TYPE	Type of reef (1 for artificial structures, 0 for others such as rocks and caves)
Depth range	DEPTH	Dive site depth range (1 for < 20m, 0 for otherwise)
Reef location	DIST	Distance from pier (1 for < 1.5 nmi, 0 for otherwise)
Season	SEASON	Time of the year (1 for July and August, 0 for otherwise)

The model accounts for the separate effects of reef type (natural or artificial), depth of the reef (i.e. shallow or deep), location (i.e. inside Santa Maria bay area or Elsewhere), and season (i.e. summer or non-summer). Four binary (i.e. dummy) explanatory variables were included to evaluate their influence on dive site options as seen in the supply model (Equation 1).

$$(1) \qquad DTS_i = \beta_1 + \beta_2 Type_i + \beta_3 Depth_i + \beta_4 Dist_i + \beta_5 Season_i + u_i$$

Where: 'DTS' is the outcome score for the number of diving trips for the i^{th} observation; β_1 is the coefficient for the intercept; β_2 , β_3 , β_4 and β_5 are the coefficients for the slope when considering the dummy variables 'reef type, 'reef depth, 'reef location', and 'season', respectively; $Type_i$, $Depth_i$, $Dist_i$, and $Season_i$ are the dummy variables for the type of reef (1 if the i^{th} observation is an artificial reef, 0 otherwise), maximum depth of the reef (1 if the i^{th} observation is a shallow reef, 0 otherwise), reef location (1 if the i^{th} observation at Santa

Maria bay area, 0 otherwise), respectively; season (1 if the i^{th} observation is for the months of July and August, 0 otherwise), respectively; u_i is the residual for each i^{th} observation. It should be noted that reef effects were included in the analysis in a single way: as a shift dummy (i.e., 0 for observations at the natural reef, 1 for those at the artificial reef).
Statistical analyses were conducting using R Project for Statistical Computing version 2.14.1 (Fox and Weisberg, 2011; R Development Core Team, 2011).

7.4 RESULTS

The dive supply allocation was done according to Figure 7.4. Most of the divers were allocated within shallow water dive sites and mainly took advantage of the natural reefs, whereas fewer divers were allocated to artificial reefs but they are distributed more evenly among shallow and deeper sites. Demand for diving off Sal Island varied depending on the year season. Two main diving seasons were found: one during the summer for less experienced divers diving in shallow waters, and another during the winter for more experienced divers who prefer deeper sites.

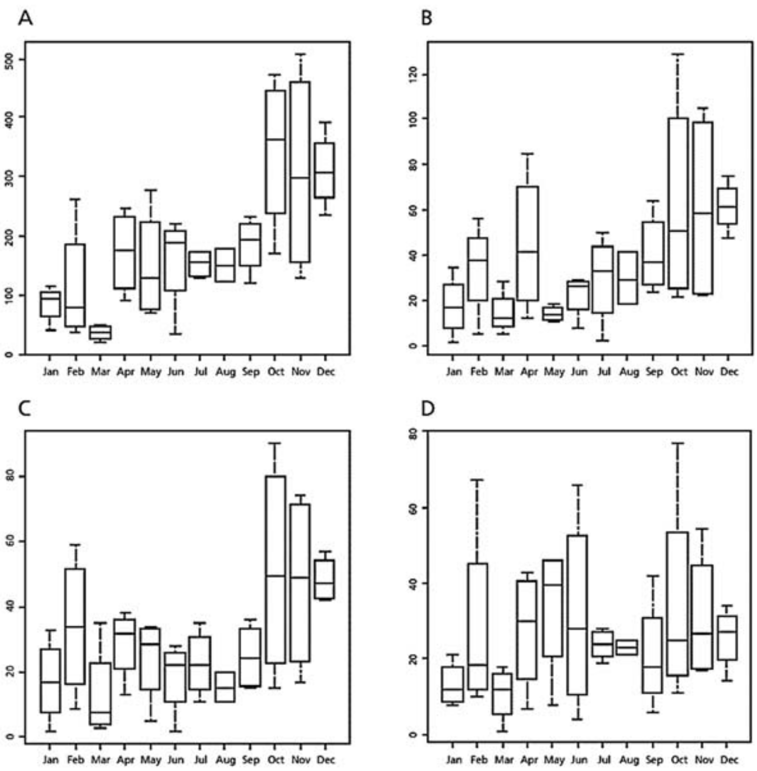

Figure 7.4 – Box plots representing the aggregated monthly percentage of divers according to type of reef (Natural reefs – NR and Artificial reefs – AR) and water depth during the period 2008-2011: A) NR shallow, B) NR deep, C) AR shallow, D) AR deep. Boxes stand for the interquartile range (IQR) between first and third quartiles and the line inside the boxes represents the median. Bars refer to the lowest and highest values within the 10th and 90th percentile range.

It was important to verify the different patterns between both types of structures. Figure 7.5 shows the diving supply of natural reefs *versus* artificial reefs. The plot shows an overall increase of the average number of divers over time, with some seasonal peaks and drops. The higher supply of artificial reefs found in trimester 1 coincided with the deployment of the ship *Sargo*. Soon after, in trimester 2, a decrease was found in terms of divers' demand and consequently the diving operator shifted its supply to natural reefs. By trimesters 3 and 4, there was a slight increase of divers and the operator shifted again in order to bring their clientele to artificial reefs and then a shift back to natural reefs. Afterwards there was a similar demand for diving, with on average slightly more natural reefs than artificial reefs being supplied. In the last two trimesters in analysis, the operator faced a higher demand for diving and supplied slightly more natural reefs than artificial reefs.

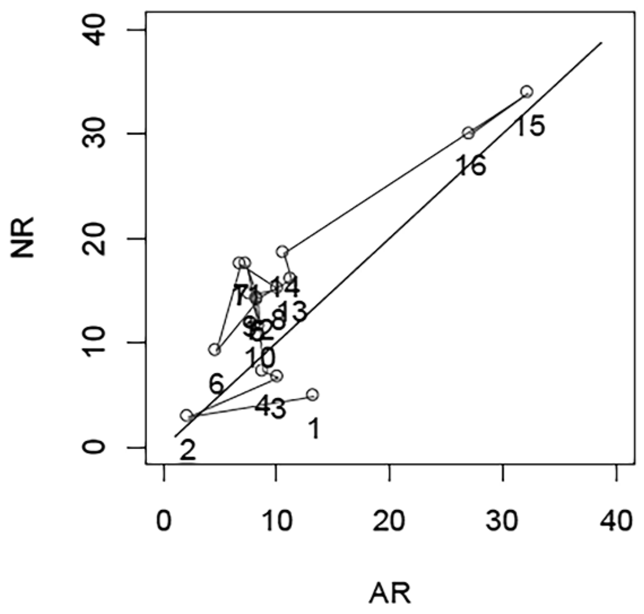

Figure 7.5 – Comparative trend of diver average number by trimester in each reef type. Numbers 1 to 16 represent trimesters starting in January 2008. NR, Natural reefs; AR, Artificial reefs.

The results of the linear model indicated that all independent variables were statistically significant (Table 7.3). From the coefficient of the independent variable 'TYPE' (-3.8) at the artificial reefs would be expected to be around 4 divers less than they would at the natural reefs sites, *ceteris paribus*. In the same line of thought, 'DIST' implies that there would be more 15 more divers at closer sites located within the Santa Maria Bay than at further sites. The coefficient for 'SEASON' implies that there was a significant seasonal diver pattern, whereas there was a tendency to have 4 more divers participating during the combined months of July and August than in the remaining months of the year.

Table 7.3 – Regression results: linear model. N = 384; F = 48.0; R2 = 0.336 indicates that the four independent variables account for about 34% of the variability of the dependent variable. Dependent variable: DTS. Signif - Statistical significance: ns – non significant; * - p<0.05; ** - p<0.01; *** - p<0.001.

Dummy variable	*Coefficients*	*Standard Error*	*t Stat*	*P-value*	*Signif*
Intercept	1.0	1.41	0.7	0.478	ns
TYPE	-3.8	1.38	-2.8	0.006	**
DEPTH	11.0	1.38	7.9	0.000	***
DISTANCE	14.9	1.38	10.8	0.000	***
SEASON	4.1	1.85	2.2	0.027	*

The variable distance was the one that affected most the diving decision, followed by depth, whereas reef type and season had the least effect on the site choice. It is notable that the diving decision is mainly lead by the operator for divers experiencing just a few trips (divers with minimal experience), changing the decision to the diver for those experiencing larger number of trips (divers with more experience).

Operator income derived from diving at further distances is marginal and as a consequence, it seems that this option (distance) is only chosen when it is the diver who takes the lead on the trip decision (i.e., tends to be a more experienced diver). This means that divers obtain additional consumer surplus from expanding their diving experience to further sites. However, in such a situation (i.e., further distances) the present study does not evaluate the contribution artificial reefs may have in consumer surplus, because this type of reefs was not present in the reef supply option.

The log-linear model showed that all variables except 'SEASON' were statistically significant, but the coefficients had to be interpreted differently (Table 7.4). The coefficient for the TYPE variable, means that the number of divers at the artificial reefs was expected to be 0.2 (= $e^{-1.7}$) times less than they would be at the natural reefs. Similar analysis can be done for the remaining variables. For example 'DIST' showed that the number of divers was expected to be 11.7 (= $e^{2.5}$) times higher at closer sites, considering a control over the effect of the other factors. Identically, there was about 2.3 (= $e^{0.9}$) more propensity to get divers to explore shallow waters.

Table 7.4 – Regression results: log-linear model. N = 384; F =77.66; R^2 = 0.450 indicates that the 4 independent variables explain 45% of the variability of the dependent variable. *Signif* - Statistical significance: ns – non significant; *** - p<0.001.

Dependent variable: log(DTS)

Dummy variable	***Coefficients***	***Standard Error***	***t Stat***	***P-value***	***Signif.***
Intercept	0.2	0.180	1.3	0.204	ns
TYPE	-1.7	0.176	-9.5	0.000	***
DEPTH	0.9	0.176	4.9	0.000	***
DISTANCE	2.5	0.176	14.0	0.000	***
SEASON	0.2	0.236	0.7	0.476	ns

In the log-linear model the variable 'TYPE' showed a higher tendency to choose natural reefs, but results were inconclusive to define complementarity or substitutability of artificial reefs.

Figure 7.6 shows that most dives occurred at the shallowest and closest sites, regardless of season, with a preference for natural reefs. However, preference for artificial reefs over natural reefs was noted at nearby deeper sites. There were slightly more divers during summer than winter at these nearby, deeper sites. There was some over-dispersion for natural reefs preference when they were sited in deeper and closer sites.

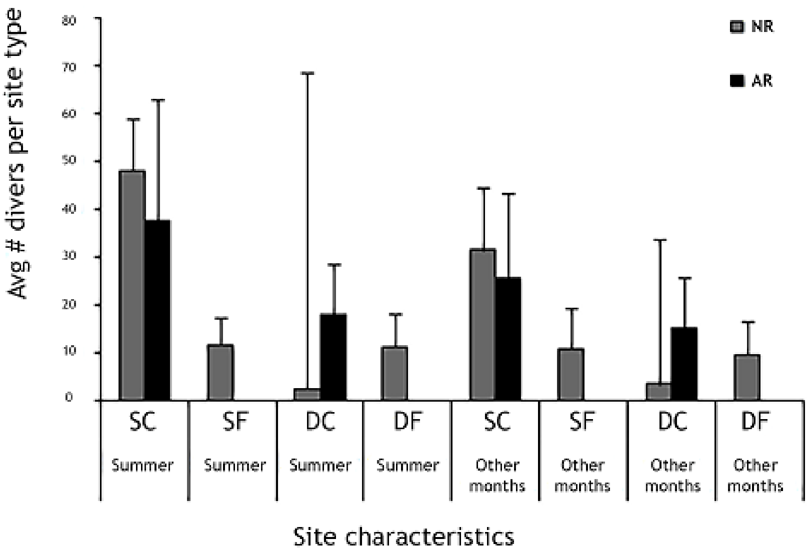

Figure 7.6 – Diver allocation activity on Sal Island diving sites (top of bar indicates the means, bars extension indicates one standard errors above the mean). S, shallow; D, deep; C, near; F, far; NR, Natural reefs; AR, Artificial reefs.

7.5 DISCUSSION

The data analysis suggests an increasing number of divers over the course of the study. The higher supply of artificial reefs found in the beginning of 2008 showed that there was the curiosity to visit the new structures (i.e. the deployed ship *Sargo*) and to a certain extent there was some degree of substitutability. This contrasted with decreasing interest of the divers towards artificial reefs over time.

This occurrence demonstrates that if by supposition there is still room to deploy additional sunken vessels, the decision should be analysed with caution. This fact may mean that despite artificial reefs' function as complementary to natural reefs by expanding the possibility of diversifying tourists' diving expectations, there is no guaranteed preference for man-made structures.

In the particular case of Sal Island, artificial reefs do not substitute natural reefs for several reasons. From the demand side, artificial reefs do not appeal to divers as much as natural reefs (Ramos *et al.*, 2006). However, associating historic interest to an artificial reef can increase its acceptability as a dive site because this information stimulates a rise in demand to visit such a site (e.g. Leeworthy *et al.*, 2006; Morgan *et al.*, 2009). When reefs are affected by supply, even if by claiming conservation reasons, it is intended to divert activities from natural reefs (whether to enhance fisheries, diving or both), there is no guarantee that this type of management decision is effective. Moreover, the argument of supply may be acceptable to explain fishing (alleging that fishermen just seek similar revenues), but it may fail for diving if the operator's effort to promote the artificial reefs' dive trips diminishes or divers consumption diminishes due to lack of interest because of the diversion to artificial reefs (market failure).

In places where traditional small-scale fisheries exist alongside a robust diving tourism, it seems wise to manage artificial reefs for both activities but keeping the fisheries at a reduced level. Ideally, fisheries must be allocated to non-dive sites or to sites with lower diving importance (Arin and Kramer, 2002). Otherwise, if an extra effort is inflicted into the overall reef system, the economic returns from diving expectations created on tourists may consequently divert to other tourist destinations. The local economy may suffer if this happens because diving as a tourist activity generates more income than fisheries (Santos, 2011). However traditional small-scale fisheries have their own importance to supply fresh fish to tourism as well as for feeding local people.

Deploying artificial reefs for fishing purposes may have a negative effect on the local economy if it is managed inefficiently as there may be overharvesting and user conflict of the sites may also occur (Milon, 1989).

In terms of management, it seems that one possibility could be to allocate artificial reefs in areas where they are absent. This could mean to deploy artificial reefs further from Santa Maria Bay, either at shallow or deeper sites. However, from our results it seems that closer sites are in greater demand. There are some situations (Johns *et al.*, 2001) where one should consider that too many artificial reefs will diminish each reef's individual value. However, our results show that interest in sites decreases when vessels were deployed: 1) close to Santa Maria bay in shallow waters, 2) further away in shallow waters, and 3) further away in deeper waters.

In Sal Island the increased demand from tourism in recent years is possibly due to an attenuated demand from European tourists and competition from the new airport on Boa Vista Island. Sal Island tourists traditionally comprised more than half of total tourists' arrivals to the archipelago. Since 2009, however, tourism noticeably decreased on Sal Island (Table 1). Both reasons may generate expectations by operators to create and diversify dive sites. Increasing artificial reefs deployments to enhance tourism diving may be anticipated in the future.

It should be noted that from a demand perspective diving tourists prefer diverse sites, which may not coincide to the conservationist's preference from a supply perspective. Consequently, if there is an intention to alleviate human pressure by substituting natural reefs, from a supply perspective, those with a demand perspective will not get complete satisfaction and the full utilization of the resource diminishes. In such a scenario, a decrease in Sal Island dive consumption may lead to a decrease in tourism. By maintaining the same level of diving utility it seems that there is a marginal rate of substitution of natural by artificial reefs.

Considering that the price per dive is based on site distance from shore, and does not depend upon the type of reef, divers are indifferent as to which type of reef they visit. If divers simply want a diversity of sites, artificial reefs can complement natural reefs by increasing the overall surplus of dive sites.

From obtained results, the variable "depth" is not significant in terms of diver allocation. In terms of demand there are two distinct diving site attributes: one for shallower water and another for the more challenging deep water (i.e., restrictive to more experienced divers).

Considering these two types of divers, and assuming divers want maximum utility from their experience, the possibility of diving on an artificial reef at any depth should be sought. However, based on the obtained results, it seems that diving in deeper water has higher demand during the low season (i.e., October to April).

If we consider the reef's attributes analysed here, it seems that some sites' attributes deserve additional consideration. It has been found that 'distance' was the most important attribute in terms of the contribution for the diving trips. It has been found that distant sites are less visited. However, despite the lack of artificial reefs at further distances, it seems counterproductive to deploy artificial reefs at distances far from Santa Maria. This is because, either for the diver as a consumer as well as for the diver as a supplier, 'distance' has an extra cost independent of the type of reef. The consumer does not get greater satisfaction from the distant site and the operator gets only a low marginal profit gain and does not get compensated for investing in such a reef site differentiation.

Consequently the attribute 'shallow depth' increases the importance at sites during summer months when most divers are inexperienced. This is in accordance with Kirkbride-Smith *et al.* (2013) who found that novice divers have a higher preference for artificial reefs than natural reefs. They have more than twice the tendency to dive at shallower reefs than to dive at deeper reefs (Kirkbride-Smith *et al.*, 2013). By contrast, fewer experienced divers visit the island for diving and do so more often in the winter months. Despite the occurrence of higher number of divers during the summer months, the variable 'season' does not seem to affect the diving supply. The 'type' of reef is important in terms of supply, and there is a tendency to offer more natural reefs sites than artificial reefs ones, because there are more natural reefs sites. There is a possibility that if more artificial reefs were available, more divers would use them (particularly if new artificial reefs were located closer and in shallower waters).

According to Milon *et al.* (2000) artificial reefs directed toward socio-economic objectives are only successful if people take advantage of them and the socio-economic performance of artificial reefs projects can be established. For example, if a new artificial reef contributed to raise incoming for the dive operators and tourism industry is considered as successful.

As suggested by Lino *et al.* (2011) artificial reefs attract marine species with high site fidelity artificial reefs create habitat fidelity for marine species (e.g. African Hind) and can be important when increasing local fish biodiversity and supporting local sustainable development of diving tourism (Santos *et al.* 2013). Santos *et al.* (2010) found in Brazil that limiting one of the activities is important, otherwise the interaction of both activities will dissipate any extra economic value created by artificial reefs.

Off Sal Island, artificial reefs are fished by small-scale vessels using hook-and-line. This practice has negligible influence on the deterioration of the reef and its subtractive effect on fishery resources is apparently sustainable. Hook-and-line also has a lower impact on marine protected species (Guebert *et al.*, 2013).

A considerable amount of the total economic value (TEV) of such hook-and-line is associated to several different uses. Extractive use (fisheries), non-extractive use (e.g. diving to observe fish shoals), and other indirect-use values (e.g. diverting local fisheries activity from preferred fishing areas to other areas where there is a lower interest for diving (Williams and Polunin, 2000) and passive use values (e.g. promoting biodiversity through reef-based protection)).

7.6 CONCLUSION

The deployment of artificial reefs in Sal Island may achieve both conservation and socio-economic objectives. Artificial reefs have promoted an increase in dive trips - acting as a complementary function to natural reefs. Concomitantly, ‘rules’ and community engagement should be promoted to maintain the extractive value of sustainable fishing along with other important economic values.

4TH PART: ENVIRONMENTAL CONSERVATION AND MANAGEMENT OF THE LOCAL DIVING INDUSTRY

CHAPTER VIII

Can the diving industry promote marine conservation and enhance environmental awareness? (Sal Island, Cape Verde case)

Submited to *Zoologia Caboverdiana Journal*
Adapted version

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Can the diving industry promote marine conservation and enhance environmental awareness? (Sal Island, Cape Verde case)

8.1 ABSTRACT

In Sal Island (Cape Verde) there is a growing will and investment in the creation of tourism synergies. However, much of the economic potential of the island can be found submerged in the sea: it is its intrinsic 'biodiversity'. Due to this fact, the diving industry is growing and diving has become one of the biggest attractions for tourists. In light of the scarcity of scientific studies on the impacts associated with this activity and tools for diver engagement, the local diving operators have proposed the development of several tools. An Underwater Species Identification Guide and four underwater routes were proposed for four popular scuba diving sites off Santa Maria Bay (Sal Island, Cape Verde): “Kwarcit”, “Sargo”, “Três Grutas” and “Tchuklassa”. To better understand how the diving industry could promote environmental education, conservation and enhance biodiversity awareness among divers, we also established the diver tourists’ profile using an online survey. Of a total of 347 respondents, of which 85% have higher education, 67% stayed more than seven nights in Cape Verde. Moreover, natural reefs are the primary dive site to be visited, while artificial reefs preference increases after a second dive. The majority would recommend the use of the Underwater Species Identification Guide and the underwater routes. The results showed that divers strongly embrace the use of new tools for better understanding of diving site biodiversity and that the diving industry can play an important role in the enhancement of biodiversity awareness.

Keywords: Underwater routes, underwater species guide, scuba diving, underwater tourism, awareness, environmental education, Sal Island (Cape Verde).

8.2 INTRODUCTION

The Cape Verde Archipelago is composed of ten islands (and thirteen islets), located 750 km off Senegal (west coast of Africa), between 15–17ºN and 22–25ºW. Tourism is the country's main source of income and of socioeconomic development for several of the islands. Tourism in the Archipelago has a close relationship with marine-related activities, due to the tropical climate, sandy beaches, clear water and high diversity of marine species. Cape Verde was visited by 539,621 tourists in 2014 (INE, 2015b), with 41.5% visiting Sal Island, the main tourist area, followed by Boavista Island with 32.9% of the total number of visitors to the Archipelago (INE, 2015a). Diving is one of the fastest growing industries (Davenport and Davenport, 2006) and, worldwide, there are over 23,000,000 PADI individual divers (PADI, 2015), with an increase of 66.1% between 1996 and 2010 (PADI, 2011) and the business activity supporting scuba diving tourists has become an important tourism sector stimulating a billion dollar global industry (Garrod, 2008). Although there are no statistics for Cape Verde, six dive centres currently operate in Santa Maria Bay, Sal Island (Dive-Report, 2016), increasing the human pressure on local natural and artificial reefs. Unfortunately, the impact of tourism on marine coastal areas remains largely unknown (INMG, 2010; Claudet *et al.*, 2010) with scarce scientific literature on the issue (Garrod and Gossling, 2008). The impacts related to dive pressure on natural areas are an increasing concern for the scientific community (Milazzo *et al.*, 2002; Rouphael *et al.*, 2011).

A number of studies have reported how divers can damage benthic marine organisms (hard and soft corals, sponges, ascidians and large bryozoans) directly (physical contact) or indirectly (raised sediments) (Rouphael and Inglis, 1997; Tratalos and Austin, 2001; Zakai and Chadwick-Furman, 2002; Luna *et al.*, 2009). Furthermore, fish can also be disturbed due to selective search by divers (e.g. cryptic species) and change their natural behaviour (e.g. during mating) (Uyarra and Cote´, 2007; Heyman *et al.*, 2010). The scientific information on local fish assemblages is very limited, consisting mostly of an inventory list of species (Lloris *et al.*, 1991; Reiner, 1996; Monteiro *et al.*, 2008). However, almost half of the total cryptobenthic fish species richness in Cape Verde comprises endemic species (Freitas, 2014) and Roberts *et al.* (2002) listed Cape Verde in the top 10 coral reef biodiversity hotspots in the world and in the top eight of threatened centres of endemism.

Aware of this scenario, a private diving operator (Manta Diving Centre, Sal Island, Cape Verde), supported by The Ministry of Environment and Marine Resources of Cape Verde, put forward a project to deploy artificial reefs in Cape Verde coastal waters (Santos *et al.* 2013) to satisfy the demand for 'non-natural' habitats (Ramos *et al*, 2011) and promote environmental awareness among divers using "soft" management tools (i.e. education and interpretation) instead of "hard" management tools such as restrictions or visitors' fees (Townsend, 2008a) (Figure 8.1).

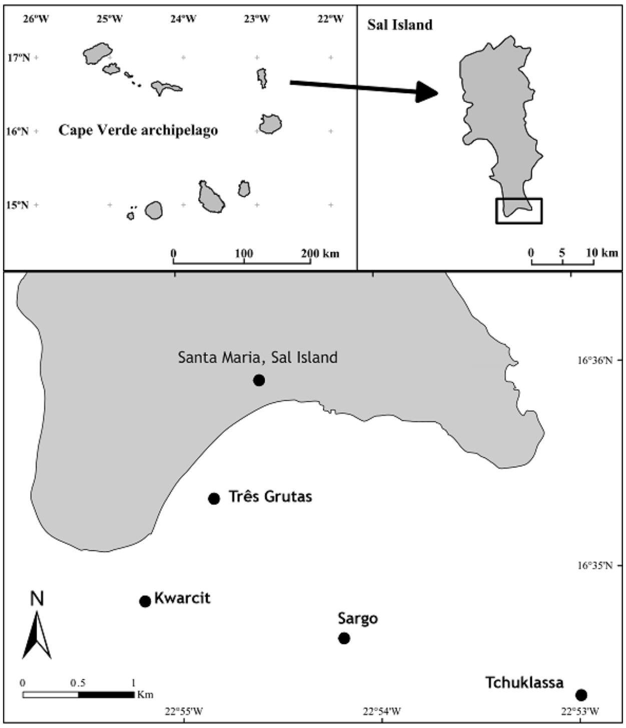


Figure 8.1. Map of the Baía de Santa Maria, Sal Island, Cabo Verde with diving sites marked. Três Grutas and Tchuklassa represent natural reefs, Sargo and Kwarcit are artificial reefs (deployed vessels).

Divers are open minded and eager to learn about the dive sites visited. They tend to look for information and support regarding the dive in general (Barker and Roberts, 2004) and environmental education must be included in diving activities through "pre-diving environmental briefings" (Barker and Roberts, 2004, 2008). Education is advocated as an advisable method for reducing environment damage caused by divers (Barker and Roberts, 2004; Plathong *et al.*, 2000), but to be truly effective it should be adapted to each diving site, the socio-demographic characteristics of the divers, their previous knowledge about the environment and their learning capacity (Barker and Roberts, 2004).

Underwater routes are perceived as an effective way to improve biodiversity awareness among the diving community (Rangel, 2013) and have been used to enhance environmental awareness (Hannak, 2008; Harriott, 2002) and to reduce scuba-diver impacts on the environment (Plathong *et al.*, 2000; Lloret *et al.*, 2006; Di Franco *et al.*, 2009; Claudet *et al.*, 2010), by constraining divers to certain areas (Hawkins and Roberts, 1993; Ríos-Jara *et al.*, 2013), as well as to provide information along the path (Claudet *et al.*, 2010).

For the purpose of this study, the book *Sob os Mares de Cabo Verde - Diving Into Adventure* and an *Underwater Species Identification Guide* were published. Additionally four *Underwater Diving Routes* were proposed for popular scuba diving sites off Santa Maria Bay (Sal Island, Cape Verde): "Kwarcit" and "Sargo", the artificial reefs off Santa Maria Bay and two natural reefs within the area, "3 Grutas" and "Tchuklassa".

A growing number of publications in recent years have highlighted many issues and concerns relevant to scuba diving tourism but little research has included the scuba diving industry, host communities or efforts towards sustainability (Dimmock and Musa, 2015). Scuba diving tourism is an economically important industry as evidenced by the increasing number of other locations promoting their marine resources in efforts to become scuba diving destinations and Cape Verde aspires to follow popular, 'must dive' places widely promoted in social and other media such as Phuket and Koh Tao in Thailand, Layang Layang and Sipadan in Malaysia, and the Great Barrier Reef, Australia and Sharm El Sheikh – Red Sea, Egypt, among others.(Roberts *et al.*, 2002; Bennet, 2003; Dearden *et al*, 2007; Lew, 2013). In this study, a survey was carried out to provide some preliminary data for Sal Island, Cape Verde, on the socio-economic profile of divers, their perceptions about the environmental awareness of the local area and potential uses of the produced tools for environmental awareness.

8.3 TOOLS DEVELOPED

Environmental educations and interpretation

Sob os Mares de Cabo Verde - Diving Into Adventure

The conservation of marine biodiversity can only be achieved with engagement of all stakeholders. Following the challenge put forward by a Cape Verde bank to develop a book about the local oceanic waters to serve as a Christmas gift for their clients, *Sob os Mares de Cabo Verde - Diving Into Adventure* became a reality in 2008 (Figure 8.2). This work was carried by a large team of people including biologists, diving operators managers, marketers, dive masters and an internationally recognized underwater photographer. 3500 units of this book were produced, which covered the following aspects: Artificial Reefs – History and

Applications, Rebuilding Nature Project, Diving into Nature, Fauna and Flora (Laíns *et al*, 2008).

Figure 8.2. Covers of the book: Sob os Mares de Cabo Verde - Diving Into Adventure´s.

Underwater Species Identification Guide

The first step to produce the Species Identification Guide was the selection of species. This work was carefully carried out by a team of marine biologists with the collaboration of dive masters from local dive centres in order to select the most interesting species within the area, but also keeping in mind the most relevant to divers. A total of 124 species were selected, photographed underwater and distributed among 12 slates (Figure 8.3 and *annex* I). For each species the scientific and common names (Portuguese and English) were indicated. Through a set of produced pictograms, several aspects that are important to divers were included (e.g. Danger, Fragile, Cryptic, Pelagic and Schooling) as well as the warning “do not stress, touch or feed the animals” to increase the diver’s responsible behaviour following Lindgren *et al.* (2008). This guide was published in 2009 with 1200 units in its first edition (Santos *et al.*, 2009).

Figure 8.3. *Underwater Species Identification Guide*, 6 slates, 12 pages.

Underwater routes

Two Artificial Reefs and two Natural Reefs diving sites, among the 25 available diving sites in Sal Island, were selected (Oliveira *et al*, 2013a, b, c, d). This selection was based on site popularity and pre-established features such as high biodiversity, charismatic fauna and flora species and geological features. Pictograms (Danger, Fragile, Cryptic, Pelagic and Schooling) and "do not stress, touch or feed the animals" were included as described for the Underwater Species Identification Guide. The selected sites were also used for several studies carried out within the framework of the *Rebuilding Nature - Cape Verde Artificial Reef Creation Project*. Motivating features for divers visits, such as presence of fish and other aquatic life forms, pristine surroundings (Ditton *et al.*, 2002) were also considered in order to provide a a better description of the sights for divers (Figures 8.4 to 8.7).

KWARCIT - One of the artificial reefs created by Manta Diving Center is now an obligatory stopping-off point for all divers who visit Sal Island. A short boat ride, of 5 to 7 minutes, brings us to the dive site.

Sunk on January 6, 2006 by Manta Diving Center, this former soviet trawler has in a short space of time become a refuge for the numerous species that it protects from the attentions of larger predators. This site offers multi-level diving, from the rocky platform, at a depth of 28 meters, which encircles the slightly starboard-leaning hull to the top of the mast, at 14 meters.

As it is near the cape marking the western edge of Santa Maria Bay, it is a place where larger ocean-going species, such as Mantas (*Manta birostris*), can sometimes be encountered. The dive is of medium to high difficulty, with visibility ranging from 15 to 35 meters.

This was the first of the artificial reefs created by Manta Diving Center and it is one of the research focuses for the Cape Verde Artificial Reef Creation Project.

Figure 8.4. *Underwater route – KWARCIT* (Front and Back page, see details in *Annex* II)

SARGO - This is the second of the ships sunk by Manta Diving Center in order to create an artificial reef diving spot. This former Coastguard patrol vessel was offered to the project by the Cape Verde Minister of Defense and sunk on April 28, 2008.

One mile out from the Santa Maria pontoon, only a few minutes are needed to reach this site that, within a month of its deployment, had already been colonized by a large number of species. Lying at a depth of between 34 and 41 meters, it serves today as a cradle for a vast range of species, as well as a stopping-off point for others, such as cutlass fish, rays and turtles. The dive is of medium difficulty, with visibility ranging from 15 to 30 meters.

Figure 8.5. *Underwater route – SARGO* (Front and Back page, see details in *Annex* II)

TCHUKLASSA - Located about two miles off the Santa Maria pontoon, this is one of Sal's natural sanctuaries for underwater fauna. Thanks to its location, extent and morphology, this natural reef offers the chance of more than one dive. Its rounded wall, covered in yellow polyps, is one of the dive highlights. Standing out from the coast, this reef rises from the depths of the channel separating Boavista and Sal Island and is sometimes bathed by currents that bring the necessary ingredients to make it a place where many species can settle. It is also a waypoint for tuna, jacks, some species of sharks, mantas and other species. The dive is of medium to high difficulty, with depths ranging from 20 to 40 meters. Visibility is between 15 and 40 meters. This site was one of the natural reefs that served as points of comparison in the study which is part of the Cape Verde Artificial Reef Creation Project (Santos *et al.*, 2013).

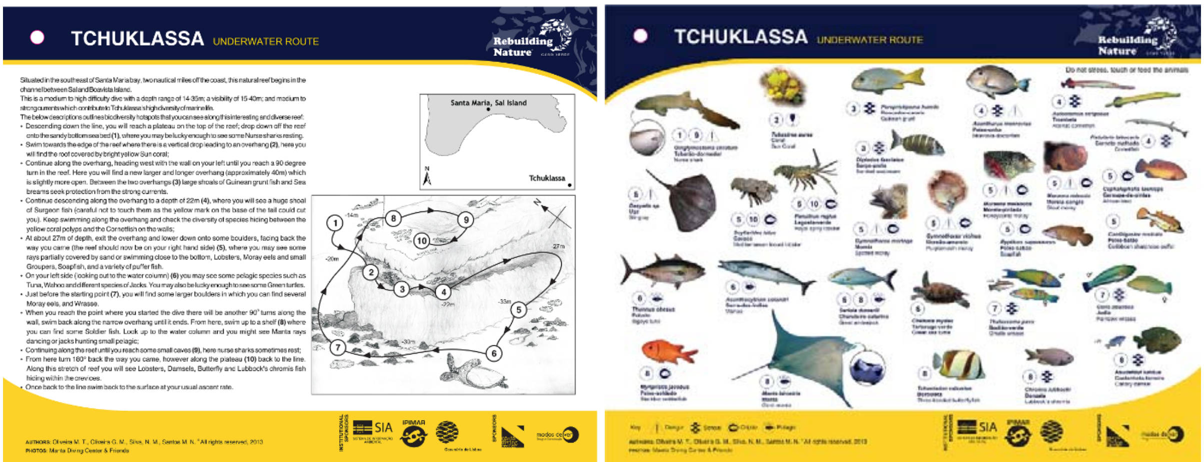


Figure 8.6. *Underwater route – TCHUKLASSA* (Front and Back page, see details in *Annex* II)

TRÊS GRUTAS - This is another natural reef that was studied in the Cape Verde Artificial Reef Creation Project, namely in terms of possible migrations between this natural reef and the artificial reefs created by Manta Diving Center (Lino *et al.*, 2011). An 18 meters descent take divers to the bottom of a wall that runs east to west. One of the characteristics of this wall, as in many of other reef walls in Cape Verde, is the existence of a narrow cavity along the base which affords an excellent safe cave for a wide variety of species. Those that can be seen here range from rays to lobsters, puffer fish to parrot fish and, less frequently, turtles and sharks. Following this wall to the east we pass by three caves, in descending order of size. These are modestly-sized rather than extensive caverns, but they do allow us to come face to face with the huge quantity and variety of fauna that shelter within. The second cave is actually known as Trumpet Fish Cave. Sharply focused eyes might even, eventually, catch sight of the virtually undetectable frog fish that sits motionless on top of the coral waiting for a pray.

Figure 8.7. *Underwater route – TRÊS GRUTAS* (Front and Back page, see details in *Annex* II)

Environmental diving briefing

Specific diving environmental briefings where designed, with a scuba diving operator, for each one of the four selected diving sites. Dive masters were also trained to provide correct information. The briefing, given by Manta Diving Center dive masters, addressed subjects such as a quick description of the diving site, the underwater route presentation, geographical characteristics of the zone, expected currents, possible dangers and difficulties, expected species and environmental issues considered important and/or interesting for the visitor.

Figure 8.8. Nuno Marques da Silva, Manta Diving Center's owner and diving instructor giving an environmental *dive briefing* (©Manta Diving Center).

8.4 DIVERS' SOCIO-ECONOMIC AND TRAVEL PROFILE

Survey and data analysis

The survey instrument was pre-tested on a sub-sample of five divers in October 2012. After some adjustments, a questionnaire survey was placed online. A covering letter introducing the purpose of the survey, namely the value of marine biodiversity conservation off Sal Island and a link to a survey was emailed to 7,434 addresses drawn from a list of divers who had visited Sal Island and went out with a local dive operator. The questionnaire was active between February 18^{th} and March 18^{th}, 2013. Because it was aimed to reach a wide audience, both the cover letter and the questionnaire were presented in English. The expected average time to complete the questionnaire was 15-20 minutes and it consisted of 29 questions. The survey included questions about the geographic origin of respondents and some of their personal characteristics (e.g. age group, gender, marital status, job occupation group), holiday and tourism choices (e.g. season of the year to go on holidays, number of visits to Cape Verde, staying time, accommodation type), diver characteristics (e.g. dive expertise, dive avidity, preferences), and specific questions related to marine biodiversity (perceived status of marine biodiversity, perceived diving impact). This survey was also used to estimate the value of marine biodiversity off Sal Island (Oliveira *et al.*, 2015b).

8.5 RESULTS

Socio-economic and travel profile

From the 7,434 e-mails sent out, we received 347 replies (4.67%). Of those, only 292 surveys were filled out completely; these were used for subsequent analyses. Most respondents were Portuguese (70%), males (69%), over 40 years old, married (53%), with a college degree (85%) and with Professional and technical occupations such as doctor, teacher and engineer, among others (62%) (Table 8.1). For the majority it was the first visit (73%), on vacations (92%) and hotels with four or more stars were preferred (76%) for stays of seven to fourteen days (58%) (Table 8.2).

Table 8.1. Socio-economic profile of the respondents in the case study (n=292).

SOCIO-ECONOMIC PROFILE	%
Nationality	
Portugal	70%
Netherlands	5%
United Kingdom	3%
Spain	3%
Sweden	3%
Other European	16%
Gender	
Male	69%
Female	31%
Age	
<26	8%
26-40	44%
41-60	46%
>60	2%
Education	
<9 years (Secondary education)	2%
9-12 years (High schools)	14%
>12 years (College degree)	85%
Marital status	
Single	27%
Married	53%
Divorced	8%
Widowed	1%
Other	12%
Professional area	
Professional & technical occupations (such as: doctor, teacher, engineer, artist, accountant)	62%
Higher administrator occupations (such as: banker, executive, government official, union official)	9%
Clerical occupations (such as: secretary, clerk, office manager, book keeper)	4%
Sales occupations (such as: sales manager, shop owner, shop assistant, insurance agent)	8%
Service occupations (such as: restaurant owner, police, waiter, caretaker, barber, armed forces)	6%
Skilled worker (such as: foreman, motor mechanic, printer, tool and die maker, electrician)	4%
Semi-skilled worker (such as: bricklayer, bus driver, cannery worker, carpenter, baker)	1%
Student	7%

Table 8.2. Travel profile of the respondents in the case study (n=292).

TRAVEL PROFILE	%
How many times have visited Sal island?	
1	73.0%
2	12.0%
3 to 5	8.0%
>5	7.0%
How long did stay in Cape Verde?	
< 7 days	33.1%
7 to 14 days	58.0%
15 to 30 days	4.8%
> 30 days	4.1%
Your last trip to Sal Island was due to:	
Exclusively vacation	92.3%
Exclusively work	4.0%
Working and vacation	3.7%
Enter the month of your last arrival /visit to the Sal island.	
January	2.5%
February	7.7%
March	6.5%
April	10.5%
May	6.8%
June	10.8%
July	8.0%
August	14.8%
September	7.4%
October	9.6%
November	7.7%
December	7.7%
During your visit where do you usually stay?	
5 stars hotel	23.5%
4 stars hotel	52.8%
3 stars hotel	12.3%
Residential / Hostel	5.6%
Personal residence	2.8%
Friends / relatives	2.0%

The majority of divers were inexperienced, with less than 50 dives (62%) and under 10 dives per year (65%) and less than half of them with experience diving abroad in other countries. On the other hand, 77% of the divers claimed to have enjoyed the experience of diving in artificial reefs for their uniqueness (42%) and for the feeling of adventure (23%). Only 5% disliked artificial reefs and the main reason was their unnatural look (46%).

Diving packages with 6 dives and an attractive price are the most preferred ones (40%) and 95% of the tourist divers would recommend diving in Sal Island to family and friends (Table 8.3).

Table 8.3. Travel profile of the respondents in the case study (n=292; *n=224, **n=15).

DIVING PROFILE	%
Diving experience?	
< 50 dives	62%
50 to 200 dives	21%
201 to 500 dives	8%
> 500 dives	9%
How often do you dive in a year?	
< 10 dives	65%
10 to 25 dives	18%
26 to 50 dives	8%
> 50 dives	9%
Do you often travel abroad to dive?	
Yes	46%
No	54%
Do you Like to dive into artificial reefs (wrecks, sunken ships or other man-made structures)?	
Yes	77.0%
No	5.0%
Indifferent	18.0%
Let us know why you like to dive into artificial reefs.*	
More interesting	22.0%
For the adventure	23.0%
Greater adrenaline	7.0%
Different than usual dives	42.0%
Other (specify)	6.0%
Let us know why you do not like to dive into artificial reefs.**	
Unnatural	46.0%
Unaesthetic	13.0%
Dangerous	8.0%
Fear	17.0%
Other (specify)	16.0%
Imagining that you stay 7 days at Sal Island, which of the following "packages" of dives would be your choice?	
1 Try dive (40€)	3.7%
2 dives (60 €)	22.0%
4 dives (€ 110)	25.8%
6 dives (€ 150)	40.3%
2 dives + boat + fishing aboard (120 €, one day program)	8.1%
Would you recommend a diving trip to Sal island to your friends and family?	
Definitely not	0.0%
Probably not	5.0%
Probably Yes	40.0%
Definitely yes	55.0%

Opinions and perceptions regarding environmental education

The large majority of divers are aware of the vulnerability of the marine ecosystem (41%) but there are just as many divers who have no opinion or knowledge about it (39%). More than half of the respondents claim that diving has low or no impact on marine ecosystems (Table 8.4).

The majority of divers reported a positive overall appreciation of the underwater identification guides and routes, claiming an improvement of the diving experience (91% and

100%, respectively) and a better understanding of marine biodiversity of the dive site (99% for both) and there was a consensual opinion for recommending the use of such guides and routes plans (Table 8.5).

Most respondents agreed (12%) or strongly agreed (87%) that the information about biodiversity provided during the briefing increased their environmental awareness.

Table 8.4. Environmental awareness profile of the respondents in the case study (n=292).

ENVIRONMENTAL AWARENESS PROFILE	%
In your opinion what is the current state of Cape Verde's marine ecosystems?	
Least concern	6%
Near Threatened	9%
Vulnerable	41%
Critically endangered	5%
I do not know	39%
In your opinion what is the negative impact of diving in the Cape Verde's marine ecosystem?	
None	13%
Low	41%
Moderate	19%
High	3%
I do not know	24%

Table 8.5. Tools for environmental awareness (n=292).

SPECIES ID FIELD GUIDE & DIVING ROUTES	%
Species ID field guide **improve your diving experience.**	
Strongly agree	48%
Agree	43%
Disagree	8%
Strongly disagree	1%
Species ID field guide **provides a better understand of marine biodiversity of the dive site.**	
Strongly agree	67%
Agree	32%
Disagree	1%
Strongly disagree	0%
I will recommend the use of *Species ID field guide* to my diving friends.	
Strongly agree	89%
Agree	9%
Disagree	2%
Strongly disagree	0%
Did the Information about biodiversity provided during the *briefing* your environmental awareness?	
Strongly agree	87%
Agree	12%
Disagree	1%
Strongly disagree	0%
Diving routs guide **improve your diving experience.**	
Strongly agree	77%
Agree	23%
Disagree	0%
Strongly disagree	0%
Diving routes guide **provides a better understand of marine biodiversity of the dive site.**	
Strongly agree	71%
Agree	28%
Disagree	1%
Strongly disagree	0%
I will recommend the use of *Diving routes guide* to my diving friends.	
Strongly agree	94%
Agree	6%
Disagree	0%
Strongly disagree	0%

8.6 DISCUSSION

Ensuring the sustainable future of scuba diving tourism requires: an understanding of the issues which arise from the divers' desire to maximise their experiences; the industry's efforts to enable these experiences while achieving commercial goals; the host community's needs and priorities; and the imperatives to preserve pristine environments and conservation values in the long term. These complex and sometimes competing goals can challenge the multiple stakeholders who utilise, manage and value marine environments (Plummer and Fennell, 2009; Dimmock *et al.*, 2014; Strickland-Munro *et al.*, 2010).

Preferences for marine biodiversity may vary according to different cultural backgrounds (Ressurreição *et al.*, 2012). However, a higher value is attributed to visiting a place where there is a strong conservation culture. The origin of the diving tourists may vary according to the destination, but certain patterns can be found, especially regarding tropical destinations (Hu and Wall, 2005; Dicken and Hosking, 2009; Vianna *et al.*, 2012), perhaps due to the pristine waters and higher biodiversity of marine species (Asafu-Adjaye and Tapsuwan, 2008). The need for a reinforced ecological management of the coastal areas where diving is practiced (Garrod and Gossling, 2008; Rouphael and Inglis, 2002; Tratalos and Austin, 2001; Zakai and Chadwick-Furman, 2002) should include measures to maintain ecosystem equilibrium and increase visitors' environmental awareness (Vanhooren *et al.*, 2011).

Several authors highlighted the importance of socio-demographic studies for defining divers motivations and perceptions towards several aspects of the activity and better address environmental awareness and education programs (Mundet and Ribera, 2001; Rouphael and Inglis, 2001; Luna *et al.* 2009 and Pedrini *et al.*, 2010).

Most of the surveyed divers were Portuguese, probably due to the fact that Portuguese tourists are among the four main nationalities visiting the Islands (INE, 2015b) and being a Portuguese owned diving center tends to attract more Portuguese divers (Oliveira M.T., *personal observation*).

As observed in most other divers' surveys (Hannak, 2008; Hannak *et al.*, 2011; Mundet and Ribera, 2001; Musa, 2003; Musa *et al.*, 2006; Rangel *et al.*, 2011; Rangel, 2013; Tabata and Miller, 1991) male divers are the majority, most have a college degree, and professional and technical occupations such doctors, teachers, and engineers. In fact, it was observed that diving is mostly practiced by individuals with a high level of formal education (Garrod and Gossling, 2008). Similar results have been observed in other surveys (Musa and Dimmock, 2012, 2013). Nevertheless, more than half of respondents claim that diving has low or no impact in the marine ecosystems and only 41% are aware of the vulnerability of the marine ecossistem.

With almost half of the diver population with ages above 41 years and 76% of all divers staying in hotels of four stars or more, it is clear that diving is mostly practiced by people who are economically well off, as suggested by Musa *et al.* (2010).

The vast majority of the interviewed divers were inexperienced, with less than 50 dives and many of them were experiencing diving as part of a holiday or once-only activity (Wilks, 1992). Similar results were obtained by Rangel (2013) for south Portuguese coast divers. Given that more experienced divers (measured in number of dives) caused less impact on the system (Luna *et al.*, 2009), divers' profiling should be evaluated and adjusted prior to the development and implementation of educational programs.

Understand if teaching environmental education can, in fact, influence the way people behave in practice is fundamental (Hart *et al.*, 1999). Addressing environmental problems by placing youngsters in natural, undisturbed places can act as a powerful environmental education tool (Hart *et al.*, 1999), and the marine environment can be used as an "outdoor laboratory", where the diving operator provides *in situ* biological and ecological information to visitors (Salm and Siirila, 2000).

The sustainability of scuba dive tourism requires not only the conservative use of natural and social resources, but also economic viability of all stakeholders, community integration and the provision of satisfying diving experiences (Wongthong and Harvey, 2014). Sal Island, having multiple artificial and natural reefs contributing to conservation and socio-economic purposes (Oliveira *et al.*, 2015c), seems to be in the right path to achieve a good position among the world's leading scuba diving hotspots. In fact, 95% of the respondents would recommend a dive trip to Sal Island to friends and family, indicating a high level of diving satisfaction.

In the case of Sal Island, diving and social and environmental issues are not isolated and are similar to Belize in the Caribbean (Diedrich, 2007), Mozambique in East Africa (Tibiriçá *et al.*, 2011) and Palau in the Pacific (Poonian *et al.*, 2010; Vianna *et al.*, 2012) where fishing and agriculture exist along with scuba dive tourism. Nevertheless the dive tourism industry here is dominant over other land-based and marine-based industries. This has led to high competition in tourism operating businesses and resulted in irresponsible management practices. Sal's diving operators use the same dive spots, prices and product offering are commodities and there is no cooperation and no collaborative development plan for the industry (Oliveira M.T., *personal observation*). For this reason, this study suggests a new paradigm for the management of this reef-based dive tourism destination, integrating the concepts of Sustainable Tourism Development (STD) for development guidelines and Integrated Coastal Management (ICM) for management interventions (Graci and Dodds, 2010; Marafa and Chau, 2014). These two conceptual frameworks have been influenced by the principles of sustainable development formulated in Agenda 21, at the Rio Earth Summit in 1992 (UNEP and UNWTO, 2005), and have been proposed as the way forward in dealing with the increasing constraints in coastal zones and accommodating growing pressures from tourism development (Auyong, 1995; Kanji, 2006; Murray, 2007; Phillips and Jones, 2006; Westmacott, 2002). With STD and ICM approaches, management questions are addressed and analysed in an integrated manner. A practical management framework for Sal Island dive tourism can be implemented integrating various domains including science management integration, spatial integration and stakeholder integration. These key elements of 'integration' in dive tourism management should not be considered separately, rather each should be recognized as overlapping and interacting with the others (Figure 8.9).

For the diving industry, leadership can help to engage the host community in a range of adaptive management opportunities, and to encourage participation and build inclusion. In doing so, the main factors of development should be addressed: a) the integration between natural and social sciences - management, land and ocean, and multiple stakeholders; b) community-oriented tourism development; and, c) voluntary management, along with education and good governance, long-term viability of the dive tourism industry can be achieved (Wongthong and Harvey, 2014).

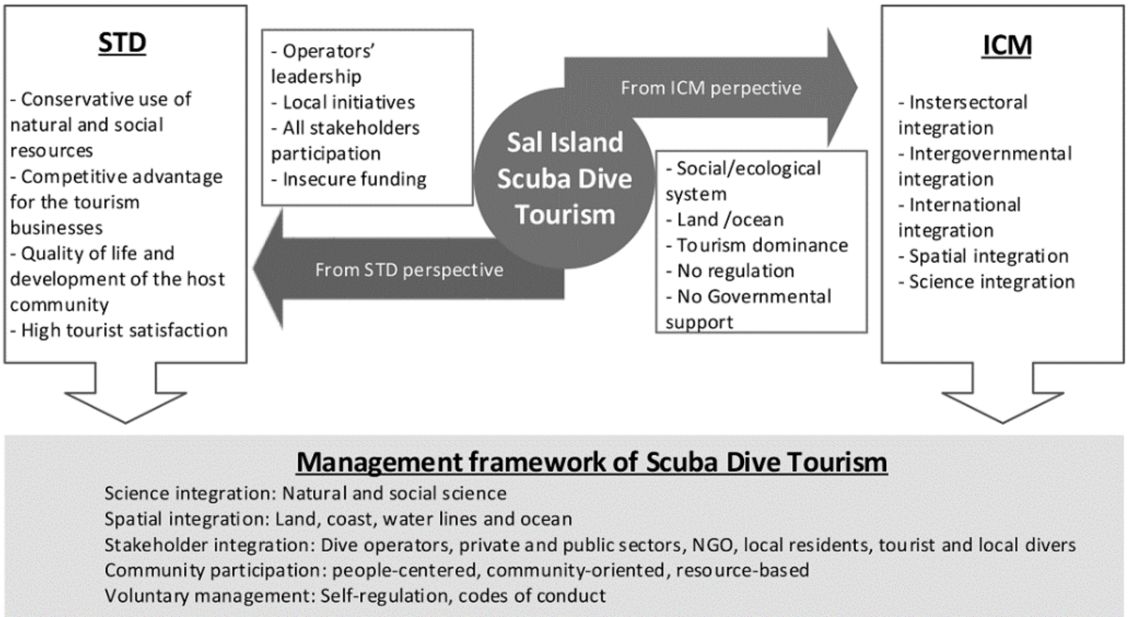


Figure 8.9. Illustrative diagram for the management of scuba dive tourism. Adapted from Pearce (1997) and Wongthong & Harvey (2014).

The vast majority of our surveyed divers claim that the *Species ID field guide* and the *Diving routes guide* had contributed to improving their diving experience and provided a better understanding of marine biodiversity of the dive site and would recommend them to their friends and family. The same was observed for the dive briefing, where 87% strongly agreed that this is a powerful tool to improve environmental awareness. Barker and Roberts (2008) and Camp and Fraser (2012) advocated on-board "environmental briefings", provided immediately before diving, thereby ensuring a pleasant and safe experience, while simultaneously effectively promoting an increase in environmental awareness. These pre-diving briefings are highly effective at reducing divers' contact with the surroundings, since they emphasize the importance of buoyancy control and careful action, important educational tools, resulting in an increase in environmental awareness and, thus, reduction of diver damage (Barker and Roberts, 2004; Luna *et al.*, 2009; Medio *et al.*, 1997; Townsend, 2008a; Uyarra and Côté, 2007).

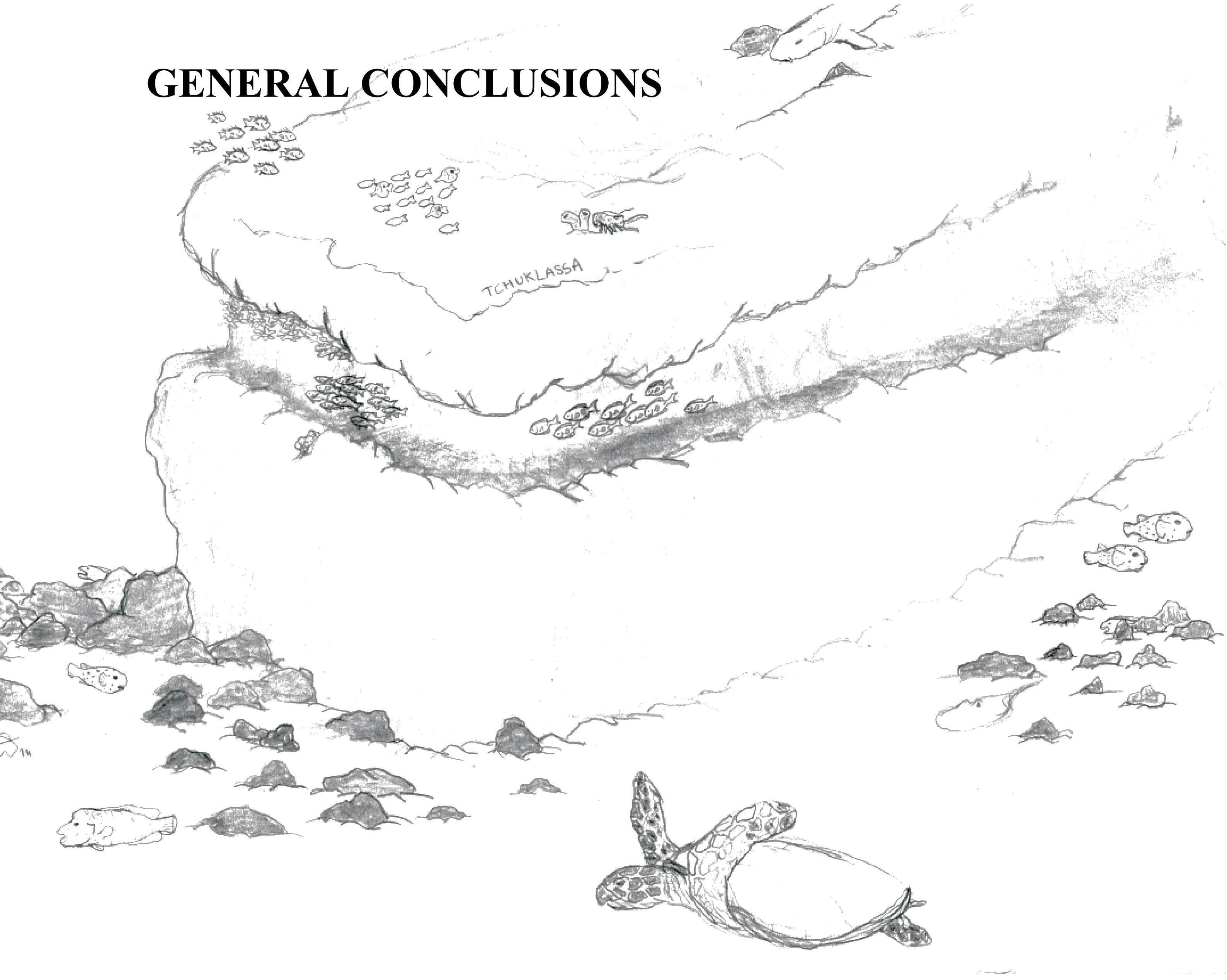
8.7 CONCLUSION

Marine environmental sustainability is a critical global issue which, nonetheless, has the potential to be a strategic business opportunity for host communities and the scuba diving tourism industry that seeks to attract tourists to a destination.

In this study, Sal Island's divers can be classified as promoters of the diving sites visited and related products, as they seemed to enjoy their experience with the environmental tools designed for them, namely the Species ID field guide, Diving routes guide and the Environmental diving briefing. Moreover, these tools appear to have increased the diver's environmental awareness and were considered an effective way to increase environmental education and knowledge, but also to improve divers experience within the dive site.

This study was a first approach to better understand the diving industry in Cape Verde. A theoretical proposal was suggested, incorporating human and social dimensions into the management of scuba dive tourism in Sal, including ICM and STD in an integrative way. Future research should be carried to better understand this industry from a holistic point of view, identify stakeholder concerns and interactions, improve management and planning processes, review current issues, devise solutions allowing decision-making processes to modify and adapt management frameworks such as ICM and STD to best fit the local conditions, and move toward a sustainability management.

GENERAL CONCLUSIONS



GENERAL CONCLUSIONS

This study began in April 2008 with the deployment of the *Sargo* artificial reef off Santa Maria, Sal Island (Cape Verde). It was totally funded by private organizations, proving that science and market objectives can be successfully pursued, respecting the aims and legitimate expectations from all stakeholders.

Nevertheless, it is important to emphasise that several difficulties of different kinds were successfully overcome. Overcoming problems of financing, travel and accomodation, organisation of a scientific team, scientific and diving equipment costs and unexpected daily constraints of working in an African Island, were a significant part of the work that we had to carry out.

Today it is consensual that increasing biodiversity knowledge in areas of implementation of ecotourism is essential for sustainable management (Lim and McAleer, 2005). Nonetheless, the information on Cape Verde marine biodiversity is limited and dispersed (Stromme *et al.*, 1981; Reiner, 1996; Wirtz and d'Udekem-d'Acoz, 2001; Vakily *et al.*, 2002). Additionally, there is an absolute lack of background information on diving tourism in the Archipelago. However, this is not a problem that is unique to Cape Verde. In fact, although diving tourism represents one of the most important sectors within coastal tourism (Townsend, 2003; Davenport and Davenport, 2006; Townsend, 2008b; Rouphael *et al.*, 2011), worldwide research on this subject is scarce, consisting mostly of "grey literature" such as project reports (Hall, 2001; Garrod and Gössling, 2008b).

Here a general description and analysis of the major findings of this Thesis is provided, within the context of the general objectives of this dissertation, which were:

- ⇨ better understand the colonisation process of the artificial reefs, in terms of the macro benthic and ichthyological communities;
- ⇨ compare the macro benthic and ichthyological communities of natural reefs with those of the artificial reefs;
- ⇨ study the dynamics of use of artificial reefs structures for one of the major local fish species;

- ⇨ evaluate socio-economic impacts of artificial reef deployment in the promotion of underwater ecotourism in Cape Verde;
- ⇨ address measures to be established by coastal managers, aiming at better environmental conservation and sustainable development of underwater ecotourism in Cape Verde;
- ⇨ produce contents for local environmental campaigns to promote the environmental conscience concerning the fauna and flora in the Cape Verde waters.

What follows is a synthesis of what we believe are the most important conclusions of this study.

The monitoring and assessment of the fish assemblages of the artificial reefs must make use of a broad variety of sampling techniques. These do not differ significantly from those traditionally used for the evaluation of marine resources. However, since the artificial reefs became interactive with the surrounding area, introducing changes in the natural habitat, some modifications in the techniques were necessary for each set of assessment circumstances (Santos, 1997). Visual censuses (non-destructive methods) were essential for assessing the fish assemblages that occur in the reefs and in a narrow band around them (5m from the reefs edge) and were performed by divers who recorded all fish species present within the area, as well as their size and abundance. Due to the different habitat complexities and diving time limitations (due to depth), a combination of methodologies were used as suggested by Bortone *et al.* (2000): transect (Brock, 1954; Buckley and Hueckel, 1989) and species–time random count method (Thompson and Schmidt, 1977; Jones and Thompson, 1978). These methods are well adapted for investigating community structure, organisation (including daily and seasonal variations, and vertical distribution) and fish behaviour towards the reefs. The random count and the stationary point count proved to be the most suitable visual methods for studying our reefs. A five minute interval was considered, as this was the time estimated to observe 90% of the species on the four study sites, according with species–time random count method developed by Harmelin-Vivien *et al.* (1985).

The comparative study of the fish assemblages from an artificial reef and a neighbouring natural reef, based on all the sampling techniques, lead to the following conclusions:

- ✓ Decommissioned vessels can mimic the local NRs by supporting diverse fish assemblages similar to those from nearby natural habitats.

- ✓ The total number of species and mean fish densities at the ARs were similar to those of the NRs;

- ✓ The local NRs have a higher rugosity and structural complexity (more holes and crevices) than the ARs, but the ARs showed higher values for the investigated ecological indices (mean species richness, mean diversity and mean equitability);

- ✓ Similar assemblage's composition at the ARs and at the NRs (differences were mainly due to rare species) were recorded, suggesting that these ARs may have already reached an equilibrium point;

- ✓ The results related to the size structure of the most abundant species do not allow a detailed understanding of the role of the study sites for the different species. However, based on our *in situ* observations during data collection, it appears that both reef types provide some common uses. These include sheltering, growth and nursery areas for juveniles and spawning/mating areas for adults (the latter particularly for the wrasses, genus *Abudefduf*, for which nests were commonly observed).

To characterize the benthic communities within Santa Maria Bay, some destructive method had to be applied. Vertical surfaces from NRs and ARs were scraped with chisels by divers and the material was collected with the help of an airlift (Moura *et al.*, 2007). This samplings lead to the following conclusions:

- ✓ Benthic assemblages within Baía de Santa Maria present different structure and composition between artificial and NRs but also between depth ranges. At 9m depth the communities were characterised by low abundance and high species turnover, both within and between ARs and NRs. At 25m depth the assemblages showed higher abundance and species richness and generally presented lower species turnover (β diversity) within each site. These differences form a complex mosaic adding complexity to the benthic communities of the area, namely in what concerns the species pool or diversity.

- ✓ ARs enhance the local species pool, mostly because they are able to provide new niches for colonization, proving that they are complementary to the NRs. One of the major concerns in the introduction of ARs in the marine environment, especially in islands, is that these structures may facilitate the dominance of benthic communities by invasive species, which most of the times are strong competitors and early colonizers.

- ✓ The use of relatively small ARs for specific purposes, namely nature based sustainable tourism, as long as properly monitored and managed, seem to be a good alternative, removing pressure from natural areas and eventually enhancing local populations and biodiversity. For example, at low depth, where benthic assemblages are so constrained by physical disturbance, the added effects of human activities can deteriorate the NRs and reduce species diversity.

Regarding benthic assemblages, as the present study is a snapshot of the community at the time of sampling, it is impossible to know how the dynamics in terms of diversity will evolve with time. Will the ARs allow some species to persist by providing new niches and adding ecological roles to the community? Is community structure going to be stabilized or destabilized by the addition of these species? Nevertheless, existing ARs can be used to alleviate the pressure of diving on the NR. Although some differences were found between the assemblages, even after a long period of time, and considering the small size of the Santa Maria Bay, at this time, it is not recommended that more vessels should be sunk at low depths.

Following the numerous sampling for benthic organisms, it was possible to identify a new genus and species of the subfamily Caprellinae (Leach, 1814): *Mantacaprella macaronensis*. Acording to Vázquez-Luis *et al.* (2013) the term *Mantacaprella* is dedicated to the Manta Diving Center (www.mantadivingcenter.cv) for its initiative for the deployment of the first artificial reefs in Cape Verde waters within the framework of the *Rebuilding Nature Project* and its invitation to the Portuguese research team responsible for studying the assemblages of the natural and artificial reef assemblages of the Bay of Santa Maria (Sal Island, Cape Verde), where this species was originally identified.

With the deployment of *Kwarcit* (2006) and *Sargo* (2008), these new man-made habitats were monitored since 2008 in terms of colonization. The information gathered has shown that among the abundant fish community observed around and within the Kwarcit, there is a large number of juvenile African hind - *Cephalopholis taeniops*. Since there is very little biological information on this species, its behaviour in terms of migratory and daily movement is particularly important for the assessment of the standing stock from two perspectives: as an attraction for underwater tourism and as a sustainable fishery resource for the local fishers (hand-lining and spear-fishing). Recurring to acoustic telemetry to assess the use of the AR habitat by this species and to investigate possible movements to and from the nearby NRs, results have shown that all the fish remained in the study area for 44 days and showed greater activity at night. These results reinforces the need for species specific studies of habitat use to clarify the role of vessel reefs in the life cycle of these species, but also ascertain the importance of ARs in the protection and restoration of local biodiversity.

From June 2008 to June 2013 the *Rebulding Nature* Team carried out several fish size sampling surveys in markets and landing ports. Specimens were caught with several different types of fishing gear, namely, hand-lines, bottom long-lines and purse-seines, at a wide bathymetric range and covering all seasons of the year. A total of 8,328 specimens were sampled, belonging to 29 fish species across 14 families. It was possible to estimate Length-Weight and Length-Length relationships for coastal reef fish species in Cape Verde waters, for which previous data were either limited in terms of their size range and number of specimens sampled, or in terms of the sampling period, because samplings from previous studies were obtained on scientific cruises that covered limited time periods. To our knowledge, this study had provide the first available references on WLRs:

- ✓ for five fish species worldwide;
- ✓ for 10 species for the Eastern Atlantic;
- ✓ and for 12 species for the Cape Verde Archipelago.

Furthermore, the study provided additional WLRs for 11 species of Cape Verde waters, based on a wider size range and seasonal coverage. As regards the LLRs, this study provides the first reference:

- ✓ for 23 species worldwide;
- ✓ for 24 species for the Eastern Atlantic;
- ✓ and for all 26 studied species for Cape Verde waters.

Ideally, these results will contribute to future weight and length reconstitutions, diet studies, life history comparisons, biomass estimations and stock assessments.

In the Cape Verde archipelago, the island shelf, of limited extent, is associated with a relatively low primary production and consequently the biodiversity is apparently lower than that of the African continental coast (Menezes *et al.*, 2004). The ichtyofauna is of tropical type. As Cape Verde is an archipelago there are a few dozen endemic *taxa*, probably due to speciation related to isolation and thermal stability (Brito *et al.*, 2007). In Cape Verde in recent years there has been a noticeable decline in the biodiversity of local marine life, especially due to increasingly intensive and unregulated fishing practices. As a result, underwater tourism may be affected by virtue of there being 'less to see'. Biodiversity sustainable management presupposes to enhance the tourist experience and also to protect the local fauna and flora. For this purpose it is necessary to investigate how tourists see proposed biodiversity management measures.

In terms of recommendations for action, the decision regarding the 'best practice for marine biodiversity conservation on Sal Island' would be for the promotion of greater protection for the rocky bottom type diving spots and to facilitate the process of sinking obsolete or man-made structures in order to diversify diving spots. These results support a preliminary approach whereby divers would be diverted from natural to artificial structures.

The value of marine biodiversity off Sal Island (Cape Verde) through a contingent valuation methodology were estimated. Tourist divers, who had recently dived off Sal island, were asked about their willingness to pay (WTP) for the protection of local marine biodiversity through donations, fees, or other forms for the creation of a trust fund. Of 347 respondents, 32% stated they were unwilling to contribute (protest bidders). Of those respondents who said they would be willing to contribute, 50% chose "fee" as the option where they were willing to pay less, whereas the "combined" option (i.e. including "donation", "fee" and "souvenir") was the one where respondents were willing to pay more, with around €1-7 and €0-800, respectively. Having a clear communication on how the biodiversity conservation trust fund would be used increases the potential of trust funds as potential revenue sources to support marine biodiversity conservation and improve resilience of both local diver operator businesses, other tourist enterprises, and the local community as a whole.

The deployed ARs have promoted an increase in dive trips - acting as a complementary function to NRs. The data analysis suggests an increasing number of divers over the course of the study. The higher supply of artificial reefs found in the beginning of 2008 showed that there was the curiosity to visit the new structures (i.e. the deployed ship *Sargo*) and to a certain extent there was some degree of substitutability. This contrasted with decreasing interest of the divers towards artificial reefs over time. This occurrence demonstrates that if by supposition there is still room to deploy additional sunken vessels, the decision should be analysed with caution. This fact may mean that despite artificial reefs' function as complementary to natural reefs by expanding the possibility of diversifying tourists' diving expectations, there is no guaranteed preference for man-made structures. Concomitantly, 'rules' and community engagement should be promoted to maintain the extractive value of sustainable fishing along with other important economic values.

Scuba diving tourism is an economically important industry as evidenced by the increasing number of other locations promoting their marine resources in efforts to become scuba diving destinations and Cape Verde aspires to follow popular, 'must dive' places widely promoted in social and other media such as Koh Tao in Thailand, Layang Layang and Sipadan in Malaysia, the Great Barrier Reef off Australia and Sharm El Sheikh – Red Sea, Egypt, among others (Roberts et al., 2002; Dearden et al, 2007; Lew, 2013). In this study the Tourists diver Socio-economic and travel profile was established and it was clearly proven that they are open to receive more information about environmental awareness of the local area. Marine environmental sustainability is a critical global issue which, nonetheless, has the potential to be a strategic business opportunity for host communities and the scuba diving tourism industry that seeks to attract tourists to a destination. The use of environmental awareness tools appear to have increased the diver's environmental education and knowledge, but also to improve divers experience within the dive site. For this reason we have produced a *Species Identification Guide* with 124 species distributed among 12 slates and 4 Underwater Routes, two Artificial Reefs (Sargo and Kawarcit) and two Natural Reefs diving sites (Três Grutas e Tchuklassa).

A theoretical proposal was developed, incorporating human and social dimensions into the management of scuba dive tourism in Sal, including ICM and STD in an integrative way. Nevertheless the dive operators still have a non-collaborative view of the business and it is expected to take some time to see its implementation of Sal Island.

Finally, it is important to highlight that this study was the first of its kind carried out in Cape Verde. Its multidisciplinary character did not allow to cover deeply all the aspects but provided relevant biological information on the contribution of the ARs towards the local biodiversity and also to better understand the diving industry in Cape Verde. Thus, it is highly recommended that any future project, independently of it's goals, should involve multidisciplinary teams, in order to answer several questions that remain unanswered and develop new studies, such as:

- ✓ What are the interactions between reef fish communities (e.g. predation, competition, etc.)?
- ✓ What are the energy flows in artificial reef communities?
- ✓ What is the seasonal movement patterns of *C. taeniops* (area and time) and other iconic species and how the ARs are part of it?
- ✓ Can a management plan involving all the stakeholders be developed to avoid conflicts and maximize ARs potential?
- ✓ What would be the best organization type to run Biodiversity trust fund to maximize tourist divers WTP?
- ✓ Can a theoretical proposal, incorporating human and social dimensions into the management of scuba dive tourism in Sal, including ICM and STD in an integrative way be implemented in Sal?

However, it should be noted, that due to the diversity of subjects, the above are not listed in order of importance.

In conclusion, research and incorporating human and social dimensions into the management of scuba dive tourism is the key for future long-term artificial reef use. Attempting to extrapolate results reported from the studies here described to different areas can be very useful, but also risky as a substitute for investing in local research, especially if there are significant differences between areas, their environmental and social conditions.

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ANNEX I

Weight–length and length–length relationships for reef fish species from the Cape Verde Archipelago

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Weight-length and length-length relationships for 29 reef fish species from the Cape Verde Archipelago (Tropical North-eastern Atlantic)

9.1 SUMMARY

This study reports weight–length and length–length relationships for selected coastal reef fish species of the Cape Verde Archipelago (tropical north-eastern Atlantic). Specimens were caught with different types of gear (long-lines, handlines, purse-seines and traps) during commercial fishing activities and sampled during fish market operations. A total of 8328 individuals were sampled, representing 29 species from 14 Families. This study provides the first references on weight–length and length–length relationships for five and 23 fish species worldwide, for 10 and 24 species for the Eastern Atlantic and for 12 and 26 species for Cape Verde Archipelago, respectively. Additionally, it provides revised weight–length relationships for 11 species from Cape Verde waters.

***Keywords*:** Fish weight-length relationships; length-length relationships; Cape Verde Archipelago; Eastern Atlantic Ocean.

9.2 INTRUDUCTION

Weight–length relationships (WLRs) and length–length relationships (LLRs) have diverse applications, namely for studies on fish biology, physiology, ecology, and fisheries assessment (Santos *et al.*, 2002). This is because size is generally more biologically relevant than age; consequently, variability in size has important implications for diverse aspects of fisheries science and population dynamics (Erzini, 1994).

The Cape Verde Archipelago is composed of ten islands (and thirteen islets), located 750 km off Senegal (west coast of Africa), between 15 and 17°N and 22–25°W (Santos et al., 2013). Local fisheries are predominantly small-scale and artisanal, aiming to supply the local markets and occurring mostly on near-shore reefs, as the continental shelf is narrow. Although several researchers have studied the ichthyofauna of the Cape Verde Islands, basic biological knowledge is still lacking. The present study was conducted because the LWRs were missing for many species of the local reef assemblages, which were the subject of a comparative study between natural and artificial reefs of the Santa Maria Bay (Santos et al., 2013). Therefore the present study represents a new contribution on LWRs for 23 and the LLRs of 26 reef fish species.

9.3 MATERIAL AND METHODS

Data reported in the present study were collected between June 2008 and June 2013. Data collection was undertaken during periodic (monthly and/or seasonal) size sampling surveys in markets and landing ports, carried out by the Rebuilding Nature project research team and local INDP (Instituto Nacional de Desenvolvimento das Pescas) technicians (Figure I.1). Specimens were caught with several different types of fishing gear, namely, hand-lines, bottom long-lines, and purse-seines, at a wide bathymetric range and covering all seasons of the year. The nomenclature adopted was that of FishBase (Froese and Pauly, 2014).

Figure I.1. Sampling survey in Santa Maria pier.

Fish fork length (FL) and total length (TL) was measured with an ichthyometer to the nearest millimeter (mm); individual of less than and over 2 kg were weighed on a top loading digital balance with a precision of 1g and10g respectively.

Total length–fork length relationships (TFLRs) were calculated for each species using linear regression analysis with the equations $TL = a + bFL$, where TL is the fish total length (cm) and FL is the fish fork length (cm), a is the intercept of the regression and b is the coefficient of the regression. The weight–length relationships were estimated following the most common approach (Froese, 2006), using the log form of the equation: $W = aTL^b$, where W is the total weight (g) and TL is the fish total length (cm), a is the intercept of the regression and b is the coefficient of the regression (growth coefficient, i.e. fish relative growth rate). The allometry coefficient was expressed by b coefficient of the WLRs. In order to confirm whether b values obtained were significantly different from the isometric value (3), a t-test (H_0: $b = 3$) with a confidence level of 95% ($a = 0.05$) was applied (Sokal and Rohlf, 1987).

Additionally, for both WLRs and TFLRs, 95% confidence limits of the parameters *a* and *b* were estimated. Goodness-of-fit of the regressions were given by the coefficients of determination (r^2), and the statistical significance were assessed with ANOVA tables (*F*-tests). The regression analysis was carried out using the R language for statistical computing version 3.0.1 (R Core Team, 2013).

Web database services were consulted for specific data on WRLs and LLRs, with particular emphasis on FishBase (Froese and Pauly, 2014). Due to statistical constraints in the WLRs, only species represented by at least 50 individuals and with a relatively broad size range were considered for estimation of the different relationships. The only exceptions to these criteria refer to selected fish species for which there were no WLRs reported in the literature or where the size range covered by the available WLRs was narrower.

9.4 RESULTS

We sampled a total of 8328 specimens belonging to 29 fish species across 14 families. Best represented was the family Sparidae (five species), followed by Carangidae (four species) and Haemulidae and Scaridae (three species). In numerical terms, the best represented species were *Gymnothorax vicinus* and *Spicara melanurus*, with 2285 and 1569 specimens, respectively, followed by *Diplodus prayensis* (603), *Cephalopholis taeniops* (342), *Diplodus fasciatus* (333), and *Lithognathus mormyrus* (306). Results obtained for the WLRs and TFLRs, respectively, for 23 and 26 selected coastal reef fish species along with several descriptive statistics, are given in Tables I.1 and I.2.

WLRs were highly significant ($P < 0.001$) for all 23 species. Coefficients of determination (r^2) of the WLRs relationships ranged from 0.868 for *Chromis lubbocki* to 0.999 for *Pomadasys incisus*, corresponding to a mean value of 0.966 (0.029). In addition, $r^2 > 0.900$ was found for 22 species (96%) and $r^2 > 0.950$ for 17 species (74%). The exponent *b* of weight–length relationships ranged from 2.492 for *Spicara melanurus* to 3.240 for *Cephalopholis taenops*, corresponding to a mean value of 2.9895 (0.1566), meaning that all WLR slopes (*b*) were within the expected ranges ($2.5 < b < 3.5$; Carlander, 1969), with the exception of *S. melanurus*. In terms of growth type, these results revealed that five species (22%) showed negative allometries ($b < 3$, $P < 0.05$), 10 species (43%) showed isometric growth ($b = 3$, $P < 0.05$), with the remaining seven species (30%) showing positive allometries ($b > 3$, $P < 0.05$).

Table I.1. Descriptive statistics and weight-length relationship (WLR) parameters for 23 fish species caught off the Cape Verde archipelago coast (Tropical North-eastern Atlantic).

Family/Scientific name	Species common name	N	TL, mean ± SD (TL_{Min}–TL_{Max})	W, mean ± SD (W_{Min}–W_{Max})	WLR equation	Determination coefficient (r^2)	SE of b[1] (95% CI of b)	Notes
Balistidae								
Balistes punctatus	(Bluespotted triggerfish)	122	32.7 ± 11.39 (15.7–51.8)	901.7 ± 709.78 (82–2478)	$W = 0.0585TL^{2.6936}$	0.9931	0.0205 (2.6531–2.7342)	d
Carangidae								
Decapterus punctatus	(Round scad)	138	18.2 ± 6.69 (8.3–31)	89.1 ± 86.18 (5–343)	$W = 0.0084TL^{3.0666}$	0.9922	0.0234 (3.0203–3.1128)	d
Seriola fasciata	(Lesser amberjack)	50	47.8 ± 10.13 (30.5–65)	1893.6 ± 1190.67 (460–4500)	$W = 0.0125TL^{3.0475}$	0.9702	0.0770 (2.8926–3.2023)	d
Trachinotus ovatus	(Pompano)	33	27.9 ± 8.12 (15.7–44)	199.1 ± 175.59 (32–650)	$W = 0.0089TL^{2.9370}$	0.9443	0.1281 (2.6757–3.1984)	c
Centracanthidae								
Spicara melanurus	(Blackspot picarel)	1569	26.4 ± 2.31 (18.2–32.8)	251.3 ± 56.57 (87–425)	$W = 0.0713TL^{2.4915}$	0.9215	0.0184 (2.4555–2.5276)	a
Haemulidae								
Parapristipoma octolineatum	(African striped grunt)	65	25.5 ± 3.37 (19.7–31.6)	219.4 ± 86.6 (96–404)	$W = 0.00937TL^{3.0916}$	0.9865	0.0456 (3.0005–3.1828)	a
Pomadasys incisus	(Bastard grunt)	41	33.5 ± 15.52 (7.6–53.5)	717.4 ± 533.29 (6–1873)	$W = 0.0160TL^{2.9275}$	0.9991	0.0137 (2.8998–2.9552)	d
Holocentridae								
Myripristis jacobus	(Blackbar soldierfish)	37	19.1 ± 1.46 (15.1–21.7)	124.1 ± 29.44 (67–187)	$W = 0.01476TL^{3.0563}$	0.9464	0.1229 (2.8061–3.3059)	b
Sargocentron hastatum	(Red squirrelfish)	130	20.7 ± 3.9 (13.1–27.9)	153.8 ± 79.16 (37–347)	$W = 0.0309TL^{2.7786}$	0.9722	0.0415 (2.6965–2.8607)	d
Lethrinidae								
Lethrinus atlanticus	(Atlantic emperor)	236	27.5 ± 4.89 (12.8–41)	311.1 ± 166.85 (35–950)	$W = 0.0155TL^{2.9622}$	0.9826	0.0258 (2.9114–3.0129)	d
Lutjanidae								
Apsilus fuscus	(African forktail snapper)	108	33.4 ± 10.71 (18.3–52.7)	517.3 ± 470.07 (35–1586)	$W = 0.0049TL^{3.2023}$	0.9896	0.0319 (3.1391–3.2654)	c
Lutjanus fulgens	(Golden African snapper)	214	27.9 ± 6.97 (15–43.3)	346.1 ± 239.44 (42–1116)	$W = 0.0150TL^{2.9686}$	0.9888	0.0217 (2.9258–3.0114)	d
Mullidae								
Mulloidichthys martinicus	(Yellow goatfish)	235	31.3 ± 7.02 (18.9–44.8)	463 ± 305.43 (66–1234)	$W = 0.0100TL^{3.0726}$	0.9839	0.0257 (3.0220–3.1233)	b
Muraenidae								
Gymnothorax vicinus	(Purplemouth moray)	2285	83.1 ± 12.61 (46.7–132)	1001 ± 500.39 (140–3700)	$W = 0.0014TL^{3.0368}$	0.9207	0.0187 (3.0003–3.0734)	b
Pomacentridae								
Abudefduf saxatilis	(Sergeant-major)	55	14.8 ± 2.38 (10.1–20.1)	73 ± 36.04 (21–183)	$W = 0.0187TL^{3.0392}$	0.9617	0.0833 (2.8721–3.2063)	b
Chromis lubbocki	(Lubbock's chromis)	43	13.2 ± 0.63 (11.2–14.4)	40.1 ± 5.74 (25–56)	$W = 0.0298TL^{2.7875}$	0.8677	0.1700 (2.4442–3.1307)	a
Scaridae								
Scarus hoefleri	(Guinean parrotfish)	27	51.8 ± 9.89 (32.5–66)	2470.7 ± 1257.57 (690–4890)	$W = 0.0199TL^{2.9472}$	0.9764	0.0916 (2.7587–3.1357)	a
Sparisoma cretense	(Parrotfish)	101	31.4 ± 6.67 (18.2–43)	476.6 ± 275.96 (82–1090)	$W = 0.0148TL^{2.9755}$	0.9861	0.0355 (2.9050–3.0459)	b
Sparisoma choati	(Redfin parrotfish)	54	38.9 ± 7.95 (24.3–50)	974 ± 529.61 (215–1990)	$W = 0.0175TL^{2.9525}$	0.9795	0.0592 (2.8337–3.0712)	a

Table I.1. (Continued)

Family/Scientific name	Species common name	N	TL, mean ± SD (TL_{Min}–TL_{Max})	W, mean ± SD (W_{Min}–W_{Max})	WLR equation	Determination coefficient (r^2)	SE of b[1] (95% CI of b)	Notes
Serranidae								
Cephalopholis taeniops	(Bluespotted seabass)	342	29.7 ± 6.36 (15–50.1)	456.1 ± 375.12 (42–2100)	$W = 0.0065TL^{3.2400}$	0.9865	0.0206 (3.1995–3.2805)	d
Sparidae								
Diplodus fasciatus	(Banded seabream)	333	31.1 ± 7.13 (18.1–45)	573.7 ± 373.26 (94–1558)	$W = 0.0228TL^{2.9057}$	0.9770	0.0245 (2.8575–2.9539)	d
Diplodus prayensis	(Two-banded seabream)	603	24.8 ± 2.78 (15–29.8)	258.2 ± 75.85 (54–432)	$W = 0.0142TL^{3.0423}$	0.9420	0.0308 (2.9818–3.1028)	d
Diplodus sargus lineatus	(White seabream)	290	24.7 ± 4.75 (6.6–35)	312.2 ± 173.89 (6–880)	$W = 0.0142TL^{3.0828}$	0.9764	0.0282 (3.0272–3.1384)	d

N, sample size; L, total (TL) length (cm); W, total weight (g); Min, minimum; Max, maximum; SD, Standard deviation; SE, Standard error; CI, Confidence interval; *b*, slope.
Notes: a – first reference worldwide; b – first reference for Eastern Atlantic; c – first reference for Cape Verde Archipelago; d – revised WLR for Cape Verde waters.
[1]Refer to linear regression. $\text{Log}\ TW = \text{Log}\ a + b\ \text{Log}TL$.

Table I.2. Descriptive statistics and total length-fork length relationship parameters for 26 fish species caught with several different fishing gears off the Cape Verde archipelago coast (Tropical North-eastern Atlantic).

Family/Scientific name	Species common name	N	FL, mean ± SD (FL_{Min}–FL_{Max})	TL, mean ± SD (TL_{Min}–TL_{Max})	LL equation	Determination coefficient (r^2)	SE of b^1 (95% CI of b)	Notes
Acanthuridae								
Acanthurus monroviae	(Monrovia doctorfish)	282	29.9 ± 4.49 (17–39.1)	32.8 ± 4.68 (19.1–42.6)	TL = 1.684 + 1.039FL	0.9957	0.0041 (1.031–1.047)	a
Balistidae								
Balistes punctatus	(Bluespotted triggerfish)	11	31.4 ± 4.73 (25.5–38.5)	33.5 ± 5.65 (26.4–42.2)	TL = −3.742 + 1.186FL	0.9889	0.0419 (1.091–1.281)	a
Carangidae								
Caranx crysos	(Blue runner)	126	38.3 ± 8.95 (21–55.1)	44.9 ± 10.47 (24.2–64.6)	TL = 0.167 + 1.168FL	0.9964	0.0063 (1.156–1.181)	b
Decapterus punctatus	(Round scad)	138	17 ± 6.51 (7.2–29.5)	18.2 ± 6.69 (8.3–31)	TL = 0.763 + 1.026FL	0.9970	0.0048 (1.017–1.036)	a
Seriola fasciata	(Lesser amberjack)	17	37.5 ± 5 (30.8–49.3)	44.3 ± 5.9 (36.1–56.8)	TL = 0.427 + 1.168FL	0.9828	0.0400 (1.083–1.254)	a
Trachinotus ovatus	(Pompano)	33	22.7 ± 6.63 (12.7–35.9)	27.9 ± 8.12 (15.7–44)	TL = 0.143 + 1.223FL		0.0104 (1.202–1.244)	c
Centracanthidae								
Spicara melanurus	(Blackspot picarel)	23	23.9 ± 1.38 (21–25.5)	26.7 ± 1.78 (23–28.9)	TL = −2.977 + 1.244FL	0.9405	0.0683 (1.102–1.386)	a
Haemulidae								
Parapristipoma humile	(Guinean grunt)	166	24.9 ± 3.31 (18.9–33.3)	26.4 ± 3.34 (20.1–34.6)	TL = 1.367 + 1.005FL	0.9904	0.0077 (0.989–1.020)	a
Parapristipoma octolineatum	(African striped grunt)	65	24.3 ± 3.67 (17.3–31.1)	25.5 ± 3.37 (19.7–31.6)	TL = 3.242 + 0.917FL	0.9925	0.0100 (0.897–0.937)	a
Pomadasys incisus	(Bastard grunt)	41	31.3 ± 14.51 (7.2–49)	33.5 ± 15.52 (7.6–53.5)	TL = 0.088 + 1.070FL	0.9998	0.0021 (1.065–1.074)	a
Holocentridae								
Myripristis jacobus	(Blackbar soldierfish)	34	17 ± 1.51 (13.5–19.9)	19.1 ± 1.45 (15.1–21.7)	TL = 3.360 + 0.928FL	0.9360	0.0429 (0.840–1.015)	a
Sargocentron hastatum	(Red squirrelfish)	45	19.6 ± 0.85 (18.3–21.4)	21.3 ± 0.97 (19.5–23.5)	TL = 1.169 + 1.028FL	0.8153	0.0746 (0.878–1.179)	a
Lethrinidae								
Lethrinus atlanticus	(Atlantic emperor)	231	25 ± 4.38 (11.7–36.8)	27.3 ± 4.79 (12.8–41)	TL = 0.114 + 1.089FL	0.9903	0.0071 (1.074–1.103)	a
Lutjanidae								
Apsilus fuscus	(African forktail snapper)	108	29.4 ± 9.13 (16.8–46.1)	33.4 ± 10.71 (18.3–52.7)	TL = −0.997 + 1.170FL	0.9935	0.0092 (1.152–1.188)	a
Lutjanus fulgens	(Golden African snapper)	26	27.4 ± 5.93 (21.5–40.4)	29 ± 6.53 (22.5–43.3)	TL = −1.222 + 1.101FL	0.9975	0.0113 (1.078–1.124)	a
Mullidae								
Mulloidichthys martinicus	(Yellow goatfish)	206	28.9 ± 6.22 (16.8–39.8)	32 ± 7.19 (18.9–44.8)	TL = −1.365 + 1.152FL	0.9933	0.0066 (1.139–1.165)	a
Pseudupeneus prayensis	(West African goatfish)	211	20.7 ± 3 (13.4–28)	22.8 ± 3.17 (15.9–30.5)	TL = 1.356 + 1.037FL	0.9638	0.0139 (1.010–1.065)	a

Table I.2. (Continued)

Family/Scientific name	Species common name	N	FL, mean ± SD (FL_{Min}–FL_{Max})	TL, mean ± SD (TL_{Min}–TL_{Max})	LL equation	Determination coefficient (r^2)	SE of b[1] (95% CI of b)	Notes
Pomacentridae								
Abudefduf saxatilis	(Sergeant-major)	55	13.1 ± 2.07 (9.2–18)	14.8 ± 2.38 (10.1–20.1)	TL = −0.0269 + 1.135FL	0.9764	0.0243 (1.086–1.184)	a
Chromis lubbocki	(Lubbock's chromis)	43	11.3 ± 0.63 (9.5–12.6)	13.2 ± 0.63 (11.2–14.4)	TL = 2.337 + 0.961FL	0.9042	0.0489 (0.862–1.060)	a
Scaridae								
Scarus hoefleri	(Guinean parrotfish)	27	46.6 ± 10.5 (26.5–61)	51.8 ± 9.89 (32.5–66)	TL = 7.916 + 0.940FL	0.9979	0.0086 (0.922–0.958)	a
Sparisoma choati	(Redfin parrotfish)	26	39.9 ± 4.58 (28–47)	41.6 ± 5.05 (29–49.5)	TL = −1.869 + 1.091FL	0.9815	0.0306 (1.028–1.154)	a
Sparidae								
Diplodus fasciatus	(Banded seabream)	312	28 ± 6.85 (15.6–43.1)	30.8 ± 7.16 (18.1–45)	TL = 1.782 + 1.037FL	0.9869	0.0068 (1.024–1.051)	a
Diplodus prayensis	(Two-banded seabream)	531	22.2 ± 2.72 (12.5–27)	24.6 ± 2.87 (15–29.8)	TL = 1.626 + 1.038FL	0.9686	0.0081 (1.022–1.054)	a
Diplodus sargus lineatus	(White seabream)	258	22.2 ± 4.42 (5.8–31.8)	24.8 ± 4.97 (6.6–35)	TL = 0.080 + 1.1147FL	0.9799	0.0100 (1.094–1.134)	c
Lithognathus mormyrus	(Sand steenbras)	306	24.9 ± 4.63 (14.6–31.2)	27.1 ± 5.6 (15.1–34.9)	TL = −2.731 + 1.196FL	0.9774	0.0104 (1.175–1.216)	a
Virididentex acromegalus	(Bulldog dentex)	38	31.8 ± 6.71 (21.4–45.1)	35.5 ± 6.99 (24.7–50)	TL = 2.424 + 1.039FL	0.9916	0.0160 (1.006–1.071)	a

N, sample size; TL, fish total length (cm); FL, fish fork length (cm); Min, minimum; Max, maximum; SD, Standard deviation; SE, Standard error; CI, Confidence interval; *b*, slope.
Notes: a – first reference worldwide; b – first reference for the Eastern Atlantic; c – first reference for the Cape Verde Archipelago.
[1]Refer to linear regression. $TL = a + bFL$.

The TFLRs were highly significant ($P < 0.001$) for all 26 species. The coefficients of determination (r^2) of the WLRs relationships ranged between 0.815 for *S. hastatum* and 0.999 for *P. incisus*, corresponding to a mean value of 0.974 (0.040). In addition, $r^2 > 0.900$ was found for 25 species (96%) and $r^2 > 0.950$ for 22 species (85%). The *b* of the TFLRs ranged between 0.917 for *Parapristipoma octolineatum* and 1.244 for *S. melanurus*, corresponding to a mean value of 1.081 (±0.0915).

9.5 DISCUSSION

Because of fishing gear size selectivity, most samples do not include juveniles or very small sized individuals. Therefore, use of these WLRs and TFLRs should be limited to the size ranges applied in the estimation of the linear regression parameters, as suggested by Santos *et al.* (2002). Accordingly, their use to extrapolate data to fish sizes outside the range used for their estimation (e.g. larvae, juveniles/immature stages, etc.) is not recommended. Additionally, since samples were collected over an extended period of time, these WLRs are not representative of a particular season or time of the year and, for comparison purposes, should be considered as mean values as suggested by Petrakis and Stergiou (1995). In fact, as the food availability, feeding rate, gonad development and spawning period are not constant throughout the year (Bagenal and Tesch, 1978), WLRs may vary according to those factors. However, parameter b is usually species-specific (Mayrat, 1970) and generally does not vary significantly throughout the year, unlike parameter a, which may vary daily, seasonally, and/or among different habitats (Bagenal and Tesch, 1978).

The most frequently represented families in terms of species numbers did not show a consistent tendency in growth type among species, with the exception of the family Scaridae, whose species presented a consistent isometric growth. Comparison of these results was only possible with those reported by Pereira *et al.* (2011) for the Cape Verde waters, as other studies for the same area did not report the 95% confidence intervals for the *b* parameters. Similar results were found for *Sargocentron hastatum*, whereas differences (higher *b* values in the present study) were found for *C. taenops* and *Parapristipoma humile*. Although the *b* parameter generally does not vary significantly throughout the year, Pereira *et al.* (2011) based their results on a much lower number of sampled specimens.

Most of the previously available TFLRs for the studied species were based on measurements from a very limited number of individuals, with no descriptive statistics [see FishBase

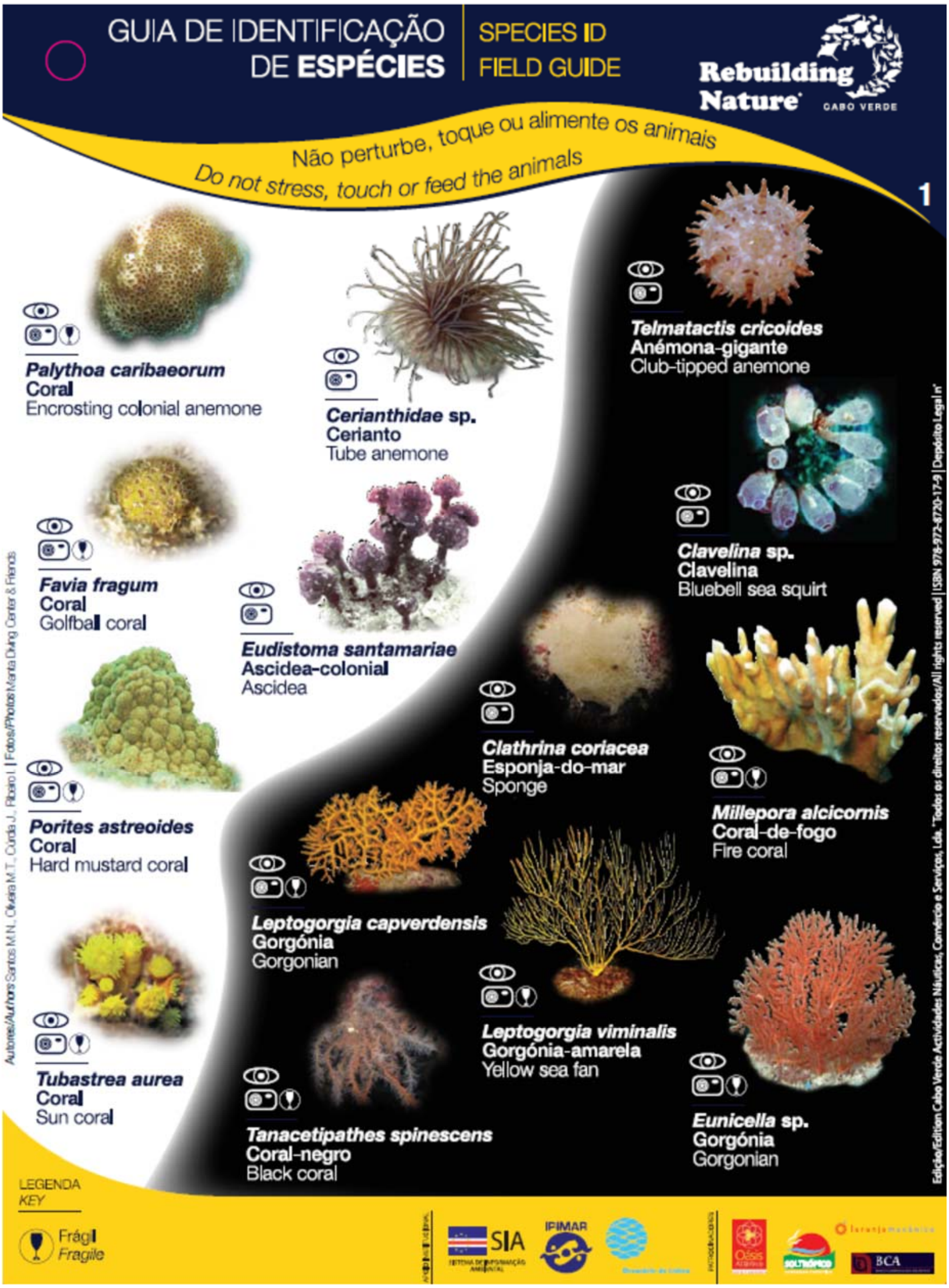
(Froese and Pauly, 2014)]. The exceptions were *Diplodus sargus lineatus and Trachinotus ovatus*, for which very similar values for the *b* parameter were provided by Morato *et al.* (2001) for the Azores Archipelago, and for *Caranx crysos* from the Caribbean (Thompson and Munro, 1974).

9.6 CONCLUSIONS

This study provides further information on LWRs and LLRs of coastal reef fish species in Cape Verde waters, for which previous data were either limited in terms of their size range and number of specimens sampled, or in terms of the sampling period because samples from previous studies were obtained on scientific cruises that covered limited time periods. To the best of our knowledge, this study provides the first available references on WLRs for five fish species worldwide (Table I.1 – Notes: *a*), for 10 species for the Eastern Atlantic (Table I.1 – Notes: *a* + *b*), and for 12 species for the Cape Verde Archipelago (Table I.1 – Notes: *a* + *b* + *c*). Furthermore, the study provides additional WLRs for 11 species of Cape Verde waters, based on a wider size range and seasonal coverage (Table I.1 – Notes: *d*). As regards the TFLRs, this study provides the first reference for 23 species worldwide (Table I.2 – Notes: *a*), for 24 species for the Eastern Atlantic (Table I.2 – Notes: *a* + *b*), and for all 26 studied species for Cape Verde waters (Table I.2 – Notes: *a* + *b* + *c*). Ideally, these results will contribute to future weight and length reconstitutions, diet studies, life history comparisons, biomass estimations and stock assessments.

ANNEX II

Underwater Species Identification Guide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1
Palythoa caribaeorum
Coral
Encrosting colonial anemone
Cerianthidae sp.
Cerianto
Tube anemone
Telmatactis cricoides
Anémona-gigante
Club-tipped anemone
Favia fragum
Coral
Golfball coral
Eudistoma santamariae
Ascidea-colonial
Ascidea
Clavelina sp.
Clavelina
Bluebell sea squirt
Clathrina coriacea
Esponja-do-mar
Sponge
Millepora alcicornis
Coral-de-fogo
Fire coral
Porites astreoides
Coral
Hard mustard coral
Leptogorgia capverdensis
Gorgónia
Gorgonian
Leptogorgia viminalis
Gorgónia-amarela
Yellow sea fan
Tubastrea aurea
Coral
Sun coral
Tanacetipathes spinescens
Coral-negro
Black coral
Eunicella sp.
Gorgónia
Gorgonian
LEGENDA
KEY
Frágil
Fragile
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2
Chromodoris purpurea
Nudibrânquio
Nudibranch
Tambja fantasmalis
Nudibrânquio
Nudibranch
Hypselodoris picta verdensis
Nudibrânquio
Nudibranch
Chromodoris rolani
Nudibrânquio
Nudibranch
Pleurobranchus garciagomezi
Nudibrânquio
Gomez snail
Dendrodoris senegalensis
Nudibrânquio
Nudibranch
Flabellina arveleoi
Nudibrânquio
Nudibranch
Zonaria picta
Cipreia
Cowry
Erosaria spurca
Cipreia
Dirty cowry
Luria lurida
Cipreia
Fallow cowry
Volvarina taeniata
Gastrópode
Margin shell
Conus sp.
Conus
Cone shell
Aplysia dactylomela
Lesma-do-mar
Annulated sea hare
Octopus vulgaris
Polvo
Commun octopus
Sepia officinalis
Choco
Cuttlefish
LEGENDA
KEY
Perigo
Danger
SIA
IPIMAR
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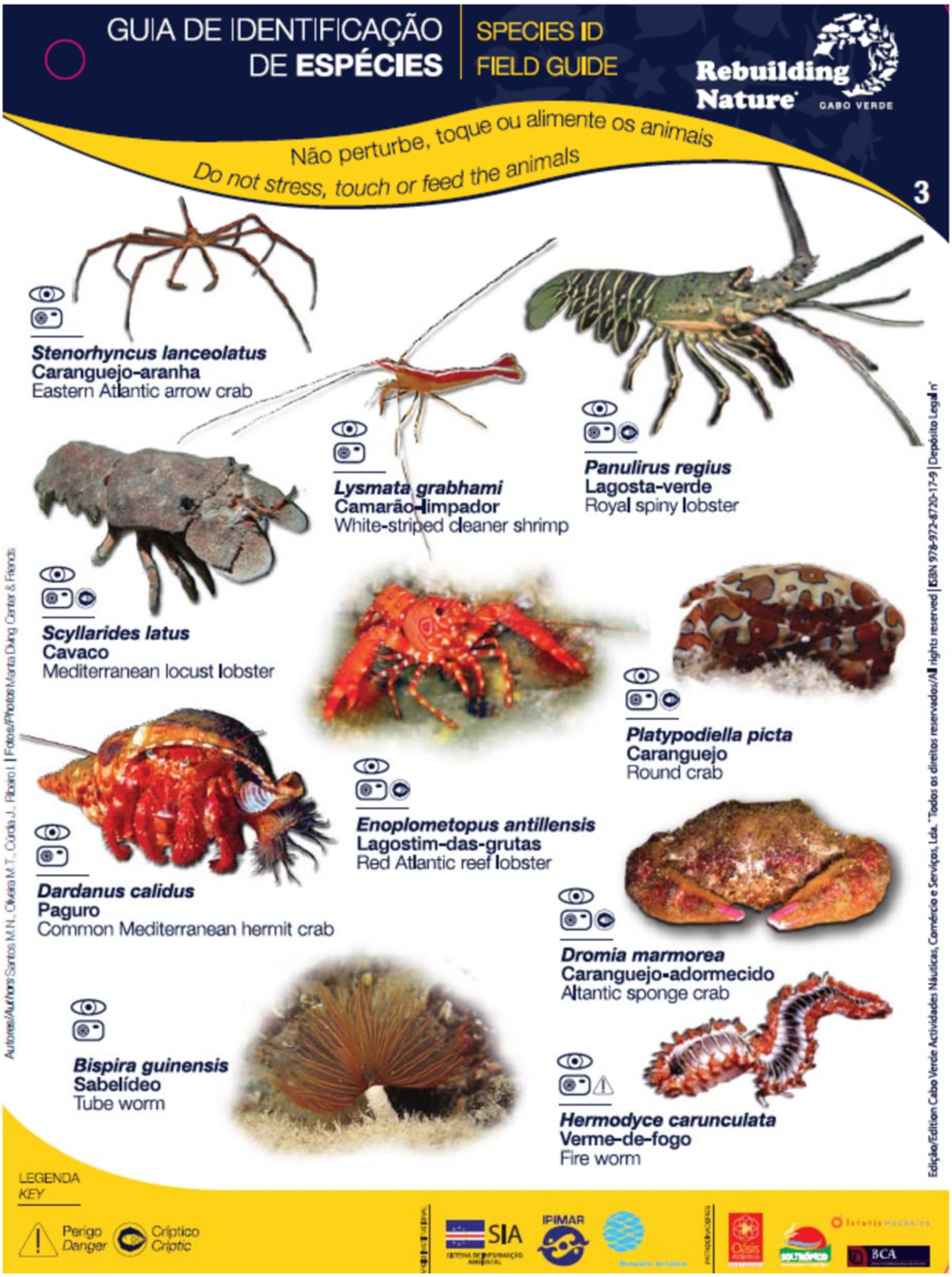
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3
Stenorhyncus lanceolatus
Caranguejo-aranha
Eastern Atlantic arrow crab
Lysmata grabhami
Camarão-limpador
White-striped cleaner shrimp
Panulirus regius
Lagosta-verde
Royal spiny lobster
Scyllarides latus
Cavaco
Mediterranean locust lobster
Platypodiella picta
Caranguejo
Round crab
Enoplometopus antillensis
Lagostim-das-grutas
Red Atlantic reef lobster
Dardanus calidus
Paguro
Common Mediterranean hermit crab
Dromia marmorea
Caranguejo-adormecido
Altantic sponge crab
Bispira guinensis
Sabelídeo
Tube worm
Hermodyce carunculata
Verme-de-fogo
Fire worm
LEGENDA
KEY
Perigo
Danger
Críptico
Criptic
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4
Ophidiaster ophidianus
Estrela-do-mar
Purple sea star
Marthasterias glacialis
Estrela-do-mar
Spiny sea star
Linckia bouvieri
Estrela-do-mar
Bouvier's sea star
Echinaster sepositus
Estrela-do-mar
Red sea star
Goniaster tesselatus
Estrela-do-mar
Cushion sea star
Linckia guildingi
Estrela-do-mar
Common comet star
Oreaster clavatus
Estrela-do-mar
Pimple sea star
Euapta lappa
Pepino-do-mar
Beaded sea cucumber
Eucidaris tribuloides
Ouriço-do-mar
Slate pencil urchin
Diadema antillarum
Ouriço-do-mar
Black long spined sea urchin
Holothuria sanctori
Pepino-do-mar
Variable sea cucumber
LEGENDA
KEY
Perigo
Danger
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5
Aulostomus strigosus
Trombeta
Atlantic cornetfish
Fistularia tabacaria
Corneta-malhado
Cornetfish
Diodon hystrix
Peixe-ouriço
Spot-fin porcupinefish
Canthigaster rostrata
Peixe-balão
Caribbean sharpnose-puffer
Diodon holocanthus
Peixe-ouriço-de-crista
Long-spine porcupinefish
JUV
Holacanthus africanus
Peixe-anjo-da-Guiné
Guinean angelfish
Chaetodon robustus
Borboleta
Three-banded butterflyfish
Similiparma hermani
Pá-mané-de-rabo-branco
Cape Verde damsel
JUV
Abudefduf luridus
Castanheta-ferreira
Canary damsel
Abudefduf saxatilis
Castanheta
Sergeant major
Chromis lubbocki
Donzela
Lubbock's chromis
LEGENDA
KEY
Perigo
Danger
Cardume
School
SIA
IFIMAR
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6
Diplodus fasciatus
Sargo-preto
Banded seabream
Diplodus prayensis
Sargo-safia-de-Cabo-Verde
Two-banded seabream
Diplodus sargus lineatus
Sargo-legítimo
White seabream
Lithognathus mormyrus
Ferreira
Striped seabream
ViridIdentex acromegalus
Dentão-de-Cabo-Verde
Bulldog dentex
Diplodus puntazzo
Sargo-bicudo
Sharpsnout seabrean
Spicara melanura
Trombeiro-malha-redonda
Blackspot picarel
Cephalopholis taeniops
Garoupa-de-pintas
African hind
Rypticus saponaceus
Peixe-sabão
Soapfish
Umbrina canariensis
Calafate-das-Canárias
Canary drum
Mycteroperca fusca
Badejo
Island grouper
Epinephelus marginatus
Mero
Dusky grouper
LEGENDA
KEY
Cardume School
Críptico Criptic
Pelágico Pelagic
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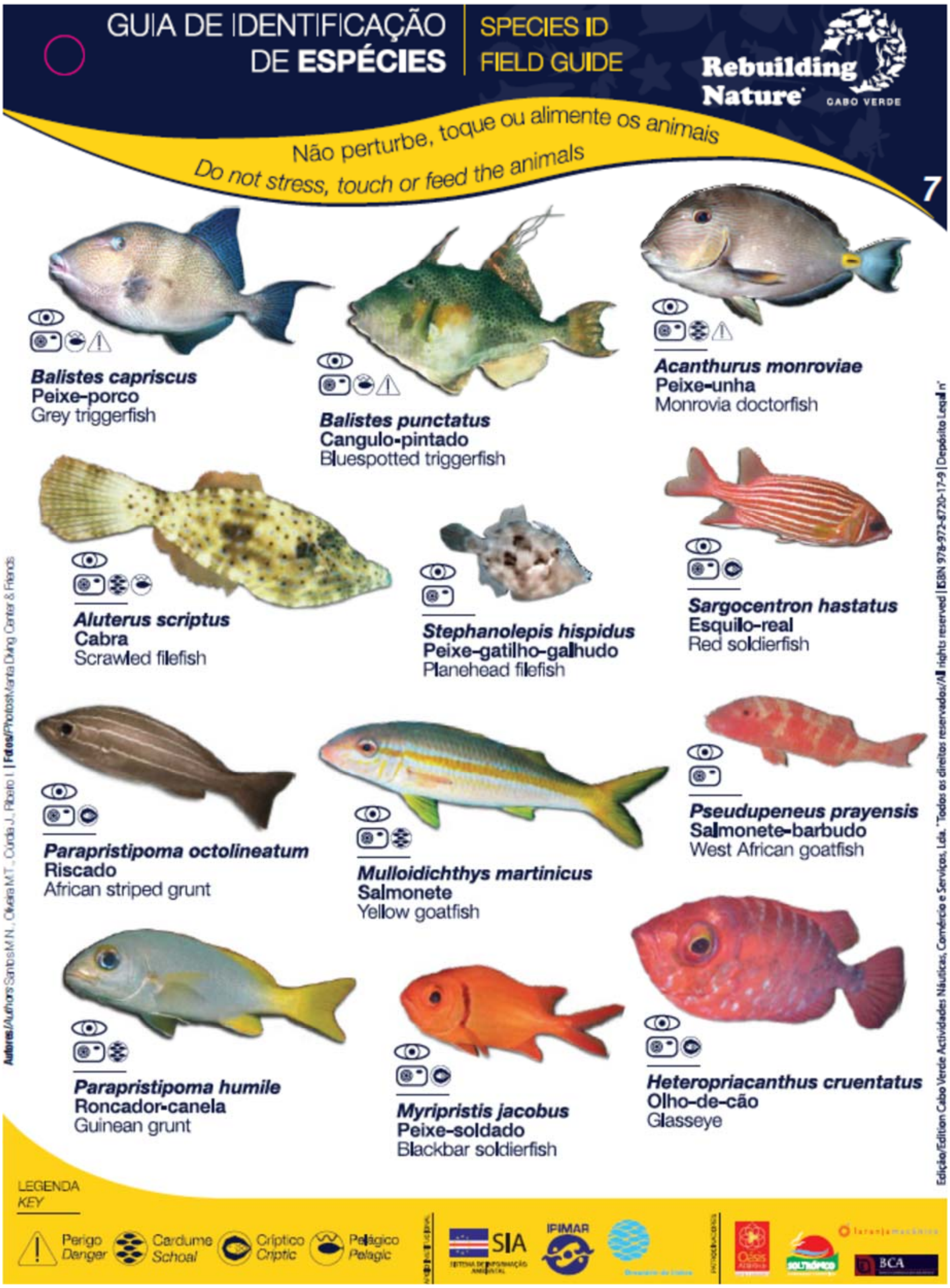
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7
Balistes capriscus
Peixe-porco
Grey triggerfish
Balistes punctatus
Cangulo-pintado
Bluespotted triggerfish
Acanthurus monroviae
Peixe-unha
Monrovia doctorfish
Aluterus scriptus
Cabra
Scrawled filefish
Stephanolepis hispidus
Peixe-gatilho-galhudo
Planehead filefish
Sargocentron hastatus
Esquilo-real
Red soldierfish
Parapristipoma octolineatum
Riscado
African striped grunt
Mulloidichthys martinicus
Salmonete
Yellow goatfish
Pseudupeneus prayensis
Salmonete-barbudo
West African goatfish
Parapristipoma humile
Roncador-canela
Guinean grunt
Myripristis jacobus
Peixe-soldado
Blackbar soldierfish
Heteropriacanthus cruentatus
Olho-de-cão
Glasseye
LEGENDA
KEY
Perigo Danger
Cardume Schoal
Críptico Criptic
Pelágico Pelagic
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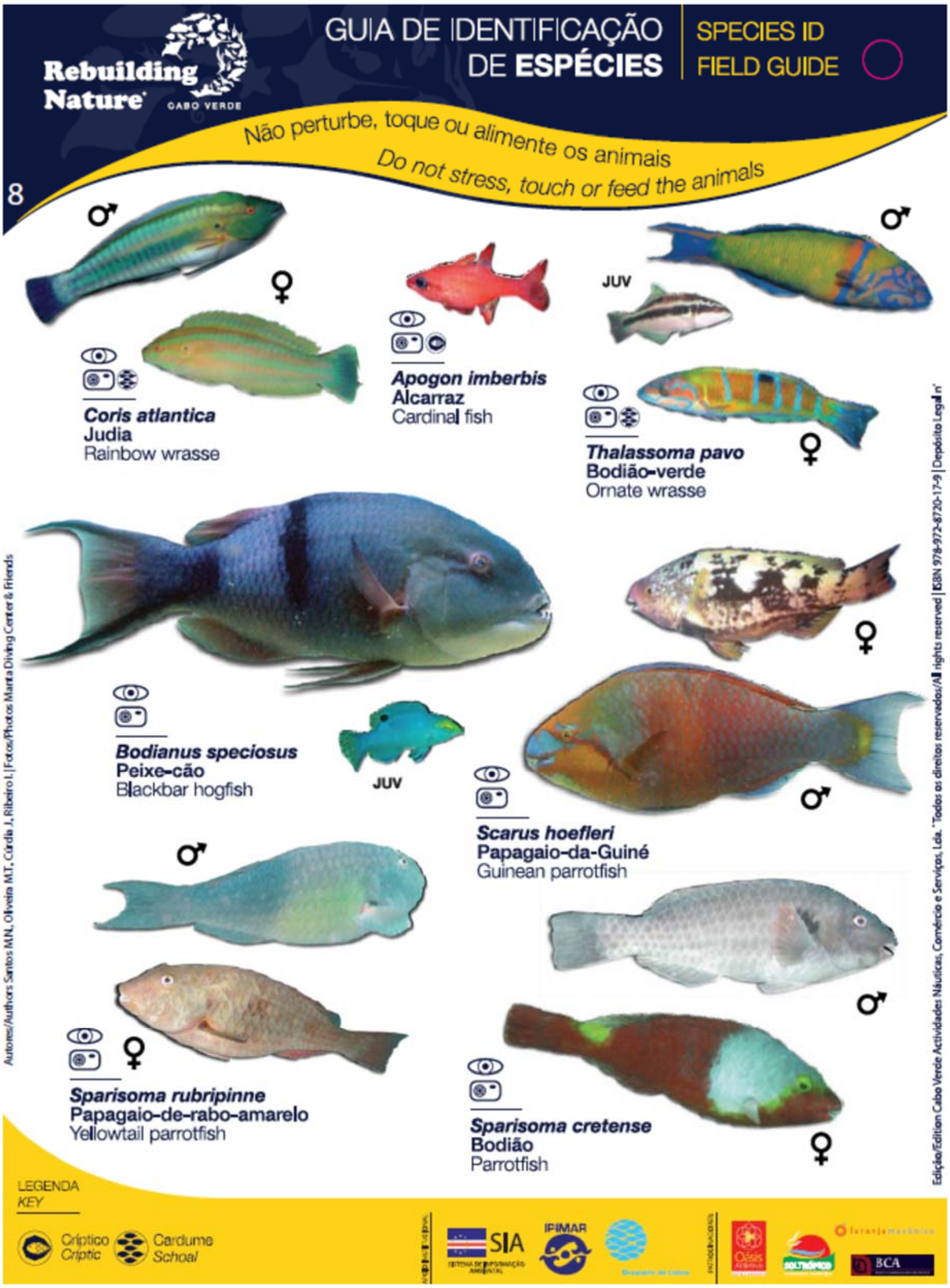
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8
Coris atlantica
Judia
Rainbow wrasse
Apogon imberbis
Alcarraz
Cardinal fish
JUV
Thalassoma pavo
Bodião-verde
Ornate wrasse
Bodianus speciosus
Peixe-cão
Blackbar hogfish
JUV
Scarus hoefleri
Papagaio-da-Guiné
Guinean parrotfish
Sparisoma rubripinne
Papagaio-de-rabo-amarelo
Yellowtail parrotfish
Sparisoma cretense
Bodião
Parrotfish
LEGENDA
KEY
Críptico
Criptic
Cardume
School
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9
Muraena melanotis
Moreia-pintada
Honeycomb moray
Gymnothorax miliaris
Moreia-dourada
Goldentail moray
Enchelycore nigricans
Moreão-negro
Mulatto conger
Muraena robusta
Moreia-congra
Stout moray
Gymnothorax vicinus
Moreão-amarelo
Purplemouth moray
Gymnothorax moringa
Moreia
Spotted moray
Synodus saurus
Lagarto-da-costa
Atlantic lizardfish
Antennarius pardalis
Peixe-sapo
Frogfish
Scorpaena sp.
Rascasso
Rockfish
Myrichthys pardalis
Cobra-leopardo
Leopard eel
Conger conger
Safio
Conger eel
Bothus podas
Carta
Wide-eyed flounder
LEGENDA
KEY
Perigo
Danger
Críptico
Criptic
SIA
IPIMAR
BCA
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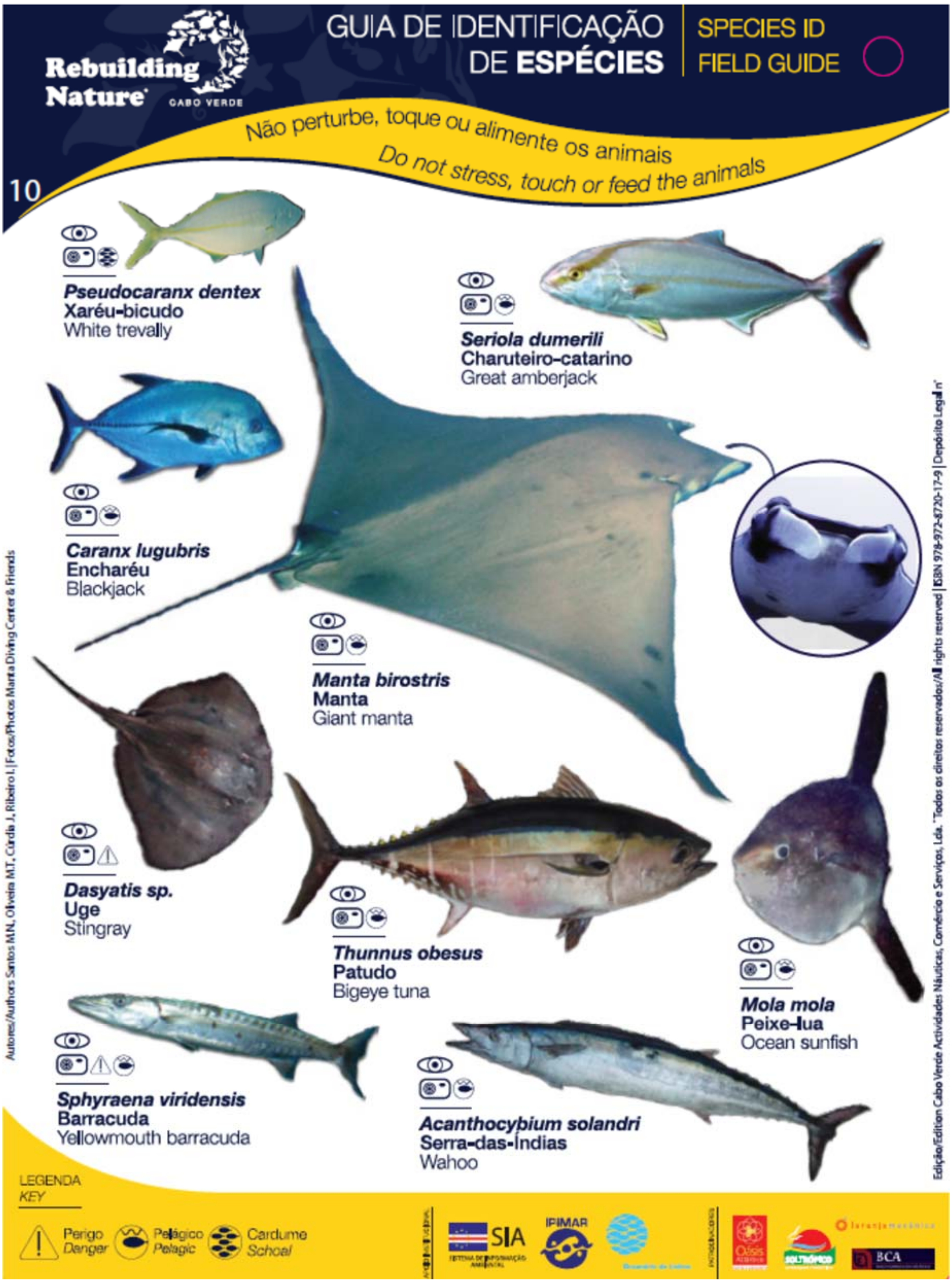
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10
Pseudocaranx dentex
Xaréu-bicudo
White trevally
Seriola dumerili
Charuteiro-catarino
Great amberjack
Caranx lugubris
Encharéu
Blackjack
Manta birostris
Manta
Giant manta
Dasyatis sp.
Uge
Stingray
Thunnus obesus
Patudo
Bigeye tuna
Mola mola
Peixe-lua
Ocean sunfish
Sphyraena viridensis
Barracuda
Yellowmouth barracuda
Acanthocybium solandri
Serra-das-Índias
Wahoo
LEGENDA
KEY
Perigo
Danger
Pelágico
Pelagic
Cardume
School
SIA
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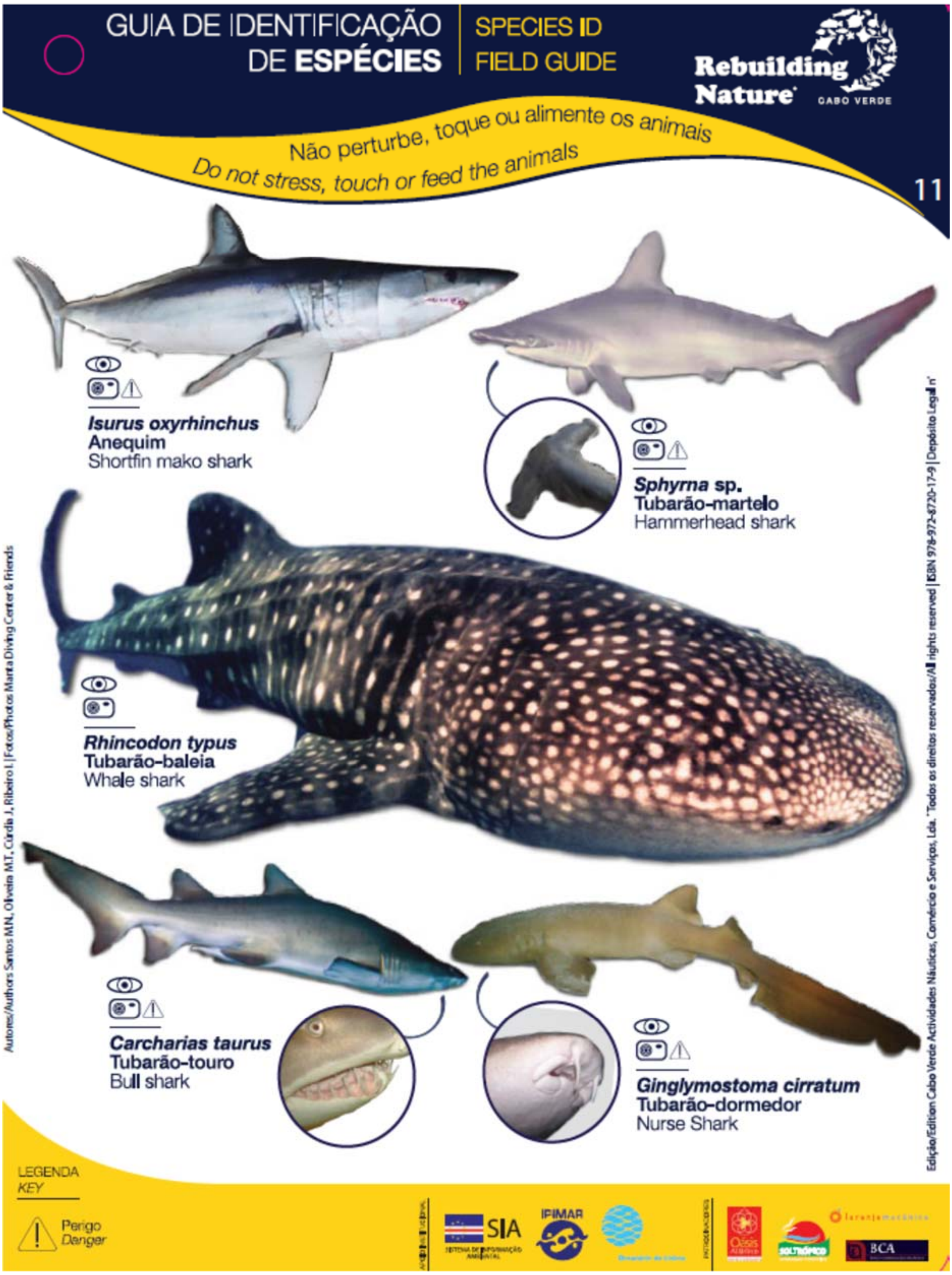
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11
Isurus oxyrhinchus
Anequim
Shortfin mako shark
Sphyrna sp.
Tubarão-martelo
Hammerhead shark
Rhincodon typus
Tubarão-baleia
Whale shark
Carcharias taurus
Tubarão-touro
Bull shark
Ginglymostoma cirratum
Tubarão-dormedor
Nurse Shark
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12
Caretta caretta
Tartaruga-boba
Loggerhead turtle
Lepidochelys olivacea
Tartaruga-verde
Olive Ridley sea turtle
Dermochelys coriacea
Tartaruga-de-couro
Leatherback turtle
Chelonia mydas
Tartaruga-verde
Green sea turtle
Eretmochelys imbricata.
Tartaruga-de-escamas
Hawksbill turtle
LEGENDA
KEY
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ANNEX III

Underwater routes

Oliveira *et al*, 2013a,b,c,d

KWARCIT UNDERWATER ROUTE

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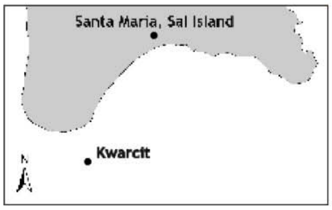
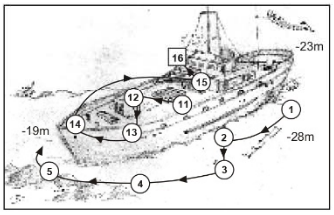
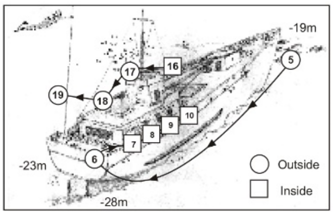
The below description is to help you discover Kwarcit, an ancient Russian fishing vessel (constructed in Leningrad in 1975) which was purposely sunk 6th January 2006 by Manta Diving Center within the scope biodiversity research project to assess the capacity of artificial reefs to mitigate biodiversity loss. The wreck can be found five minutes south-west of Santa Maria pier at a depth of 28 metres.
To help keep fauna that inhabit Kwarcit and ensure you have a safe dive, the Manta Diving Centre has set the below diving trail which highlights the structure of the ancient fishing vessel and biodiversity hotspots that can be found within this 30 minute dive:

- Upon reaching the site there is a buoy which we'll attach our boat to. Divers are to swim down the rope from the buoy which leads directly to the sunken fishing vessel;
- Once at the base of the rope which is attached to the rudder under the hull at the stern (back) of the vessel **(1)**, you will immediately find a variety of species such as White Seabream and Goatfish seeking refuge within the vessels shadows;
- Following along the port (left) side of the propeller, under the hull **(2)**, Sting rays, Spiny lobster and several small fish species can be found. As you swim along the port side of the vessel you will see on your left an old railing **(3)** which has fallen from the first deck. Here cryptic frog fish, arrow crabs and moray eels are commonly observed.
- As you continue towards the bow (front) of the vessel **(4)**, taking care not to damage the yellow and orange Gorgonians (Sea fan) and Sun corals, you may find some Red soldier fish and West African goat fish. Looking up to the mid-water you may encounter a variety of Jacks (Amber and Black) sometimes forming large shoals.
- Swimming round to the starboard side of the vessel back towards the stern **(5)**, you will find a small colony yellow sun coral (a soft coral) growing on the outside of the hull. Taking refuge deep under the hull of the vessel you may spot some Soapfish;
- As you return to the propeller, rise up to the deck level of the vessel **(6)**. Here various openings to the interior of the vessel can be found. Take care not to touch Fire worms, which carry a toxin which can burn you. If you peer through the first door on the left **(7)** you will see a well illuminated galley. If you look through the door, large Porcupine Glasseyes and the Banded seabream can be found looming in the dark towards the roof of the cabin.
- Following along the outside of the corridor on the first deck **(8)**, there is a second narrow opening which gives access to the lower deck, here the engine room fills this space. Within this space some debris covers the floor which Sharpnose puffer fish, Three banded butterfly fish and Guinean angelfish usually inhabit.
- On the third opening along the deck **(9)** large shoals of Guinean grunt and yellow goatfish can be found.
- Enter the fourth door which gives access to the main hall **(10)** and swim through to the port side of the vessel. Within this space you will see a door on the left which gives access to the galley and on the right the skipper's cabin (do not enter either of these doors as this space is too constricted).
- Exiting on the port side of the hall, swim towards the bow of the vessel. Here you will pass over the entrance of the fish stowage **(11)** where the catch was stored. It is possible to enter however not many species can be found here.
- As you continue swimming towards the bow you can find a beam **(12)** where small shoals of Rainbow and Ornate Wrasse can be found.
- At the bow on the deck level you can see some winches **(13)**. Here African hind groupers and Nudibranchs (sea slugs) are found seeking refuge. Further **(14)** Locust crabs can be found where the anchor chain used to pass through.
- Up a meter towards the bridge, you will pass over the hauler controller **(15)** which is now inhabitated by barnacles filter feeding worms and bryozoans.
- Swim through the starboard door leading into the bridge **(16)** where the captain would navigate the vessel. Within the bridge African goat fish and Guinanean grunt now inhabit. Within the crevices various Surgeon fish and moray eels shelter. Further to the left there are stairs leading down to the lower deck (do not swim down here).
- Once outside the bridge swim onto the roof of the bridge **(17)** where large shoals of small species such as Damsel fish and Lubbockies Chromis can be found.
- To finish the dive, swim up towards the chimney **(18)**, here you will see a variety of small nudibranchs (flabelina) and several species of Parrot fish.
- From here swim back to the stern and follow the rope **(19)**. Once back to the line swim back to the surface at your usual ascent rate.







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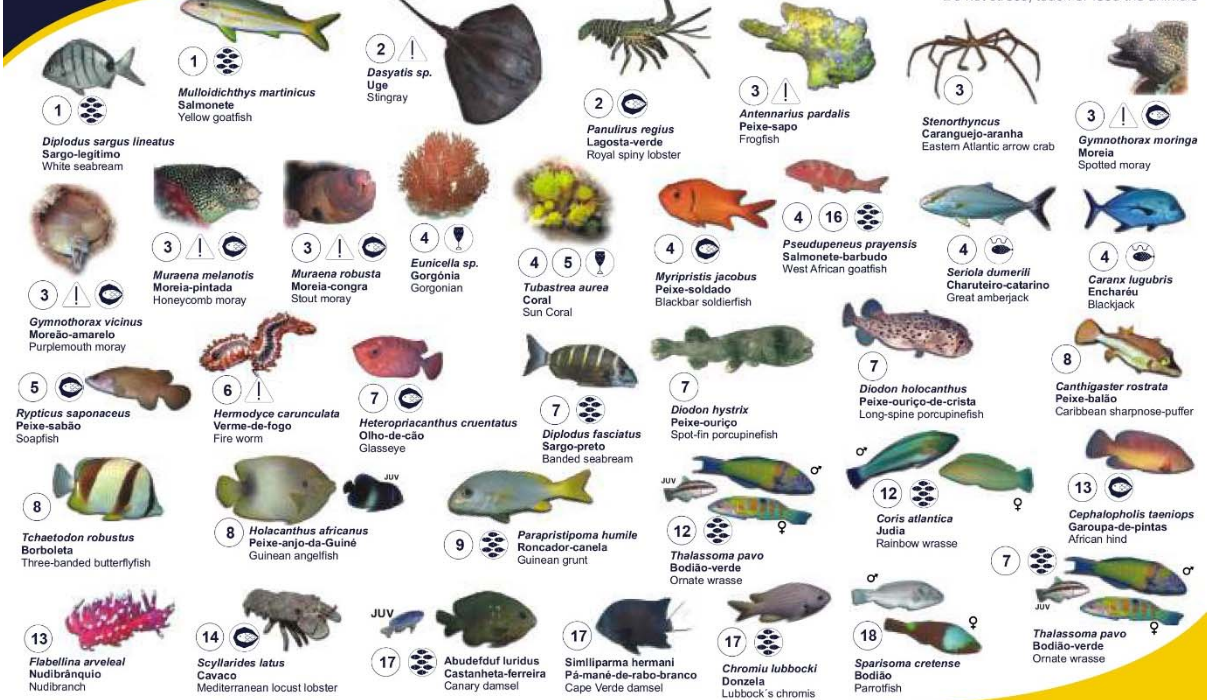

Key: Danger, School, Criptic, Pelagic

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SARGO UNDERWATER ROUTE

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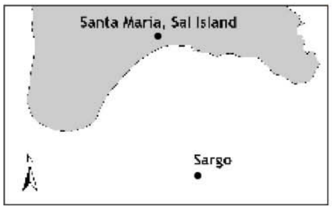
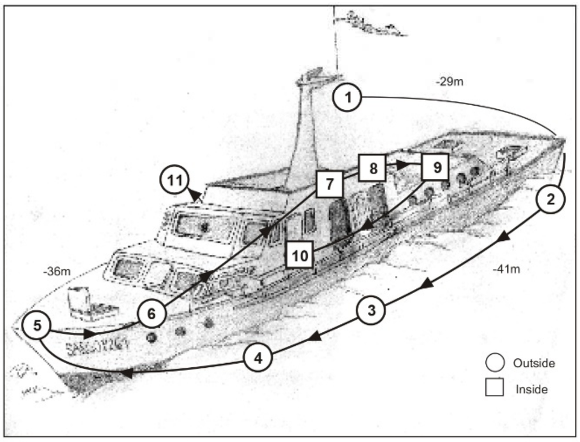


Sargo is a Coastguard patrol vessel which was purposely sunk on the 28th April 2008 by Manta Diving Center. The sunken vessel can be found at a depth of 34-41m one mile to the North-west of Santa-Maria bay. Due to the depth of this wreck, this dive usually takes 25minutes.

- As you descend down the line, you will reach Sargo slightly tilted to its port side where you will begin your dive **(1)**. Swim to the stern and look down, along the length of the hull, large rays can be found resting on the sand;
- At the stern of the vessel, where the rudder and propellers are found **(2)**, small animals such as the Spotted groupers, Breams and Rockfish can be found sheltering;
- As you continuing swimming down the port side of the vessel **(3)**, you'll pass a variety of sessile organisms such as small gorgonian, corals and sponges;
- As you reach the bow **(4)**, closer to the sand, Yellow Goatfish are seen. Here large green turtles have also been found. Ascending to the bow **(5)**, you find huge schools of Guinean Grunts;
- Continuing to the main deck **(6)**, close to the hatch, you will see that is an excellent habitat for arrow crabs.
- Within the cabin of the vessel **(7)**, many small Lubbock's Chromis seek refuge from predators;
- As you head towards the galley towards the stern, you wil be within the engine room **(8)**, Groupers and Moray eels can be seen.
- Continuing in the same direction we have a small cabin which was the dormitory for the crew **(9)** here there are two small hatches which give access to the locker and Wheelhouse **(10)**.
- Return towards the bow where you'll cross the bridge **(11)** that serves as a shelter for juvenile fish;
- Finally you will reach the mast **(12)**. Once back to the line swim back to the surface at your usual ascent rate.



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SARGO UNDERWATER ROUTE

Rebuilding Nature CABO VERDE

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1 *Dasyatis sp.*
Uge
Stingray

2 *Cephalopholis taeniops*
Garoupa-de-pintas
African hind

2 *Diplodus fasciatus*
Sargo-preto
Banded seabream

2 *Lithognatus mormyrus*
Ferreira
Striped seabream

2 *Scorpaena sp.*
Rascasso
Rockfish

3 *Eunicella sp.*
Gorgónia
Gorgonian

3 *Leptogorgia capverdensis*
Gorgónia
Gorgonian

3 *Clathrina coriacea*
Esponja-do-mar
Sponge

3 *Palythoa caribaeorum*
Coral
Encrosting colonial anemone

4 *Mulloidichthys martinicus*
Salmonete
Yellow goatfish

4 *Chelonia mydas*
Tartaruga-verde
Green sea turtle

5 *Parapristipoma humile*
Roncador-canela
Guinean grunt

6 *Stenorthyncus*
Caranguejo-aranha
Eastern Atlantic arrow crab

7 *Chromiu lubbocki*
Donzela
Lubbock´s chromis

8 *Mycteroperca fusca*
Badejo
Island grouper

8 *Gymnothorax moringa*
Moreia
Spotted moray

Key: Danger, School, Criptic, Pelagic

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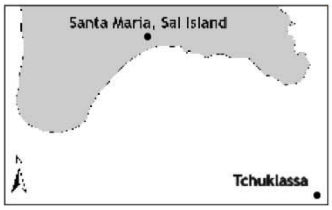
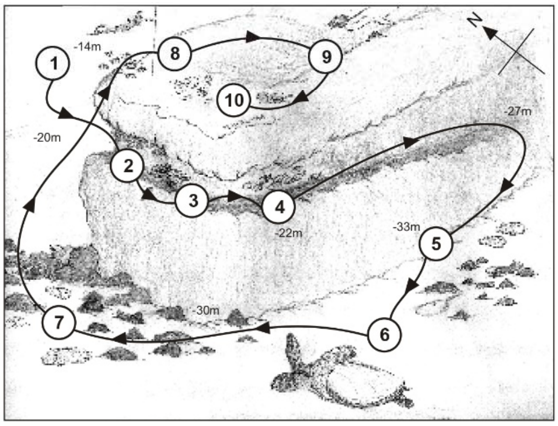
TCHUKLASSA UNDERWATER ROUTE

Rebuilding Nature CABO VERDE

Situated in the southeast of Santa Maria bay, two nautical miles off the coast, this natural reef begins in the channel between Sal and Boavista Island.
This is a medium to high difficulty dive with a depth range of 14-35m; a visibility of 15-40m; and medium to strong currents which contribute to Tchuklassa's high diversity of marine life.
The below descriptions outlines biodiversity hotspots that you can see along this interesting and diverse reef:

- Descending down the line, you will reach a plateau on the top of the reef; drop down off the reef onto the sandy bottom sea bed **(1)**, where you may be lucky enough to see some Nurse sharks resting.
- Swim towards the edge of the reef where there is a vertical drop leading to an overhang **(2)**, here you will find the roof covered by bright yellow Sun coral;
- Continue along the overhang, heading west with the wall on your left until you reach a 90 degree turn in the reef. Here you will find a new larger and longer overhang (approximately 40m) which is slightly more open. Between the two overhangs **(3)** large shoals of Guinean grunt fish and Sea breams seek protection from the strong currents.
- Continue descending along the overhang to a depth of 22m **(4)**, where you will see a huge shoal of Surgeon fish (careful not to touch them as the yellow mark on the base of the tail could cut you). Keep swimming along the overhang and check the diversity of species hiding between the yellow coral polyps and the Cornetfish on the walls;
- At about 27m of depth, exit the overhang and lower down onto some boulders, facing back the way you came (the reef should now be on your right hand side) **(5)**, where you may see some rays partially covered by sand or swimming close to the bottom, Lobsters, Moray eels and small Groupers, Soapfish, and a variety of puffer fish.
- On your left side (looking out to the water column) **(6)** you may see some pelagic species such as Tuna, Wahoo and different species of Jacks. You may also be lucky enough to see some Green turtles.
- Just before the starting point **(7)**, you will find some larger boulders in which you can find several Moray eels, and Wrasse.
- When you reach the point where you started the dive there will be another 90° turns along the wall, swim back along the narrow overhang until it ends. From here, swim up to a shelf **(8)** where you can find some Soldier fish. Look up to the water column and you might see Manta rays dancing or jacks hunting small pelagic;
- Continuing along the reef until you reach some small caves **(9)**, here nurse sharks sometimes rest;
- From here turn 180° back the way you came, however along the plateau **(10)** back to the line. Along this stretch of reef you will see Lobsters, Damsels, Butterfly and Lubbock's chromis fish hiding within the crevices.
- Once back to the line swim back to the surface at your usual ascent rate.





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TCHUKLASSA UNDERWATER ROUTE

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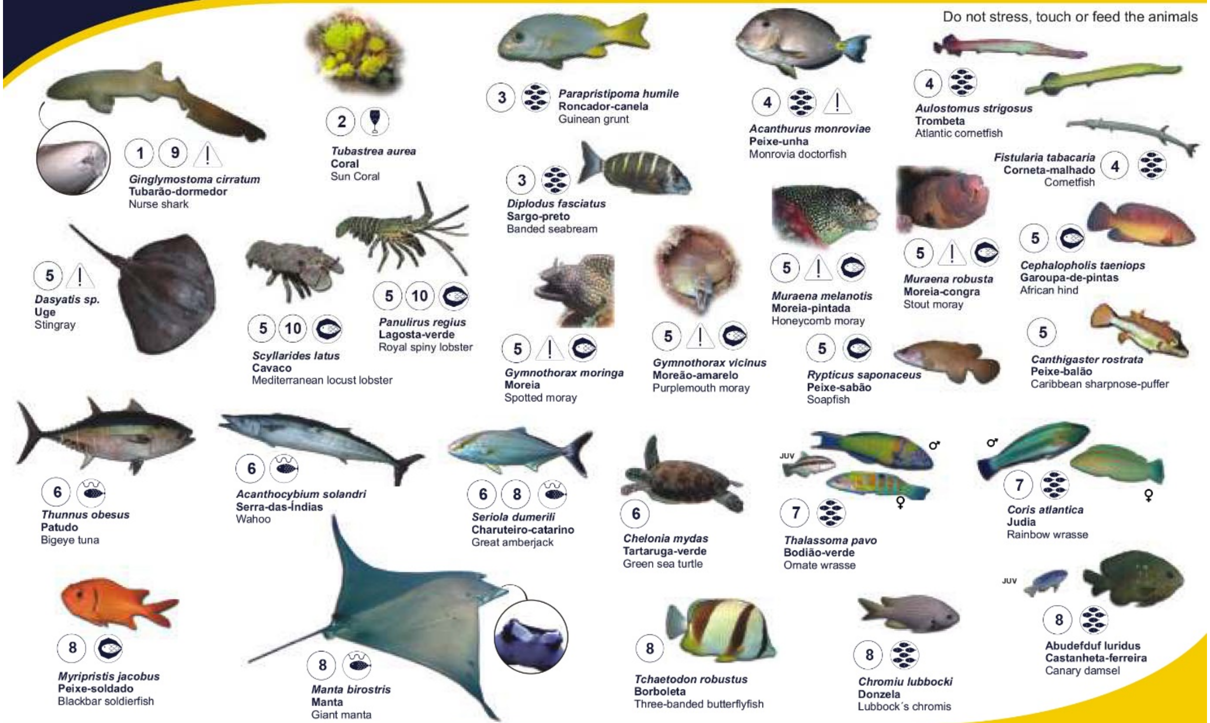

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TRÊS GRUTAS UNDERWATER ROUTE

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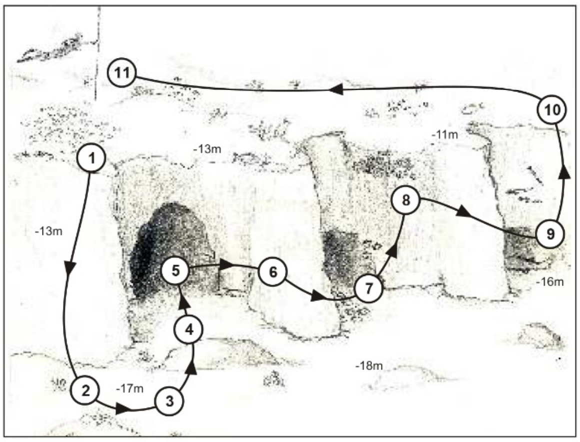
Três Grutas, meaning three caves. This is a fairly easy shallow and diverse dive consisting of 3 caves which can be entered and a fourth smaller caves. It is five minutes boat ride from the peer, located in the southwest cape of the island. The below outlines the route to see the best features of this dive:

- Follow the line down to the top of the reef **(1)**, where you'll pass some fairly large shoals of juvenile Lubbock's chromis;
- Heading east, leaving the wall to your left, you will pass a small rock **(2)** full of invertebrates such as Sea slugs and Arrow crabs. On the surrounding sandy seabed **(3)** you will see dark purple Sea squirts;
- Continuing along the base of the wall you will reach a narrow cave, take care to avoid the Black and Fire coral, if touched they will give you a burning sensation. Approaching the first cave you will see a small rock in front of the cave's entrance **(4)**, here you may see small Goldentail moray eels and Soapfish. Inside **(5)** you may see small Sting rays and lobsters;
- Continuing along the wall outside the cave **(6)** you are likely to hear the crunching sound large specimens Parrot fish feeding;
- A little further on you will see a second small cave with a wide and low entrance **(7)**, here teams of Solider fish can be seen at the caves entrance and Glasseye fish hugging the walls of the cave;
- Following along the outside the cave where there is a low overhang **(8)** covered in Sun coral;
- Continuing on, you'll reach the third and larger of the three caves **(9)**, where large shoals of Blackbar soldier fish and numerous Cornet fish surround the entrance. At the base of the wall small Nurse sharks are sometimes seen. Leaving the cave, keeping the wall to your left, Long-spine porcupine fish and Three-banded butterfly fish. If you undertake a night dive, it is possible to see big green turtles hiding from predators here;
- As you continue along the wall, reaching shallower waters, swim up to the top of the reef **(10)** and turn back the way you came. On top of the reef there are plenty of crevices where encrusting colonial Anemones, Fire and Hard mustard coral grow and juvenile fish such as Red soldier, Sharpnose puffer fish and Canary damsels shelter;
- As you follow the edge of the reef you will make your way back to the line **(11)**. Once back to the line swim back to the surface at your usual ascent rate passing some Blackspot picarel.



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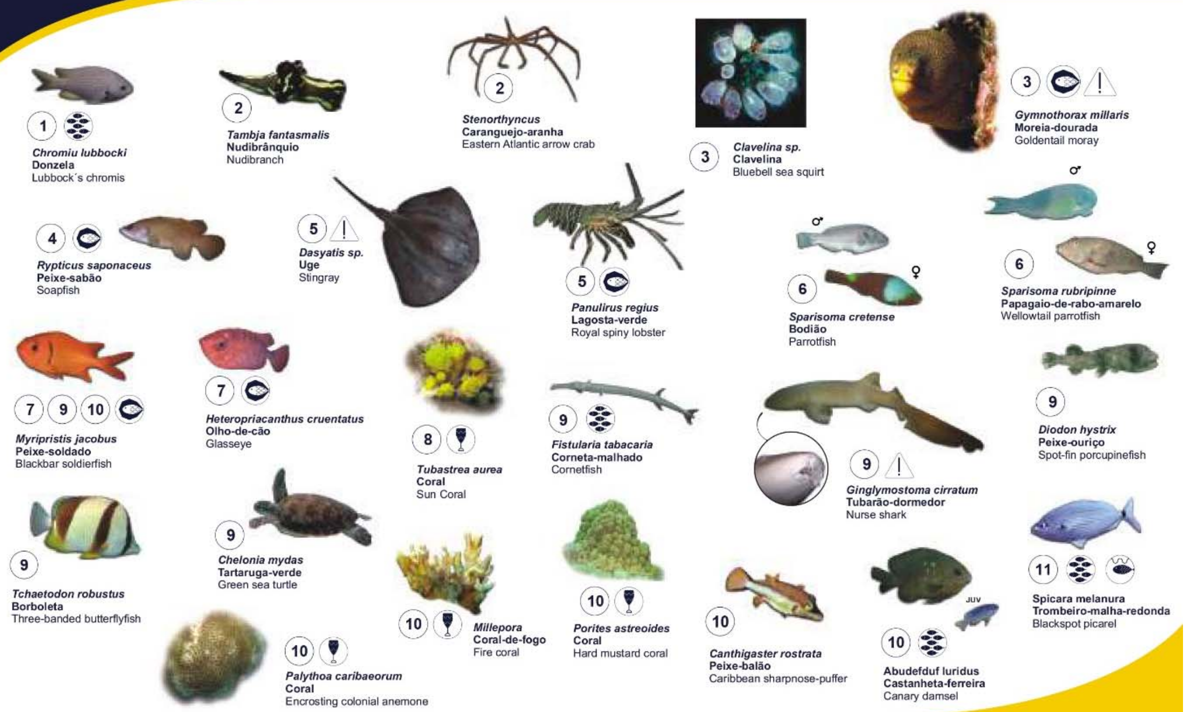

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