PROGRAMA DE PÓS-GRADUAÇÃO EM OCEANOGRAFIA AMBIENTAL
UNIVERSIDADE FEDERAL DO ESPÍRITO SANTO

UNIVERSIDADE FEDERAL DO ESPÍRITO SANTO
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PROGRAMA DE PÓS-GRADUAÇÃO EM OCEANOGRAFIA AMBIENTAL

GUSTAVO VAZ DE MELLO BAEZ ALMADA

IDENTIFICAÇÃO DE ÁREAS DE INTERESSE PARA A CONSERVAÇÃO DA BIODIVERSIDADE NA PORÇÃO PROFUNDA DA BACIA DE CAMPOS: FUNDAMENTO PARA UMA REDE DE ÁREAS PROTEGIDAS

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Orientador: Prof. Dr. Angelo Fraga Bernardino

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RESUMO

O Brasil, como signatário da Convenção sobre a Diversidade Biológica, está comprometido com a meta de incluir, até o ano de 2020, pelo menos 10% da área marinha sob jurisdição nacional em um sistema representativo de áreas protegidas. Contudo, atualmente no Brasil as áreas marinhas protegidas representam apenas 1,5% do total. Este estudo tem o objetivo de identificar áreas de interesse para conservação da biodiversidade bentônica na porção profunda (profundidade > 200 m) da Bacia de Campos, principal bacia produtora de petróleo no Brasil. Empregando habitats bentônicos como *proxies* para a distribuição espacial da biodiversidade bentônica, definiu-se como meta de conservação representar 30% da área de cada habitat presente na área de interesse em uma rede de áreas protegidas ecologicamente conectadas. A caracterização dos habitats bentônicos foi elaborada a partir de um esquema hierárquico, empregando *surrogates* abióticos que exercem grande influência na distribuição espacial da biodiversidade no mar profundo: profundidade; geomorfologia, granulometria e teor de carbono orgânico do sedimento. Como resultado, 42 tipos de habitats foram mapeados na área de estudo, sendo 21 caracterizados por talude continental sedimentar; 11 por cânion submarino; 6 por recifes de corais de águas frias; e 4 por monte submarino. O aplicativo Marxan foi usado utilizado para fundamentar o *design* de uma rede de áreas marinhas protegidas que apresentasse sobreposição mínima com as áreas concedidas para exploração e produção de hidrocarbonetos na Bacia de Campos, aplicando-se 3 cenários: 1 - sem restrições espaciais para o posicionamento das áreas protegidas; 2 - restringindo o posicionamento das áreas protegidas nas áreas concedidas à indústria do petróleo; e 3 - restringindo o posicionamento das áreas protegidas apenas em um raio de 5 km ao redor das plataformas de produção de petróleo e/ou gás natural. Ainda, no cenário 3, a diversidade da macrofauna foi utilizada como um critério secundário para o posicionamento das áreas protegidas, de modo a favorecer a seleção de áreas com maior diversidade. No cenário 1 foi atingida a meta de representação (30% da área) para todos os 42 habitats, mas a sobreposição das áreas protegidas com as áreas concedidas atingiu 60% da área total concedida dentro da área de estudo. No cenário 2 não houve sobreposição das áreas protegidas com as áreas concedidas, mas 15 habitats foram representados aquém da meta de 30%. No cenário 3 todos os habitats atingiram a meta de representação, enquanto a sobreposição com as áreas concidedas foi reduzida para 5,5%, enquanto a área total protegida foi de 31,3% da área de estudo. O resultado do cenário 3 fundamentou a proposição de uma rede de áreas marinhas protegidas, que pode ser um utilizada como ponto de partida para sua efetiva criação pelas autoridades brasileiras, preferenciamente de forma participativa, para potencializar seus benefícios ecológicos e sociais.

ABSTRACT

Brazil, as signatory to the Convention on Biological Diversity, is committed to the goal of protecting at least 10% of its marine area in a representative system of marine protected areas (MPAs) by the year of 2020. However, Brazil is currently protecting no more than 1.5%. This study aims to identify areas of interest for the conservation of benthic biodiversity in the deep portion (depth > 200 m) of the southeastern Brazilian continental margin, which is the main oil and gas exploitation area of Brazil. We have employed benthic habitats as a proxy for benthic biodiversity distribution, setting the representation of 30% of the area of all benthic habitats in the study area as the conservation goal. Habitats characterization was developed from a nested hierarchical scheme, utilizing abiotic surrogates that strongly influence biodiversity distribution in the deep sea: depth; geomorphology; sediment grain size; and sediment total organic carbon. As result, 42 habitat types were mapped in the study area: 21 characterized by sedimentary continental slope; 11 by submarine canyon; 6 by cold water coral reef; and 4 by seamount. Marxan software was used to support the design of a MPA network with minimal overlap to areas leased to the oil industry, applying three scenarios: 1 - without spatial constraints for location of MPAs; 2 - restricting MPAs location to non-leased areas; 3 - restricting the overlap of MPAs within a 5 km buffer around oil production platforms. Also, in scenario 3 benthic macrofaunal diversity was used as a secondary driver for the location of MPAs, in order to favor the selection of higher diversity areas. In scenario 1 it was possible to achieve the 30% representation target for all 42 habitats, but MPAs overlap with leased areas is 60% of the total leased areas within deep Campos Basin. In scenario 2 there was no overlap at all, but 15 habitat were represented below the 30% target. In scenario 3 all habitats achieved the 30% representation target while the overlap with leased areas was reduced to 5.5%, and still the total area for the MPA network is only 31.3% of the study area. The MPA network resulted in scenario 3 can be considered a good starting point for its effective creation by Brazilian authorities, preferably involving stakeholders in this process, in order to improve the ecological and social outcomes of biodiversity conservation.

Keywords: conservation, deep-sea, SW Atlantic, marine protected areas, habitats mapping, cold water coral reefs, oil and gas industry.

Palavras-chave: conservação, mar profundo, Atlântico sudoeste, áreas protegidas marinhas, mapeamento de habitats, recifes de corais de águas frias, indústria de petróleo e gás.

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I. INTRODUÇÃO

Em 2008 a conferência das partes da Convenção sobre a Diversidade Biológica, da qual o Brasil é signatário, reconheceu que há forte evidência indicando a necessidade de ação urgente para proteção da biodiversidade nos habitats bentônicos e áreas marinhas ameaçadas (CBD, 2008) e, em 2010, definiu como um dos alvos do Plano Estratégico para Biodiversidade 2011-2020 que até o ano de 2020 pelo menos 10% da área das águas costeiras e marinhas, especialmente áreas de particular importância para biodiversidade e serviços ecossistêmicos, estejam protegidas por meio de um sistema de áreas protegidas (meta de Aichi nº 11; CBD, 2010). Contudo, de acordo com o Cadastro Nacional de Unidades de Conservação, em atualização de fevereiro de 2014, apenas 1,5% da área marinha sob jurisdição nacional (compreendendo o mar territorial e a Zona Econômica Exclusiva – ZEE) está protegida por unidades de conservação (MMA, 2015). Considerando-se apenas as áreas sob regime de proteção integral, o percentual é de 0,14% (Magris et al., 2013). Em águas jurisdicionais brasileiras a representatividade de áreas do talude, sopé continental e planície abissal nas unidades de conservação é praticamente inexistente (MMA, 2015), e se limita a partes de unidades de conservação situadas majoritariamente sobre a plataforma continental, não existindo até o momento uma única unidade de conservação criada com objetivo principal de conservação de ecossistemas do mar profundo.

O mar profundo se inicia a partir da quebra da plataforma continental, normalmente entre 150 e 200 metros de profundidade (Kennish, 2001). Pode ser considerado o maior bioma do planeta, em termos de área, representando uma cobertura de mais da metade da superfície do globo terrestre (Garrison, 2012). Com exceção das fontes hidrotermais e *cold seeps*, onde há produção primária sustentada por microrganismos quimiossintetizantes, as assembléias biológicas no mar profundo são dependentes do aporte de matéria orgânica proveniente das camadas superiores do oceano, fundamentalmente na forma particulada. O mar profundo é compartimentado no tempo e no espaço por diversos fatores ambientais, dentre os quais pode-se destacar: o aporte de matéria orgânica; variações na intensidade e direção das correntes de fundo; correntes de turbidez; variações nas concentrações de oxigênio dissolvido; dentre outros gradientes ambientais (Glover et al., 2010). As diferentes condições biogeoquímicas do leito, em associação com diferentes condições físico-químicas da coluna d'água, resultam em habitats com características peculiares nos ambientes do mar profundo, sendo estes ocupados por comunidades biológicas igualmente singulares e únicas destes habitats. De modo geral, o talude continental é caracterizado por um pronunciado gradiente batimétrico e, consequentemente, as condições ambientais ao longo deste gradiente também são influenciadas por gradientes dos parâmetros covariantes, como temperatura, massas d'água e aporte de carbono orgânico particulado (Levin et al., 2001). Estes gradientes, em conjunto com as variações geomórficas e geoquímicas do leito marinho, tendem a promover a zonação das assembléias biológicas ao longo do talude, as quais apresentam diferentes composições faunísticas, sendo um dos parâmetros de maior influência na estrutura das assembléias o aporte de carbono orgânico particulado (Carney, 2005), o qual diminui exponencialmente com o aumento da profundidade (Rex et al., 2006; Biggs et al., 2008).

Atualmente pode-se perceber que o mar profundo, ainda que pouco acessível às intervenções humanas de modo direto, está cada vez mais ameaçado pelos efeitos indiretos do desenvolvimento econômico e atividades industriais (Halpern et al., 2007). Dentre as fontes de impactos que resultam em contaminação e alteração da biota na coluna d'água e no leito marinho, pode-se citar a atividade petrolífera *offshore,* que foi considerada por Glover (2003) como uma das cinco principais ameaças aos ecossistemas do mar profundo. No Brasil, a produção petrolífera é concentrada no bioma marinho. Em setembro de 2015 os campos marítimos foram responsáveis por 93,3% da produção nacional de petróleo e 76,1% da produção de gás natural (ANP, 2015). A Bacia de Campos destaca-se nesse contexto como a principal bacia produtora de petróleo, com 64% da produção nacional, e segunda maior produtora de gás natural, com 28% da produção. Cabe destacar que o contínuo avanço tecnológico e a crescente demanda mundial por combustíveis estão "empurrando" as áreas de explotação de petróleo e gás cada vez mais para áreas mais profundas; atualmente já existem sistemas de produção em operação em lâmina dágua superior a 2.000 m. Consequentemente, a ameaça para os ecossistemas do mar profundo tendem a ser cada vez maiores e a abranger maiores áreas das margens continentais ao redor do planeta.

Contudo, a expressiva atuação da industria do petróleo na Bacia de Campos, iniciada na plataforma continental no início da década de 1970 e na porção profunda (profundidade >200 m) em meados da década de 1980, não foi acompanhada de um planejamento espacial adequado para garantir a manutenção da integridade, funcionamento ecológico e biodiversidade nos ecosistemas do mar profundo (Mariano & La Rovere, 2007). Ainda, o licenciamento ambiental das atividades de exploração e produção de petróleo em águas marinhas marimhas sob jurisdição brasileira só foi inciado em meados da década de 1990, quando o Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis - IBAMA criou o então escritório de licenciamento de atividades de petróelo e nuclear - ELPN. Na ausência de instrumentos de planejamento de larga escala, o licenciamento ambiental na prática tem sido o principal instrumento de controle ambiental para os empreendientos de exploração e produção de petróleo *offshore*, mas sua forma de atuação é fundamentada na análise da viabilidade e mitigação de impactos de projetos individuais. Nesse contexto, a gestão dos ecossistemas na escala espacial regional, de uma bacia sedimentar, acaba sendo prejudicada pela fragmentação das avaliações de impacto de cada projeto, dificultando a interpretação dos impactos cumulativos e sinérgicos do conjunto de empreendimento sobre os ecossistemas afetados.

A legislação no Brasil prevê que impactos ambientais que não possam ser evitados ou mitigados devem necessariamente ser compensados. Cordes et al. (*no prelo*) indicam que uma forma eficaz de compensar os impactos de atividades industriais que incidem em ecossistemas do mar profundo é a criação de áreas protegidas. O planejamento sistemático de conservação (Margules & Pressey, 2000) destaca-se como um marco para concepção de áreas protegidas, pois representa a mudança de um paradigma de "beleza cênica" para uma abordagem ecossistêmica, onde as áreas protegidas passam a ser planejadas com base em representatividade, de forma a proteger toda a gama de biodiversidade presente em uma determinada região. Ainda, o planejamento sistemático de conservação tem como um de seus objetivo criar áreas protegidas representativas que causem o menor conflito possível com outras formas de uso dos espaços e recursos naturais para fins socioeconômicos, de modo que seus resultados sejam mais propensos à aceitação política. Portanto, é um processo que preferencialmente envolve os atores sociais envolvidos no uso dos espaços e recursos, de forma participativa.

Dado a atual ausência de proteção e manejo adequado para os ecossistemas do mar profundo no Brasil, a à crescente ameaça que a indústria do petróleo *offshore* representa para os ecossistemas do mar profundo, o presente estudo teve como objetivo identificar áreas de interesse para conservação da biodiversidade bentônica na porção profunda da Bacia de Campos, por meio da caracterização e mapeamento dos habitats bentônicos e da utilização de um *software* de suporte à decisão (Marxan v.2.4.3; Ball et al., 2009) para modelar o *design* de uma rede de áreas protegidas marinhas fundamentada na representatividade de habitats bentônicos e na minimização da sobreposição das áreas protegidas com as áreas concedidas para exploração e produção de petróleo e gás natural.

II. OBJETIVOS

Os objetivos do presente estudo estão divididos em duas etapas complementares, onde o resultado da primeira é utilizado como base para o desenvolvimento da etapa subsequente:

OBJETIVO 1

Caracterizar e mapear os habitats bentônicos na porção profunda da Bacia de Campos**.**

O mapeamento dos habitats bentônicos representa uma boa estimativa do padrão de distribuição da biodiversidade bentônica (Harris et al., 2008). No mar profundo, devido à imensa dificuldade logística e custos para se obter dados biológicos, é costumaz a utilização de parâmetros abióticos como *surrogates* para distribuição da biota (Huang et. al, 2010). Este objetivo trata de utilizar um conjunto de dados abióticos para a caracterização dos habitats.

OBJETIVO 2

Identificar áreas de interesse para a conservação da biodiversidade bentônica na porção profunda da Bacia de Campos.

A partir dos resultados obtidos na etapa inicial (mapeamento de habitats) utilizar o *software* Marxan v.2.4.3 para modelar *designs* de rede de áreas marinhas protegidas para a conservação da biodiversidade bentônica na porção profunda da Bacia de Campos. Este objetivo culmina com a proposição de uma rede de áreas marinhas protegidas, fundamentada em representatividade de habtiats e baixa interferência com as atividades de exploração e produção de petróleo.

III. CAPÍTULO ÚNICO (MANUSCRITO A SER SUBMETIDO PARA PUBLICAÇÃO DA PESQUISA EM PERIÓDICO)

A publicação de uma pesquisa é um objetivo supremo no contexto acadêmico. Considerando esta meta, a dissertação foi estruturada na forma de um manuscrito no padrão de submissão para publicação em periódico especializado. Este formato impõe limites ao número de palavras e de elementos gráficos (figuras e tabelas) que podem ser utilizados, mas por outro lado impele o pesquisador a ser seletivo com a informação a ser apresentada e objetivo na sua forma de apresentação, o que, com efeito, qualifica o produto gerado a partir pesquisa.

No manuscrito estão sintetizadas todas as informações relativas à pesquisa, incluindo introdução, métodos, área de estudo, resultados, discussão e referências, na forma e padrão a ser submetido para publicação em um periódico especializado em ciência marinha e mar profundo. O padrão escolhido para confecção do manuscrito foi o do jornal "Frontiers in Marine Science", seção "Deep-Sea Environments and Ecology", devido a relevância do presente estudo para a região do oceano Atlântico Sul. No padrão escolhido o limite de palavras é de 12.000 e 15 elementos gráficos. Contudo, o manuscrito final apresenta 6.220 palavras e 11 elementos gráficos (além de mais 5 elementos gráficos como material suplementar).

A fim de esclarecer a participação de cada autor no manuscrito, informa-se que os dois autores participaram de todas as etapas da pesquisa e elaboração do manuscrito, Gustavo Almada na condição de estudante de mestrado e Angelo Bernardino como respectivo orientador. Com objetivo de facilitar a leitura e interpretação, as figuras e tabelas que integram o manuscrito foram posicionadas no corpo do texto, ao invés de serem apresentadas em separado, conforme estabelecido no padrão adotado. A fim de preservar a qualidade das figuras, buscou-se representá-las com o maior tamanho possível. Entratanto, para isso foi necessário manter alguns espaços em branco ao longo do manuscrito. Contudo, cabe esclarecer que a diagramação definitiva é realizada pela editora do periódico nas etapas finais do processo de publicação. Todas as figuras que integram o manuscrito, inclusive as que constam como material suplementar, são apresentadas em alta resolução como anexos desta dissertação.

--------------- Início do manuscrito ---------------

Biodiversity conservation on the deep-sea oil fields of SW Atlantic: supporting a marine protected area network

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Abstract

This study aims to identify areas of interest for the conservation of benthic biodiversity in the deep portion (depth > 200 m) of the Campos Basin, on southeastern Brazilian margin, which is the main oil and gas exploitation area of Brazil. We have employed benthic habitats as a proxy for benthic biodiversity distribution, setting the representation of 30% of the area of all benthic habitats in the study area as the conservation goal. Habitats characterization was developed from a nested hierarchical scheme, utilizing abiotic surrogates that strongly influence biodiversity distribution in the deep sea: depth; geomorphology; sediment grain size; and sediment total organic carbon. As result, 42 habitat types were mapped in the study area: 6 characterized by cold water coral reef; 11 by submarine canyon; 4 by seamount; and 21 by sedimentary continental slope. Marxan software was used to support the design of a marine protected area (MPA) network with minimal overlap to areas leased to the oil industry, applying three scenarios: 1 - without spatial constraints for location of MPAs; 2 - restricting MPAs location to non-leased areas; 3 - restricting the overlap of MPAs within a 5 km buffer around oil production platforms. Also, in scenario 3 benthic macrofaunal diversity was used as a secondary driver for the location of MPAs, in order to favor the selection of higher diversity areas. In scenario 1 it was possible to achieve the 30% representation target for all 42 habitats, but MPAs overlap with leased areas is 60% of the total leased areas within deep Campos Basin. In scenario 2 there was no overlap at all, but 15 habitat were represented below the 30% target. In scenario 3 all habitats achieved the 30% representation target while the overlap with leased areas was

reduced to 5.5%, and still the total area for the MPA network is only 31.3% of the study area. We propose a MPA network based on the results of scenario 3, which can be considered a good starting point for its effective creation by Brazilian authorities, preferably involving stakeholders to improve its ecological and social outcomes.

1 Introduction

Continental margins host a diverse environment, with several ecosystems and habitats that are patchily distributed and supports high biodiversity and important ecosystems services to mankind (Levin & Sibuet, 2012; Thurber et al., 2014). The seafloor of continental margins have a marked spatial heterogeneity with a combination of geomorphic features (e.g. canyons; cold water coral reefs; seamounts, etc.) and strong vertical environmental gradients including depth, temperature and particulate organic carbon influx (Carney, 2005). The wide geomorphic and oceanographic conditions along continental margins support a number of ecosystems and habitats with their own biota and ecological patterns (Levin et al., 2001; Carney 2005; Menot et al., 2010). Continental margins are also a very important source of valuable resources including hydrocarbons, minerals and fish stocks, all of which are being increasingly targeted due to technological development and to the depletion of the current sources on land and on shallow waters.

Deep sea ecosystems are particularly sensitive to human impacts, given that the majority of species have slow growth, low recruitment rates and takes relatively a longer time to reproduce in comparison to species of shallower marine ecosystems (Ramirez-Llodra et al., 2010). As a result, deep sea ecosystems are less resilient to impact than many coastal and shelf ecosystems. The deep sea is becoming increasingly affected by direct and indirect anthropogenic impacts associated to economic development and industrial activities (Halpern et al., 2007; Ramirez-Llodra et al., 2011; Levin & Sibuet, 2012). Offshore hydrocarbon exploitation have become one of five major threats to deep sea ecosystems due to its growing expansion into deeper water depths (Glover & Smith, 2003; Davies et al., 2007; Kark et al., 2015). Around the globe, the offshore oil industry is subject to varying standards of environmental assessments and protection, which are related to the development level of each different nation. As a result, it is common that exploitation takes place without the appropriate level of environmental protection or compensatory actions to safeguard biodiversity and ecological processes, like the creation of marine protected areas (MPAs) (Cordes et al., *in press*).

Brazil has an extensive and a resource rich continental margin, with over 93% of the country's oil and 76% of natural gas production being exploited from offshore fields. Campos Basin, in the SE Brazilian margin, is the main production region, where exploitation began in the mid 1970's. In the last decades, deep sea ecosystems in Campos Basin and in many other deep sea basins off Brazilian margin are becoming increasingly threatened by the increasing industry's operational depth limit (which to date is already higher than 2000 m). Additionally, Brazilian regulations failed to recognize and manage the diversity of deep sea habitats prior to offering exploratory blocks at bidding rounds (Mariano and La Rovere, 2007), which resulted in leased areas in close proximity or with a high degree of overlap with many deep sea habitats of high biological and ecological relevance. A number of deep sea ecosystems of biological interest are present on Campos Basin within leased oil and gas fields and exploratory blocks, including submarine canyons and cold water coral reefs (Kitahara, 2007; Pires, 2007; Kitahara et al., 2009; Cordeiro et al., 2012). Cold-water coral reefs are specially common along Campos Basin (21º S to 24º S) in depths between 500 m and 1200 m (Arantes et al., 2009), with some reef formations reaching up to 900 m in length and 30 m in height. Additionally, there is evidence for highly diverse communities associated with slope sediments on the Brazilian margin, with marked bathymetric and regional differences associated to different water masses and productivity gradients (Costa et al, 2015; Bernardino et al., 2016). However, although there is significant scientific knowledge of Campos Basin's deep sea ecosystems and its oceanographic conditions, in part due to the long term industrial activities, there is no effective protection or management of those ecosystems and their biodiversity at a basin scale.

The important role of protected areas for biodiversity conservation is widely recognized by scientific community as well as policy makers, and Systematic Conservation Planning (SCP) (Margules & Pressey, 2000) stands out as a turning point in protected area design, grounding conservation on a ecosystem based approach and, at the same time, aiming to reduce conflicts of conservation initiatives with concurrent uses of space and natural resources for socioeconomic purposes. The SCP framework utilizes quantitative targets for the representation of the total variety of chosen conservation features (e.g. species, habitats, assemblages, spawning grounds, etc.) present on a given area and evokes transparency and stakeholders involvement, thus resulting in defensible outcomes more prone to political acceptance and general compliance. But managing deep seafloor resources, that including the biodiversity asset, is an enormous and difficult task along continental margins and on high seas international waters (Davies et al., 2007). As other nations with abundant offshore hydrocarbon reservoirs, Brazil currently has no systematic planning for biodiversity conservation allied to hydrocarbon exploitation (Kark et al., 2015). Consequently, environmental permits for the oil industry are focused at projects level, making it very hard, if possible, to manage the bigger picture and offer adequate protection at relevant ecological scales.

In the year of 2008 the conference of the parties to the Convention on Biological Diversity acknowledged the need for urgent action to protect biodiversity in threatened marine benthic habitats (CBD, 2008), while in the year of 2010 international marine conservation target was set: to protect a minimum of 10% of the area of coastal and marine ecosystems by the year of 2020 (Aichi target #11) (CBD 2010). However, Brazil is currently protecting 1.5% of the marine area under national jurisdiction, with only 0.14% comprising 'no take' areas (Magris et al., 2013). There is no representation of deep sea ecosystems in current MPAs in Brazil.

Given the current lack of proper protection and management practices for deep sea ecosystems in Brazil, and the growing activity of oil and gas industry towards deeper regions of Brazil's margin, we used an extensive oceanographic and biological database to: i) Characterize and map deep sea benthic habitats on the deep Campos Basin (200 m to 4000 m); and ii) identify areas of biological interest for conservation and design a MPA network with minimal interference on the ongoing hydrocarbon exploitation on the most productive basin of Brazil. We predict that a significant portion of biologically relevant habitats will be within the limits of oil and gas leased areas, evidencing the lack of conservation planning on Campos Basin. At the upper and middle slope of Campos Basin, we expect an accurate map to support realistic targets for a comprehensive conservation network, initiating a sound debate for management of deep sea ecosystems in the SW Atlantic.

2 Methods

2.1 Study Area

Campos Basin is located on the SE Brazilian margin under a tropical oligotrophic productivity regime (Gonzales-Silveira et al., 2004) with an area of 135.720 km^2 of deep sea habitats (depth >200 m). The slope of Campos Basin is under the western boundary current of the South Atlantic Subtropical Gyre (Stramma & England, 1999). The slope in the study region is influenced by four main water masses with distinct flow directions: (i) the South Atlantic Central Water (SACW; T= 18–6 °C) flowing northward between 300 and 550 m depth; (ii) Antarctic Intermediate Water (AAIW, T= 6–2 °C) flowing northward between 550 and 1200 m depth; (iii) North Atlantic Deep Water (NADW, T= 4–2 °C) flowing southward between 1200 and 3500 m; and (iv) Antarctic Bottom Water (AABW, T< 2 °C) flowing northward below 3500 m (De Madron and Weatherly, 1994). Campos Basin is subject to upwelling conditions (Aguiar et al., 2014; Palóczy et al., 2014) and to a intense mesoscale activity due to meanderings, eddies and vortex formations under influence of the Vitória-Trindade seamount chain (20 ºS) (Hogg & Owens, 1999), the Cabo de São Tomé (22 ºS) and the Cabo Frio (23 ºS) (Fernandes et al., 2009).

Over 60% of Brazil's hydrocarbon production comes from offshore fields located in the slope of Campos Basin, with recent reservoirs discovered on pre salt layers at water depths of over 2000 m. Exploration and production on the deep Campos Basin started in early 1980's, with no environmental regulation for the offshore operations at that time. By mid 1990's, Brazil's government began to regulate the industries, demanding Environmental Impacts Assessments (EIA) and long term monitoring. Currently, the continental slope on the deep Campos Basin is densely occupied by leased oil/gas fields (46) and exploratory blocks (8), and have over 50 floating platforms (including stationary production units and drilling rigs) and nearly 1500 drilled wells. The total leased area on depths >200 m is 11,137.7 km^2, covering over 47% of the bathyal region between 200 and 1500 m.

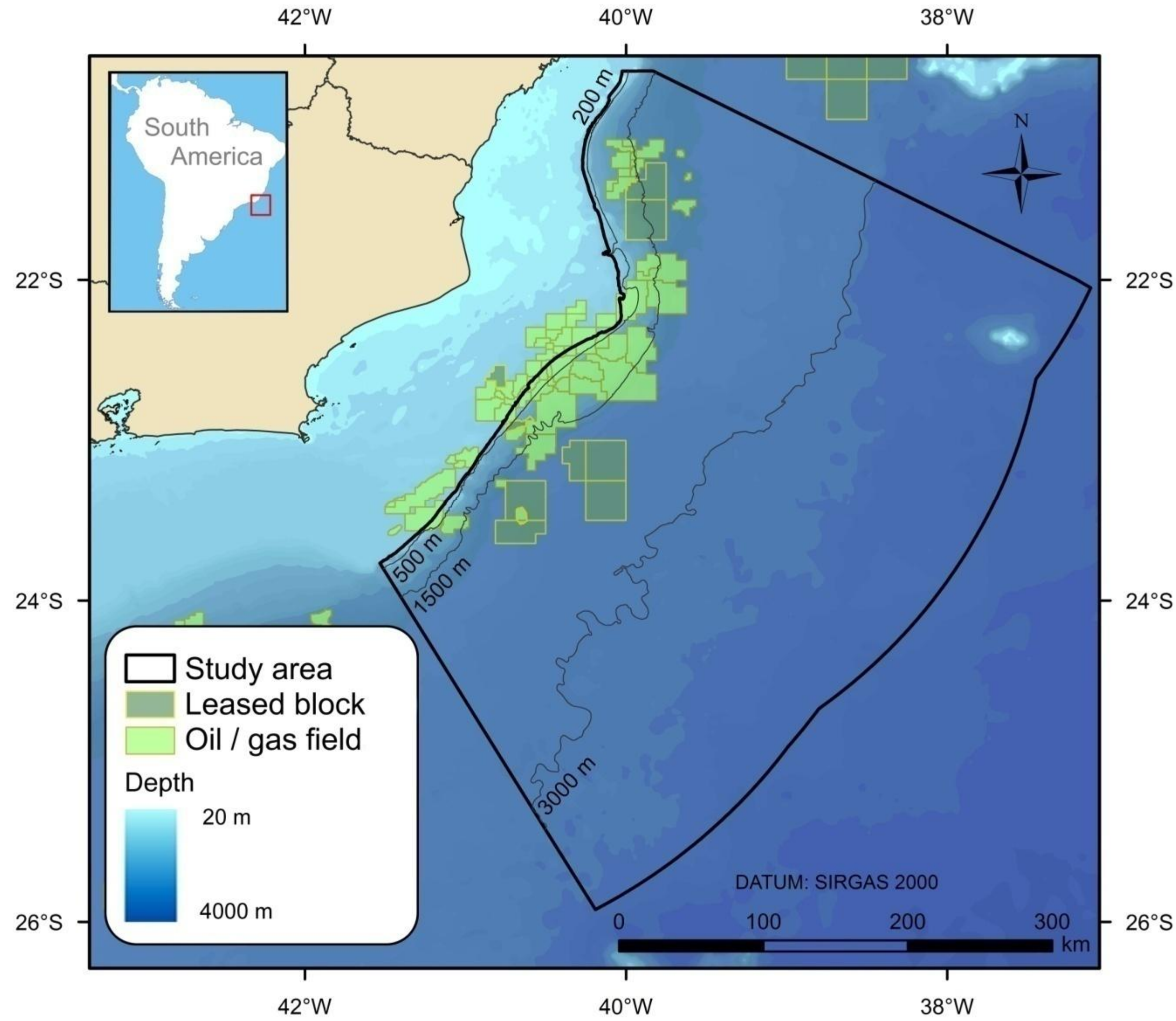

Figure 1: Map of deep Campos Basin (study area), detailing the current leased areas (exploratory blocks and oil/gas production fields). The northwestern boundary of the study area is the 200 m isobath and southeastern boundary is the Brazilian Exclusive Economic Zone limit.

2.2 Dataset

This study was based on an extensive environmental and biological dataset available from the IBAMA environmental agency, comprising a baseline characterization named 'Habitats' project, executed by Brazilian oil company Petrobras between 2008 and 2010. This project resulted in a broad baseline characterization of Campos Basin continental margin, as demanded for regulatory compliance. In this study we used geophysical, geochemical, sedimentary and biological data to characterize and map benthic habitats and support the design of a MPA network. Geochemical and biological data were obtained by box-corer sampling at 63 stations distributed along 9 transects across the slope, at depths of 400 m, 700 m, 1000 m, 1300 m, 1900 m, 2500 m and 3000 m (supplementary material - Figure S1). Geophysical and sedimentary data were a compilation of long term industrial surveys, including a 3D mapping of seabed and geomorphic features, including location and extent of reflective substrate interpreted as cold water coral reefs obtained from side scan sonar, multibean and 3D seismic. Additional bathymetric *shapefile* based on SRTM 30 data (Becker et al., 2009) was obtained from a public repository (CPRM/ANP, 2013), to represent the deepest portion of study area, not covered by the 'Habitats' database. Leased areas *shapefile* was obtained directly from Brazilian oil regulatory agency website (ANP, 2015), representing the leased areas as on September 2015.

2.3 Habitat mapping

Benthic habitats can be interpreted as areas of the seabed with singular combinations of physical, chemical and biological variables (Lecours et al., 2015). As Systematic Conservation Planning demands quantitative inputs to support quantitative goals, we have used benthic habitats as proxies for benthic assemblages, thereby setting habitat area as the conservation metric. The habitat characterization was based on abiotic surrogates for biological communities (Roff et al., 2003; Harris et al., 2008; Last et al., 2010; Huang et al., 2011; Douglass et al., 2014). We employed a habitat classification scheme fundamentally based on the hierarchical framework presented by Last et al. (2010). This framework relies on a top-down approach, with nested levels of classification, each level reflecting the processes that drives the biodiversity distribution at the respective spatial scale.

The identification of benthic habitats was carried by combining GIS layers representing each level of the classification scheme, employing a supervised approach to establish classes in each level, as performed by Roff et al. (2003). The datasets supporting each level were summarized into a single data layer (*shapefile*), in which the classes were represented as one or more polygons. The definition of the numbers of levels to be applied on the classification scheme and the choice of variables to be used as surrogates for each level mostly depends on the spatial scale addressed and on the environmental complexity of the study site. In this study we used four levels on the classification scheme due to the relative reduced spatial scale of the deep Campos Basin (Table 1). This is an adaptation of the continental scale classification system presented by Last et al. (2010). However, our four level classification yielded a habitat map with a spatial resolution of hundreds of meters, which should be adequate for spatial planning within the study area.

Table 1 - Habitat classification levels employed in the characterization of benthic habitats on the deep Campos Basin. TOC = total organic carbon.

Level 1 **Bathymetric zones**	**Level 2** **Geomorphic features**	**Level 3** **Sediment grain size**	**Level 4** **Sediment TOC**
200 - 500 m	continental slope	gravel	low (1.1 to 7.5 mg g^{-1})
500 - 1500 m	coral reef	sand	medium (7.6 to 12.0 mg g^{-1})
> 1500 m	canyon	mud	high (12.1 to 20.7 mg g^{-1})
	seamount	reef substrate	

Bathymetric zones was assigned to the first classification level (Table 1, Figure 2). The 3 classes within this level were selected to represent bathymetric changes in biological communities and thus include major transitions of faunal assemblages along the margin (Carney, 2005; McClain & Hardy, 2010; Costa et al., 2015). The selected bathymetric zones also match the range of major water masses along the slope that may drive benthic assemblage composition (Stramma & England, 1999; Arantes et al., 2009; Bernardino et al., 2016).

The second classification level was represented by geomorphic features (Table 1, Figure 2), representing large scale (>100 meters) geomorphic and structural seafloor heterogeneity on Campos Basin. For this level only conspicuous features that notably change biological assemblages were considered (a proxy for biological uniqueness, Clark et al., 2014), as ground truthing was not available for all the interpreted geomorphic features in the available dataset. Therefore, only submarine canyons (Schlacher et al., 2010), cold water coral reefs (Kitahara, 2007) and seamounts (Taranto et al., 2012) were included on the level 2 GIS layer, while the remaining slope areas were conservatively classified as sedimentary slope. The cold water coral reef dataset was originally available in a resolution of meters, and therefore it was processed in a GIS environment prior to its inclusion on the level 2 data layer. In order to use the cold water coral reef location data at a resolution compatible with the study area scale, we first created a 200 m buffer around all polygons representing coral reefs and then all patches (polygons formed by the eventual overlapping of the 200 m buffers) with area < 1 km^2 were removed from the map, so that the final level 2 GIS layer only represented larger reefs or large areas of highly connected small reefs. The removed patches accounted for only 9% of the total area of patches generated in the first step of geoprocessing. Considering that conservation planning is area based, this processing was intended to direct conservation efforts towards the most connected areas of cold water coral reef occurrence.

Third classification level was represented by the sediment grain size (Table 1, Figure 2). Although sediment grain size alone cannot be considered a strong predictor for species diversity or distribution, it is correlated to other variables that affect assemblages structure (Snelgrove & Butman, 1994). This dataset was based on piston core samples (N= 678) and box-corer samples (N= 256) obtained by Petrobras on the deep slope of Campos Basin along the last decades and were characterized based on a simplified Shepard (1954) method, according to particle size of the predominant fraction on the surface sediment layer, as gravel (phi ≤ -1), sand (-1<phi< 4) and mud (phi ≥ 4). This dataset was processed by Petrobras in a GIS environment to generate a data surface covering the whole study area. In order to avoid potentially false heterogeneity in biological assemblages, variations in sediment grain size classes were not represented in areas of cold water coral reefs, and therefore all the area classified as 'cold water coral reef' on the level 2 GIS layer was classified as 'reef substrate' on the level 3 GIS layer.

Fourth classification level was defined as sediment total organic carbon (TOC) (Table 1, Figure 2), which is of great relevance to the benthic diversity and function on the deep sea (Carney, 2005; Rex et al., 2006). The sediment TOC dataset was derived from box-corer sampling along the basin and were interpolated by the inverse distance weighting method using ArcGIS 10.1 software to obtain a GIS *shapefile* covering the whole study area. TOC values were then classified, resulting in 3 classes relative to the mean value (9.9 mg g^{-1} dw) on deep Campos Basin: i) low (from 1.1 to 7.5 mg.g^{-1} dw); ii) medium (from 7.6 to 12.0 mg g^{-1} dw) and high (from 12.1 to 20.7 mg g^{-1} dw).

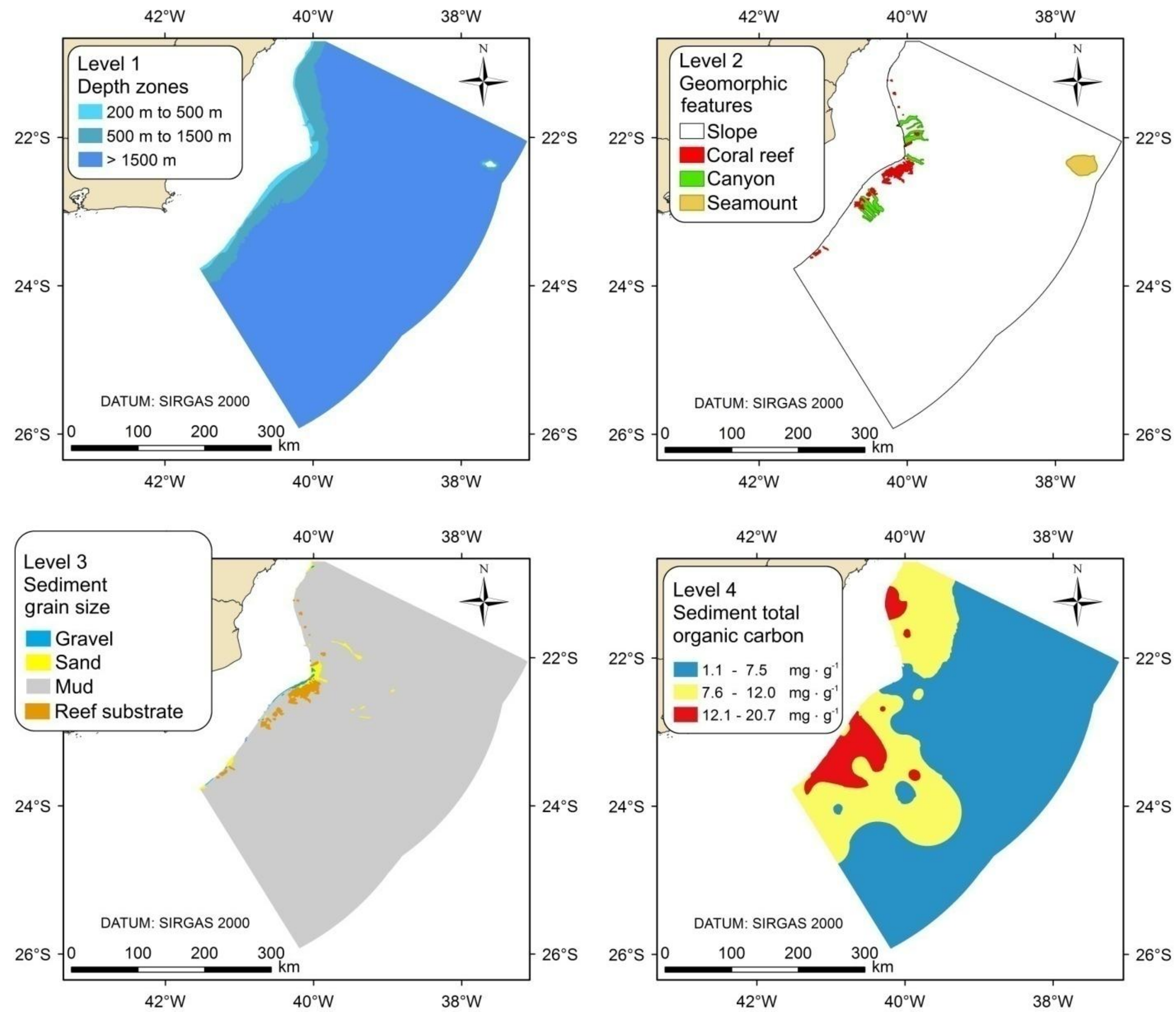

Figure 2: Representation of the variables employed on each level of the habitat classification scheme used in this study. Upper left: Level 1 - Bathymetric zones; Upper right: Level 2 - Geomorphic features; Lower left: Level 3 - Sediment grain size; and Lower right: Level 4 - Sediment TOC.

2.4 Identification of areas of interest for conservation (MPA network design)

In order to be politically acceptable, the conservation of deep sea ecosystems on Campos Basin must take into account the existing oil and gas industrial activities in the area (Kark et al., 2015; Cordes et al., *in press*). Therefore, we have adopted to use the Systematic Conservation Planning (SCP) framework as the basis for the identification of areas of interest for conservation (Margules & Pressey, 2000; Leslie, 2005; UNEP-WCMC, 2008; Pressey & Bottrill, 2009). Therefore, the outcomes of this study should be not only scientifically consistent, but it should also be politically acceptable. The SCP focus on representativeness and long term persistence of biodiversity, but the tradeoffs between conservation goals and productive and social costs are addressed in the protected area design process. In order to keep conflicts at the lowest possible level, the conservation targets should be met with the lowest possible interference with other concurrent space or resources uses. In the study area, we considered only oil and gas stakeholders directly competing for the allocation of marine space, as there were no available datasets to support the inclusion of fisheries on the present study. Nevertheless, deep bottom fisheries (i.e. trawling, gillnet and long line) are not the main source of impact on benthic habitats in the study area, given the spatial coverage of impacts associated with seabed infrastructure of the oil industries and drill cuttings in the deep Campos Basin. Also, the great majority of fishing effort is directed to the capture of pelagic fish stocks (Perez et al. 2009) and represent little threat to deep sea benthic habitats.

The conservation target was set to 30% of the area of each benthic habitat, based on the available guidelines (Soulé & Sanjayan, 1998; Agardy et al., 2003; Green et al., 2014), and also given that the 10% representation goal of the CBD's Aichi target might stand below the necessary amount to maintain the integrity of ecological processes. Applying the same target for all habitat type may not represent the optimum protection for each associated assemblage due to broad biological and ecological variability and due to variations in impact or stress levels (Johnson et al., 2014), but this precautionary approach may offer protection to a variety of threatened habitats within the study area (Bridge et al., 2016) and should be applied until more sampling and ecological studies become available to support a better management strategy.

Decision support software Marxan v.2.4.3 (Game & Grantham, 2008; Ball et al., 2009) was used to provide MPA design solutions that meet the conservation targets with minimal total area requirements (Leslie et al., 2003). For the Marxan analysis, the study area was divided into 5 km^2 hexagon shaped planning units (PUs), resulting in a total of 27,549 PUs. The PUs along the borders of the study area were clipped to produce a perfect fit to the study area. The PUs cost was set as proportional to its area and Marxan analysis was undertaken, after the calibration of the boundary length modifier, using 10^7 iterations on each run and 1000 runs for each scenario. The frequency of PUs selection (to integrate a MPA) along the 1000 runs of each scenario is a measure of PU irreplacebility for an efficient reserve design and can be considered a key Marxan output to support decision making (Game & Grantham, 2008).

Initially, two scenarios were compared for a MPA network. First, we tested how a MPA network would be designed if there were no spatial restrictions for MPA location (i.e. not considering current oil fields and leased exploration blocks nor any other spatial restriction in the design process). In the second scenario, protected area location was restricted so there would be no overlap with the existing oil fields and leased exploration blocks, thus representing the ecological outcome of an 'industry friendly' MPA network. Based on the findings of these two former scenarios, a third scenario was ran, aimed to maximize protection and minimize overlapping with leased area by restricting MPA location only within a 5 km buffer around the existing oil/gas production platforms. The 5 km buffer radius around oil production rigs is broadly intended to encompass the area needed by subsea infrastructure (mooring lines, wellheads, flow lines, manifolds, etc.), and is considered a realistic setback distance from most impacts associated with platform installation and operation (Cordes et al., in press). In this third scenario, the cost of PUs overlapping the remaining area of the oil/gas fields and leased blocks was increased by 100-fold, thus limiting the MPA overlap with leased areas to the minimum amount necessary to reach conservation targets (i.e. 30% of habitat area).

The MPAs location (site selection) in the third scenario was further refined based on a dataset of benthic biodiversity (i.e. soft sediment macrofaunal diversity based on Hulbert's rarefaction index). The cost of all PUs was scaled with macrofaunal diversity, favoring MPA site selection towards higher diversity areas. Mean Hulbert Rarefaction diversity (ES_{25}) was calculated for 56 triplicate box core samples and then interpolated by the inverse distance weighted method on ArcGIS 10.1, to create a *shapefile* covering the study area. ES_{25} values ranged from 3.6 to 34.9 (mean = 23; SD = 8.9), and the study area was divided into five ES_{25} classes (supplementary material - Figure S2).

Species diversity, genetic connectivity and dispersal patterns are important criteria to MPA networks design, but there is an enormous gap in knowledge of these patterns for deep sea assemblages (Hilario et al., 2015). As there is no relevant data to support an analysis of deep sea species connectivity in Campos Basin, we adopted a precautionary approach and addressed connectivity through MPA proximity. The top ten best solutions generated from the third scenario were checked for a threshold distance of 50 km between nearest neighboring MPAs on the network. This distance threshold was precautionary set to allow ecological connectivity between MPAs in the network, based on the limited evidence for connectivity in the deep sea (Hilario et al., 2015; Baco et al., 2016). Baco et al. (2016), working with several taxa, found evidence that *"connectivity in the deep-sea, on average, occurs on comparable to slightly larger spatial scales than in shallow water"*. This suggests that some of the available connectivity guidelines addressing coastal and shallow water ecosystems can be reasonably applied to the deep sea realm.

3 Results

3.1 Benthic habitats map

We mapped a total of 42 habitats within the study area (Figures 3 and 4); 15 located on the upper slope (200 - 500 m), 14 on the middle slope (500 - 1500 m) and 9 on the lower slope (>1500 m). The remaining 4 habitats are located on the Almirante Saldanha seamount, on the eastern Campos Basin. In order not to leave a gap in the habitat map, we have included all the area of the seamount in the habitat map by creating an additional bathymetric zone (depth <200 m) to cover its shallow summit. A total of 29 habitats (69% of habitats) are located within upper and middle slope depths, representing 8.2% of the study area. Most habitats (21) are associated to soft sediments on the slope, while 11 are associated to submarine canyons, 6 to cold water coral reefs and 4 to seamount (Table 2). Current leased areas overlaps with 29 habitats types, with 17 of these having over 66% of their total area within leased areas. Habitats associated to cold water coral reefs and submarine canyon are highly overlapped by leased areas (Table 3), given their higher concentration on the upper and middle slope (200 - 1500 m). Regarding habitats spatial distribution and coverage, the upper and middle slope (200 to 1500 m) can be depicted as far more heterogeneous and patchy than the deepest portions of the study area (Figure 4; supplementary material - Figure S3).

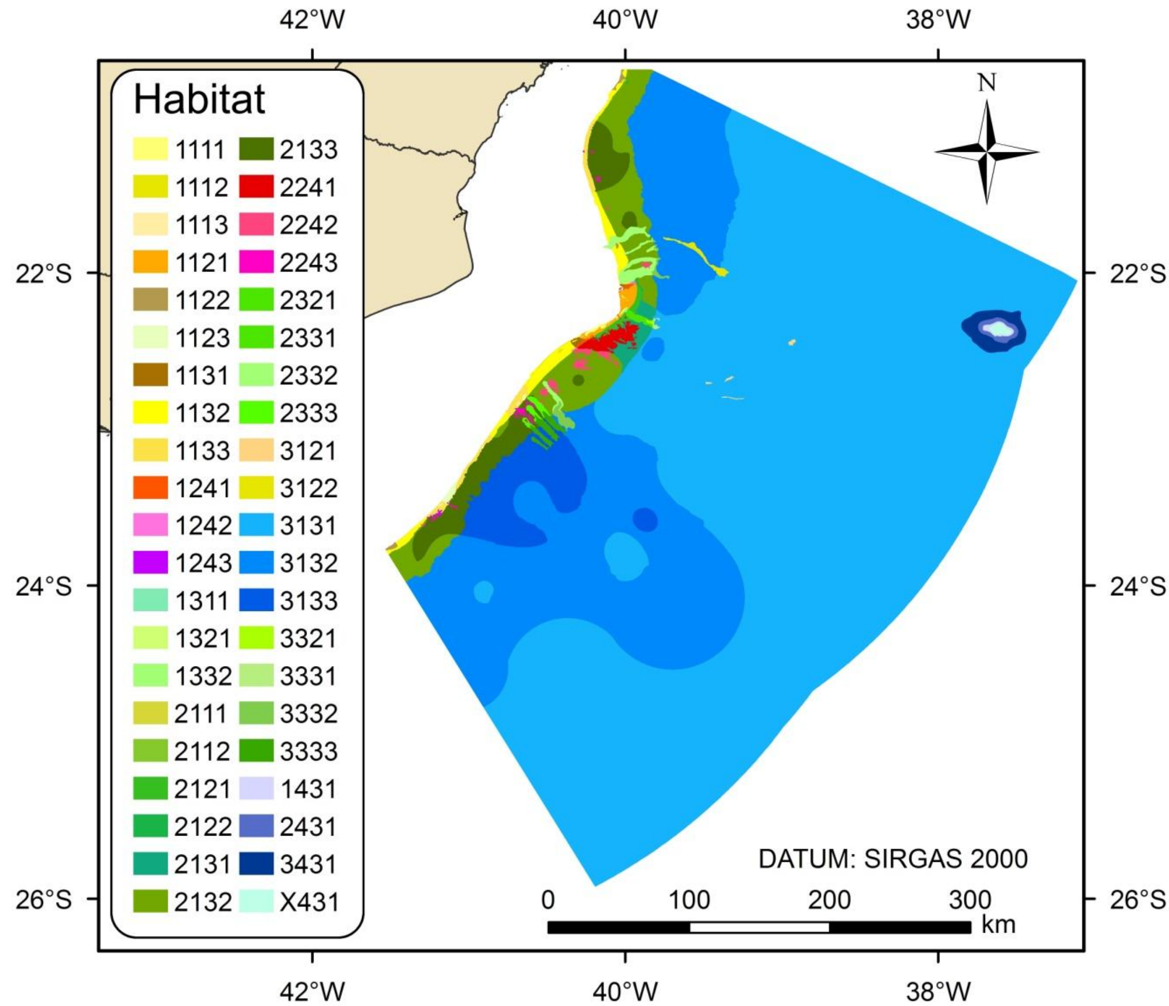

Figure 3: Benthic habitats map. Each habitat is a sole combination of classes in the 4 levels of the habitat classification scheme, represented by a four digit code (see Table 2).

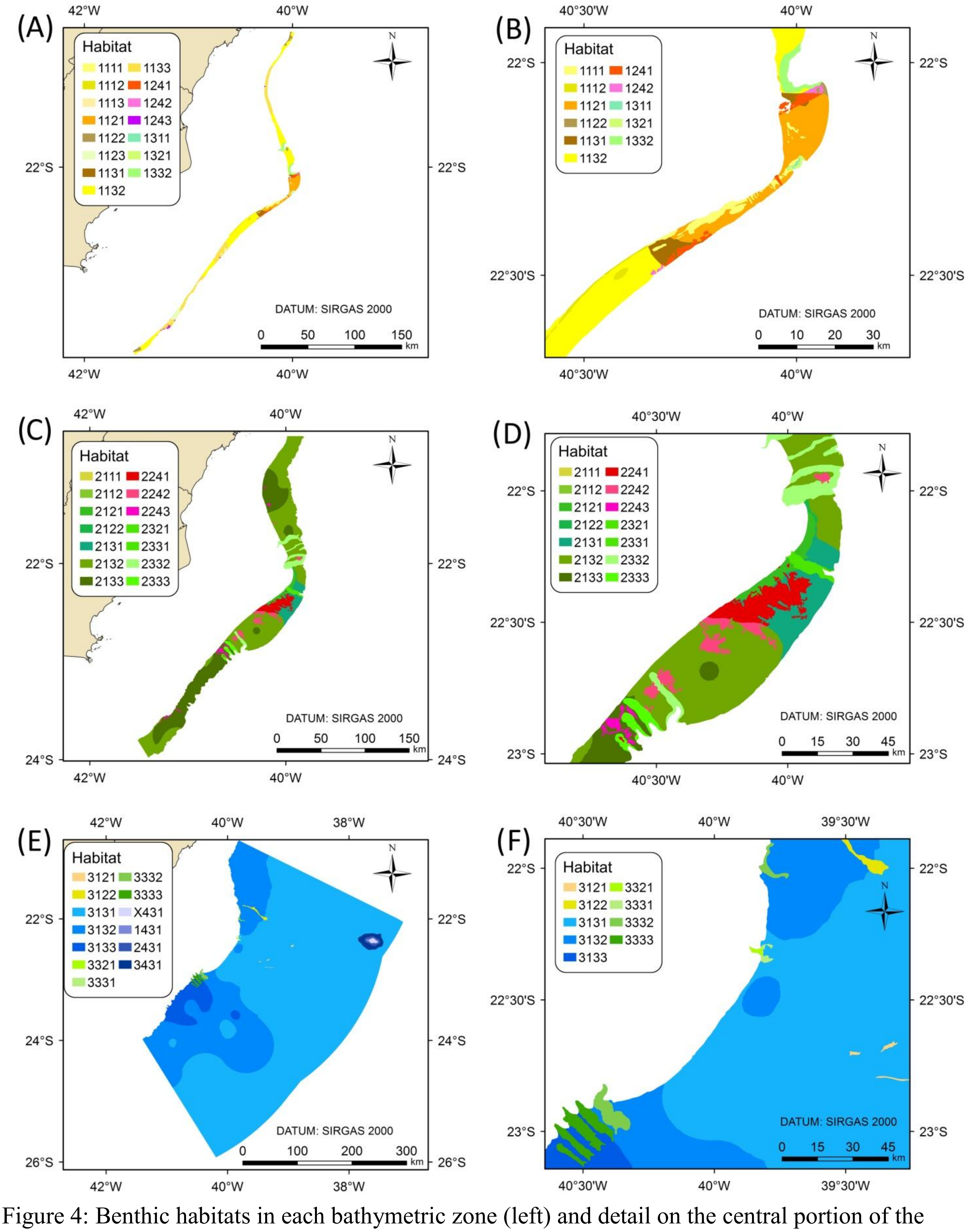

Figure 4: Benthic habitats in each bathymetric zone (left) and detail on the central portion of the continental slope (right). (A) and (B): upper slope (200 - 500 m); (C) and (D): middle slope (500 - 1500 m); (E) and (F): lower slope (>1500 m).

Table 2: Benthic habitats map summary. * Digits in brackets represent each level on the habitat four digit code: first digit represents level 1 and so on. TOC = total organic carbon.

Level 1 Bathymetric zone	**Level 2 Geomorphic feature**	**Level 3 Sediment grain size**	**Level 4 Sediment TOC**	**Habitat code**	**Number of habitat patches**	**Total habitat area (km^2)**	**Habitat area within leased areas (%)**
200 - 500 m [1]*	slope [1]*	gravel [1]*	low [1]*	**1111**	17	57.756	75.8
			medium [2]*	**1112**	9	30.977	75.7
			high [3]*	**1113**	6	16.527	52.4
		sand [2]*	low [1]*	**1121**	6	220.440	89.5
			medium [2]*	**1122**	7	60.360	7.0
			high [3]*	**1123**	4	67.995	27.1
		mud [3]*	low [1]*	**1131**	4	43.473	85.5
			medium [2]*	**1132**	9	844.613	37.3
			high [3]*	**1133**	7	416.687	35.4
	cold water coral reef [2]*	reef substrate [4]*	low [1]*	**1241**	10	35.587	86.6
			medium [2]*	**1242**	4	8.753	88.3
			high [3]*	**1243**	7	16.051	83.4
	canyon [3]*	gravel [1]*	low [1]*	**1311**	4	1.713	100.0
		sand [2]*	low [1]*	**1321**	1	4.849	98.2
		mud [3]*	medium [2]*	**1332**	4	64.732	8.6
	seamount [4]*	mud [3]*	low [1]*	**1431**	1	61.509	0.0
500 - 1500 m [2]*	slope [1]*	gravel [1]*	low [1]*	**2111**	1	0.072	0.0
			medium [2]*	**2112**	1	2.147	0.0
		sand [2]*	low [1]*	**2121**	4	162.531	69.5
			medium [2]*	**2122**	3	16.916	81.0
		mud [3]*	low [1]*	**2131**	6	480.085	75.7
			medium [2]*	**2132**	12	4,494.057	47.3
			high [3]*	**2133**	7	2,779.251	25.9
	cold water coral reef [2]*	reef substrate [4]*	low [1]*	**2241**	12	389.471	95.2
			medium [2]*	**2242**	24	233.780	91.2
			high [3]*	**2243**	16	93.831	55.8
	canyon [3]*	sand [2]*	low [1]*	**2321**	1	61.041	32.8
		mud [3]*	low [1]*	**2331**	1	18.476	61.3
			medium [2]*	**2332**	6	441.096	67.5
			high [3]*	**2333**	3	127.675	69.9
	seamount [4]*	mud [3]*	low [1]*	**2431**	1	179.609	0.0

(continues on next page)

Table 2 (continued): Benthic habitats map summary. * Digits in brackets represent each level on the habitat four digit code: first digit represents level 1 and so on. An additional bathymetric zone (<200 m) was included to create a habitat type comprising the seamount's summit, in order not to leave a gap in the benthic habitats map. TOC = total organic carbon.

Level 1 Bathymetric zone	Level 2 Geomorphic feature	Level 3 Sediment grain size	Level 4 Sediment TOC	Habitat code	Number of habitat patches	Total habitat area (km^2)	Habitat area within leased areas (%)
>1500 m [3]*	slope [1]*	sand [2]*	low [1]*	**3121**	5	35.232	0.0
			medium [2]*	**3122**	1	125.240	0.0
		mud [3]*	low [1]*	**3131**	3	89,800.530	0.6
			medium [2]*	**3132**	3	29,311.162	13.6
			high [3]*	**3133**	2	3,882.548	26.4
	canyon [3]*	sand [2]*	low [1]*	**3321**	1	10.413	0.0
		mud [3]*	low [1]*	**3331**	2	16.085	0.0
			medium [2]*	**3332**	6	167.254	54.3
			high [3]*	**3333**	4	244.370	85.9
	seamount [4]*	mud [3]*	low [1]*	**3431**	1	658.527	0.0
<200 m [X]*	seamount [4]*	mud [3]*	low [1]*	**X431**	1	83.414	0.0

Table 3: Proportion of overlap to leased areas according to each level in the habitat classification scheme (proportion is relative to total area of the respective level).

Level 1 Bathy-metric zones	**Total area (km^2)**	**Overlap to leased areas (%)**	**Level 2 Geo-morphic features**	**Total area (km^2)**	**Overlap to leased areas (%)**	**Level 3 Sediment grain size**	**Total area (km^2)**	**Overlap to leased areas (%)**
200 - 500 m	1,952.022	44.0	slope	1,758.828	45.2	gravel	105.260	72.1
						sand	348.795	63.1
						mud	1,304.773	38.3
			cold water coral reef	60.391	85.9	reef substrate	60.391	85.9
			canyon	71.294	16.9	gravel	1.713	100.0
						sand	4.849	98.2
						mud	64.732	8.6
			seamount	61.509	0.0	mud	61.509	0.0
500 - 1500 m	9,480.038	46.3	slope	7,935.059	42.0	gravel	2.219	0.0
						sand	179.447	70.6
						mud	7,753.393	41.4
			cold water coral reef	717.082	88.7	reef substrate	717.082	88.7
			canyon	648.288	64.5	sand	61.041	32.8
						mud	587.247	67.8
			seamount	179.609	0.0	mud	179.609	0.0
>1500 m	124,251.361	4.7	slope	123,154.712	4.5	sand	160.472	0.0
						mud	122,994.240	4.5
			canyon	438.122	68.6	sand	10.413	0.0
						mud	427.709	70.3
			seamount	658.527	0.0	mud	658.527	0.0
<200 m	83.414	0.0	seamount	83.414	0.0	mud	83.414	0.0

3.2 Areas of interest for the conservation of benthic biodiversity (MPA network design)

The three scenarios for MPA design resulted in similar requirements for the total area to be protected, but with variable success on the overlap with current oil and gas activities in Campos Basin. In scenario 1, where MPAs could be freely positioned, the 30% representation target was successfully met for all habitats in all 1000 generated solutions, but every solution presents a high degree of overlap of MPAs to the leased areas. The best ranked solution (according to Marxan's objective function) overlaps over 60% of the total of leased areas within the study area (Figure 5). The total area for the MPA network on the best solution is 43,316.24 km^2, which corresponds to 33.2% of the deep Campos Basin area. This MPA network cover 53.6% of the upper slope; 50.5% of the middle slope and 30.1% of the lower slope. In scenario 1 the majority of the PUs with higher selection frequency area located on the central region of the Campos Basin (Figure 5), driven mainly by the occurrence rare and patchy habitats in this region (i.e. high habitat heterogeneity). In this scenario, only 0.4% of the total PUs can be considered highly irreplaceable (selection rate ≥ 80%) for an efficient MPA network design.

In Scenario two, no solutions were able to meet the 30% representation target for all habitats, given that MPAs location was restricted to non-leased areas. On the best solution 15 habitats were underrepresented (Table 4), and least 14 were underrepresented in all solutions. In this scenario there was an increase in the proportion of highly irreplaceable PUs (i.e. selection rate ≥ 80%) compared to the first scenario. Scenario two had over 4 times more highly irreplaceable PUs if compared to scenario one, and 175 PUs (0.6%) had selection rates of 100% (figure 5). The total area for the MPA network on the best solution for scenario two is 40,735.18 km^2 (figure 5), which represents 30% of the deep Campos Basin area. This MPA network cover 34.3% of the upper slope; 28.4% of the middle slope and 30% of the lower slope, with no overlap to leased areas.

Table 4: Fifteen habitats miss the 30% representation target on the best solution for scenario 2, given that in that scenario MPA positioning was restricted to non-leased areas. TOC = total organic carbon.

Level 1 - Bathymetric zones	**Level 2 - Geomorphic features**	**Level 3 - Sediment grain size**	**Level 4 - Sediment TOC**	**Habitat code**	**Representation on MPA network (%)**
200 - 500 m	slope	gravel	low	**1111**	19.32
			medium	**1112**	24.34
		sand	low	**1121**	9.74
		mud	low	**1131**	8.59
	cold water coral reef	reef substrate	low	**1241**	8.74
			medium	**1242**	11.36
			high	**1243**	29.56
	canyon	gravel	low	**1311**	0
		sand	low	**1321**	4.77
500 - 1500 m	slope	sand	low	**2121**	28.75
			medium	**2122**	18.94
		mud	low	**2131**	24.25
	cold water coral reef	reef substrate	low	**2241**	4.56
			medium	**2242**	9.28
>1500 m	canyon	mud	high	**3333**	12.50

In the third scenario, given that MPA positioning was restricted only within a 5 km buffer around oil production platforms, 93.6% of the solutions were able to met the 30% representation target for all habitats, and all 1000 solutions presented at least 29% of representation for all habitats. On the best solution, MPAs overlap with leased areas is only 5.5% of the total area leased within deep Campos Basin (Figure 5). In this scenario 1.6% of the PUs have selection rate ≥ 80%, and these PUs may represent extremely important areas for conservation (Figure 5). The MPA network on the best solution for this scenario has a total area of 40,924.89 km^2 (30.1% of the deep Campos Basin area), and cover 34.3% of the upper slope, 31.2% of the middle slope and 30% of the lower slope.

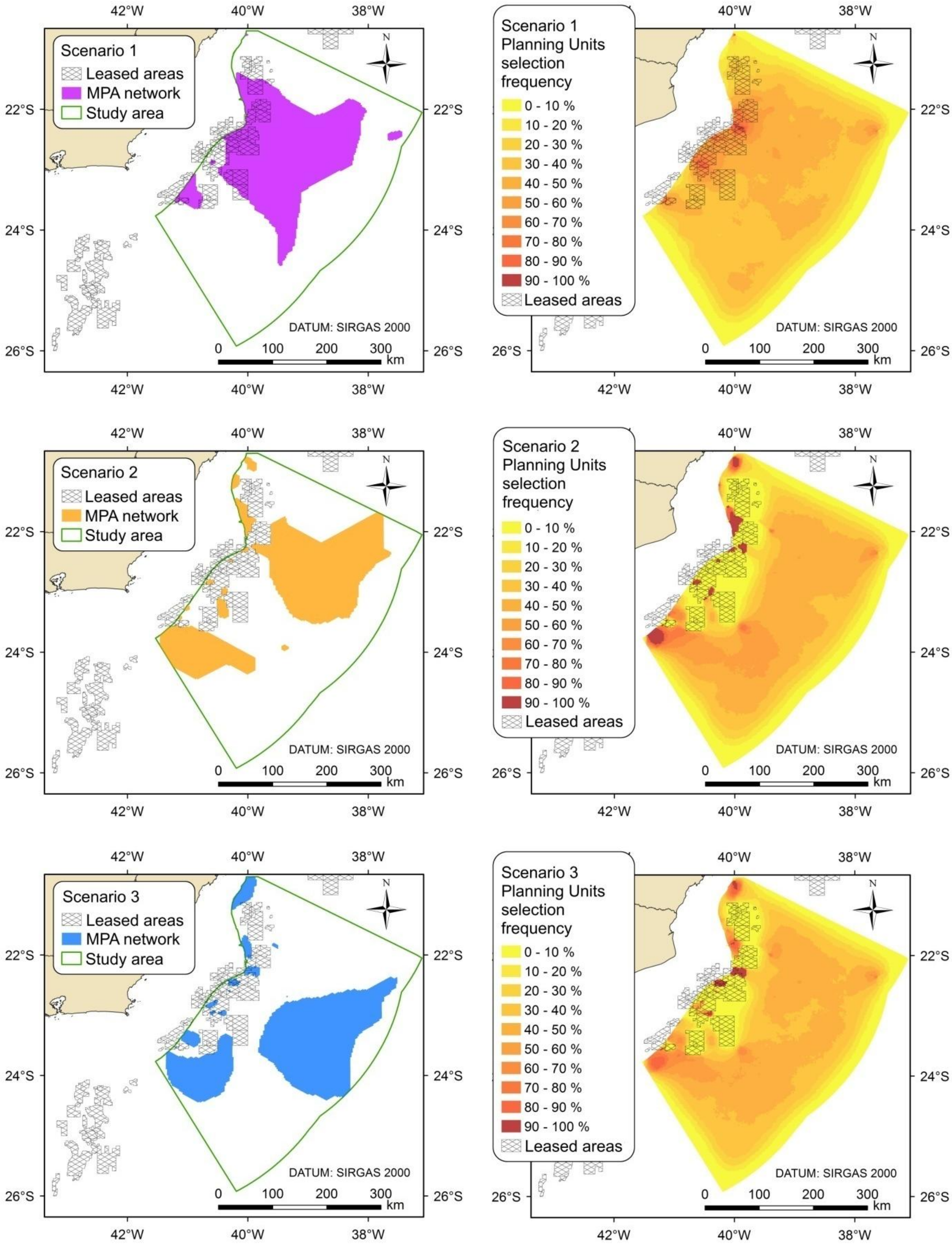

Figure 5: Results for each of the three modeled scenarios: (Left) MPA network on the best solution; (Right) frequency distribution of PUs selection.

The 50 km limit for maximum distance between nearest MPAs in the network was met by the best solution of scenario 3. Thus, we built a proposition for a MPA network based on that result, in which we have enhanced the representation of sensitive habitats associated to cold water coral reef and seamount. Three additional MPAs were included on the network in order to protect coral reef habitats that don't overlap with leased areas and remained unprotected. The Almirante Saldanha seamount was fully included on the largest MPA on the network, which already comprised 30% of the seamount. This proposition of a MPA network (figure 6) comprises 18 individual MPAs, with a total area of 42,454.76 km^2 (31.28% of the study area). The maximum distance between nearest MPAs in the proposed network is 42.33 km. but this distance is lower (15.22 km) for part of the network on the upper and middle slope (depth 200 to 1500 m). A comparison of habitat protection and overlap to leased areas between the proposed MPA network and the best solution for scenarios one and two is shown on table 5 and represented graphically on supplementary material (Figure S4). Representation of each individual habitat in the proposed MPA network is shown on supplementary material (Table S5).

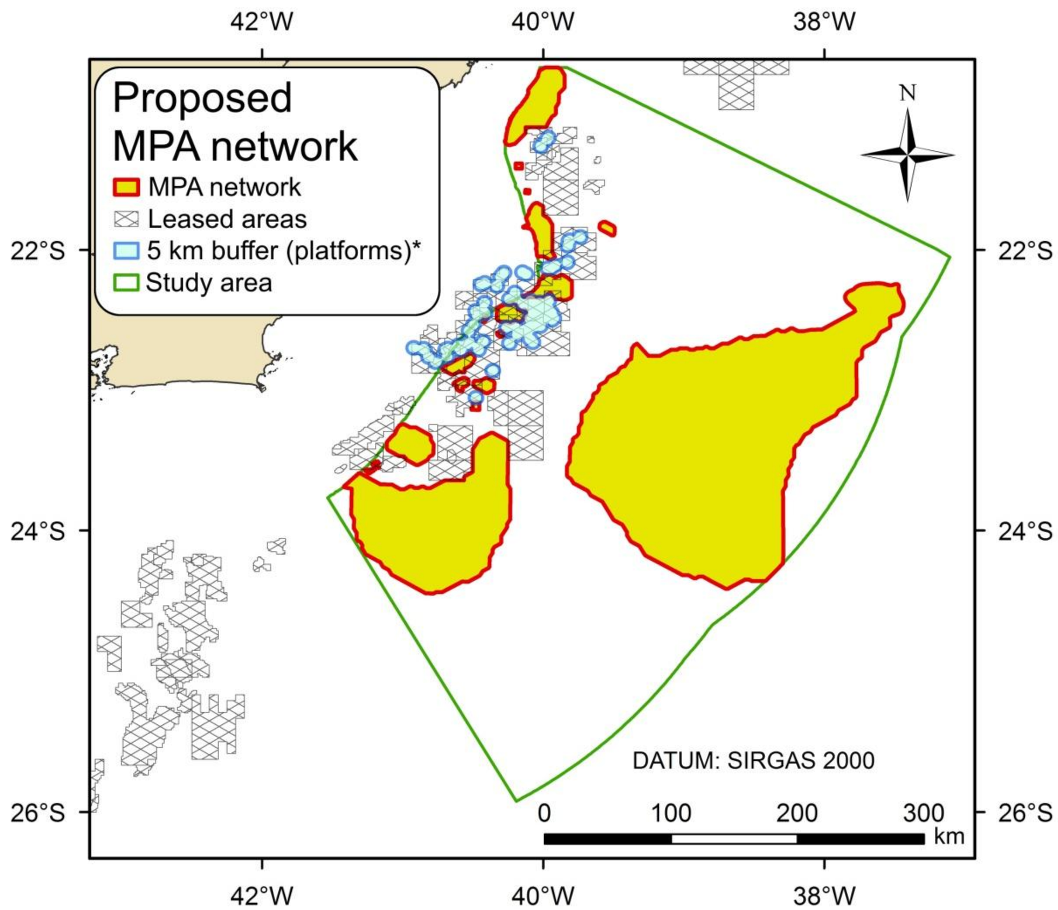

Figure 6: Proposition of a MPA network based on habitat representativeness and low overlap (5.5%) with areas leased to the oil industry. * The 5 km buffer was set only for oil/gas production units.

Table 5: Comparison of habitat protection and MPA overlap to leased areas among the 3 scenarios, grouped according to bathymetric zones and geomorphic features. cwcr = cold water coral reef.

		Scenario 1		**Scenario 2**		**Scenario 3 (Proposed MPA network)**	
Overlap of MPAs to leased areas		**60%**		**0%**		**5.5%**	
Level 1 - bathymetric zones	**Level 2 - geomorphic features**	**Area on MPA network (Km^2)**	**Represen-tation (%)**	**Area on MPA network (Km^2)**	**Represen-tation (%)**	**Area on MPA network (Km^2)**	**Represen-tation (%)**
200 -500 m	slope	863.696	49.1	592.216	33.7	638.32	36.3
	cwcr	47.544	78.7	8.821	14.6	30.019	49.7
	canyon	62.590	87.8	50.742	71.2	60.542	84.9
	seamount	18.491	30.1	27.947	45.4	61.509	100
500 - 1500 m	slope	3,693.318	46.5	2,354.847	29.7	2,525.857	31.8
	cwcr	580.408	80.9	70.233	9.8	255.965	35.7
	canyon	491.044	75.7	207.745	32.0	285.415	44.0
	seamount	72.827	40.5	56.057	31.2	179.609	100
>1500m	slope	37,043.249	30.1	36,998.637	30.0	37,516.044	30.5
	canyon	215.994	49.3	111.025	25.3	159.538	36.4
	seamount	197.813	30.0	224.676	34.1	658.527	100

4 Discussion

This study identified a number of biologically relevant and vulnerable deep sea habitats distributed along the continental slope of Campos Basin, many of them located within current leased areas for the oil and gas industry. The leased areas are concentrated over the upper and middle continental slope, mostly over the central region of Campos Basin, with a significant overlap with several unique ecosystems of high biodiversity, including cold water coral reefs, submarine canyons and slope sediments. Deep sea coral reefs on Campos Basin are structured by typical cold water reef building species, including *Lophelia pertusa*, which may harbor several associated species with no representation on non-coral habitats (Cordes et al., 2008; Arantes et al., 2009; Lessard-Pilon et al., 2010). The submarine canyons also may host a distinct biodiversity over the margin and sustain important habitats for fisheries (De Leo et al., 2010; De Leo et al., 2014). Although the degree of biological uniqueness on deep sea communities in Campos Basin is still uncertain, some of the identified habitats meet several criteria (e.g. biological relevance, uniqueness, threat, etc.) to be considered Ecologically and Biologically Significant Areas (EBSA's) (Clark et al., 2014; Dunn et al., 2014), and some can be considered critical habitats for marine industries (Martin et al., 2015), and therefore should be targeted for protection. The mapped habitats were identified based on an extensive but still limited dataset, and mostly by seabed geophysical surveys carried by the industry over areas of commercial interest. Although geophysical roughness may have low performance as a surrogate for diversity (Schlacher et al., 2009), the mapped EBSA's represent a conservative picture of the heterogeneity and diversity within the deep Campos Basin. The sedimentary and organic carbon surrogates were also conservatively applied towards habitat identification, but these variables are markedly associated with benthic diversity and assemblage composition over the slope (Bernardino et al., 2016).

We detected a high overlap of EBSA's with leased oil and gas areas on Campos Basin, which is the result of poor spatial planning coupled with limited prior knowledge of deep sea ecosystems along

Brazil's continental margin (Mariano and La Rovere, 2007). Leased areas mostly overlaps submarine canyon and cold water coral habitats, but upper and middle slope sediments are also significantly occupied by the industry. The current lack of a basin wide management strategy contrasts with the increased sampling and surveying that Brazil's EEZ has experienced in the last and present decade, and may indicate that economic and political interests have prevented a proper management of this industry (Kark et al., 2015). An ecosystem based spatial planning for the bidding rounds of offshore exploratory blocks is necessary in Brazil, as an initial effort, and could lead to safeguard important deep sea ecosystems on the Brazilian continental margin (Halpern et al., 2006; Danovaro et al., 2008; Levin et al., 2010; Snelgrove et al., 2014; Kark et al., 2015). However, the overlap and close proximity of current hydrocarbon exploration and production to those EBSA's may offer additional threat from impacts associated with regular industrial operations (Cordes et al., *in press*). Therefore, it is necessary to ensure that the ESBA's within leased areas are not only protected but also monitored to check for chronic or acute stress caused by industrial activity. Cold-water corals and other benthic assemblages have been successfully used as ecosystem indicators near offshore oil platforms and to monitor major blowouts in the deep-sea (Doughty et al., 2014; Fisher et al., 2014). This suggests that these benthic habitats should also be used to monitor the industrial operations along Campos Basin, and assessment of their health should be incorporated into management strategies to prevent long-term impacts on population dynamics and ecosystem functioning.

The Systematic Conservation Planning aims for a representation of the whole set of biodiversity within a given area and, therefore, some areas may be excluded from protection provided that ecological processes are not dramatically affected and that the biodiversity it contains can be protected elsewhere. However, our results indicate that some habitat types, including 5 of the 6 identified cold water coral reef habitats, would not reach a minimum of 30% representation on a MPA network if protected exclusively outside current the leased areas. Upper and middle slope soft bottom habitats were also significantly occupied by leased areas (Table 3). However, the proposed MPA network, with a minimum of 30% of protection for all habitats, has minimal overlap with the leased areas, using less than 6% of the leased areas within deep Campos Basin to reach the conservation goal. The highly irreplaceable areas for conservation, indicated by the planning units with high selection frequency (>80%) in scenario three (figure 5), represent extremely important areas for establishing a MPA network, as they support the co-occurrence of benthic biodiversity conservation with the current offshore industrial activities. These results suggests that an ecosystem based biodiversity conservation plan, with consistent habitat representation (30%), can be implemented without disrupting current industrial activities in the deep Campos Basin. Although the 30% representation target applied in this study may seem high if compared to the CBD's guidelines, the conservation of larger areas may also ensure protection of unmapped fish stocks and safeguard vulnerable deep sea habitats against other sources of impacts and environmental change (Roberts et al., 2006a; Davies et al., 2007; Armstrong et al., 2014).

While negotiating improvements in the design of the proposed MPA network with stakeholders, decision makers should give some attention to the tradeoffs involving coral reef habitats. Although cold water coral reefs ecosystem functions in Campos Basin are yet to be fully unveiled, it is evident that they are complex and vulnerable tridimensional habitats that support high biodiversity (Roberts et al., 2006b). Representation of cold water coral habitat types on the proposed MPA network varies from 31.8% to 56.4%, surpassing the initial 30% representation target. However, as stated before, the high resolution geophysical surveys did not cover the entire study area, and population variability and connectivity patterns for coral species is unknown in Campos Basin. Furthermore, most cold-water coral habitats on Campos Basin are concentrated within the upper and middle slope, in areas with historical industry activity, densely occupied by leased areas and prone to have new exploratory blocks offered in future bidding rounds. To address this situation, it is recommended to incorporate new areas within the depth range of cold water coral reef habitats occurrence (200 to 1500 m) to the future MPA network in deep Campos Basin, as broadly as possible. On the other hand, the oil industries are likely to offer some resistance to the expansion of the MPA network in the mentioned depth range, which may contain still undiscovered hydrocarbon reservoirs.

The characterization and mapping of benthic habitats supported the identification of areas of high importance for conservation, which should be included on the deep Campos Basin MPA network. Although we recognize that further actions are beyond the scope of this work, the identification of vulnerable and spatially restricted habitats and EBSA's along Campos Basin supports that future MPAs can protect a comprehensive set of benthic habitats and their communities. An ecosystem based representative MPA network would provide clear benefits to a wide variety of stakeholders, including the industry itself. Thus, we believe that our proposed design for the MPA network can be a starting point for government action and stakeholder involvement aiming the effective implementation of a conservation plan for the deep Campos Basin. This process should also take into account additional activities such as bottom fisheries, that can be incorporated in the MPA design process as a cost factor for planning units. We also recommend that the proposed MPA network should be managed as 'no take areas', similarly to other deep sea protected areas that offer protection to vulnerable and sensitive habitats such as cold water coral habitats (Davies et al., 2007). The industrial activity on nearby leased areas also need to be managed with a scientific rationale and follow international best practices, to assure protection and persistence to habitats and ecosystem functions (Cordes et al., *in press*). Management and conservation of biodiversity in the pelagic realm should also be addressed in the future, preferably integrated to the benthic conservation plan through SCP and hopefully supported by comprehensive datasets.

The abyssal seafloor of Campos Basin is unlikely to become leased to the oil industry in the near future due to current technical limitations for operations in water depths beyond 3000 m. However, Brazil is among the nations that have requested permission to the International Seabed Authority (ISA) to explore mineral resources in international areas (high seas) of the South Atlantic, indicating that similar conservation issues will likely rise in areas beyond Brazilian jurisdiction on the deep south Atlantic ocean. Deep sea mining can be regarded as a major source of impacts to deep sea ecosystems (Glover & Smith, 2003; Ramirez-Llodra et al, 2015), but several international efforts are underway to ensure their protection. The interests in polymetalic nodules, sulphide crusts and calcium carbonate deposits may lead to prospection for mineral resources at the south Atlantic seamounts and island chains, where deep sea biodiversity is poorly known. Some of these features are located within Brazilian exclusive economic zone (EEZ), and even on our study area a seamount is a potential mining site. Therefore, the recognition of the high biological and ecological significance of deep sea slopes, canyons, cold water coral reefs and seamounts and their adequate representation into a MPA network in the southwest Atlantic, as well as on other regions of the Brazilian margin, should be a priority to Brazilian authorities. Realistically considering the current paucity of data to adequately characterize Brazil's continental margins and nearby deep ocean basins, conservation planning should adopt a precautionary approach (Crowder & Norse, 2008) and identify potential EBSA's along areas of current and planned economic activities (e.g. Wedding et al., 2013), thus setting a landmark for protection until proper scientific knowledge is obtained to support the management of those ecosystems.

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Supplementary material

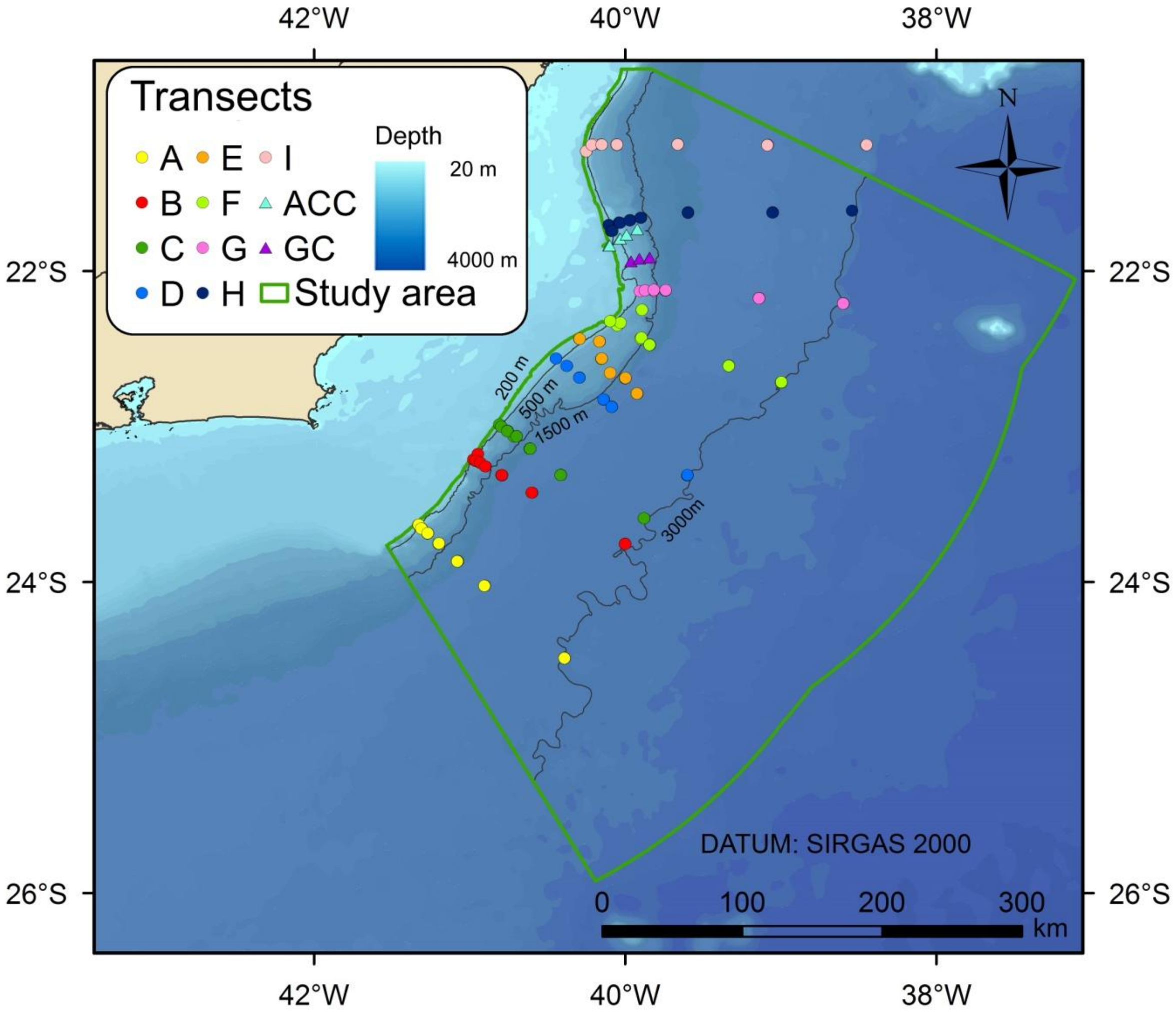

Figure S1: Sampling grid of the 'Habitats' project on the deep Campos Basin. On each transect samples were taken in real triplicate in depths of 400 m, 700 m, 1000 m, 1300 m, 1900 m, 2500 m and 3000 m. Canyon samples were taken in the same depths up to 1300 m. ACC = Almirante Câmara canyon; GC = Grussaí canyon.

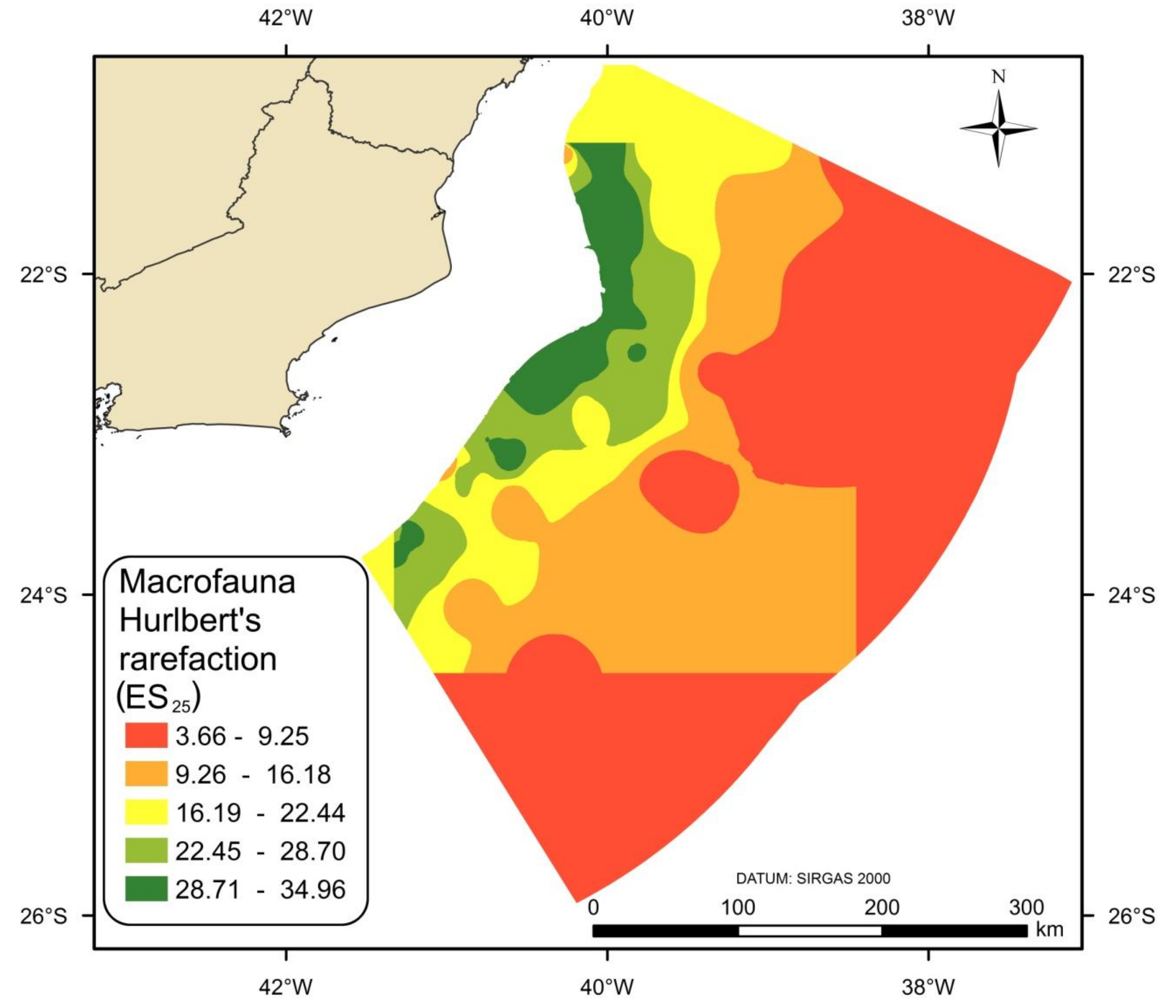

Figure S2: Benthic macrofauna diversity (Hurlbert's rarefaction curve index). 'Edges' of the study area were not covered by resulting interpolated surface, thus being conservatively assigned as middle class (ES_{25} 16.19 - 22.44) if comprising the upper or middle slope (depth 200 to 1500 m) or lower class (ES_{25} 3.66 - 9.25) if comprising only the lower slope (depth >1500 m).

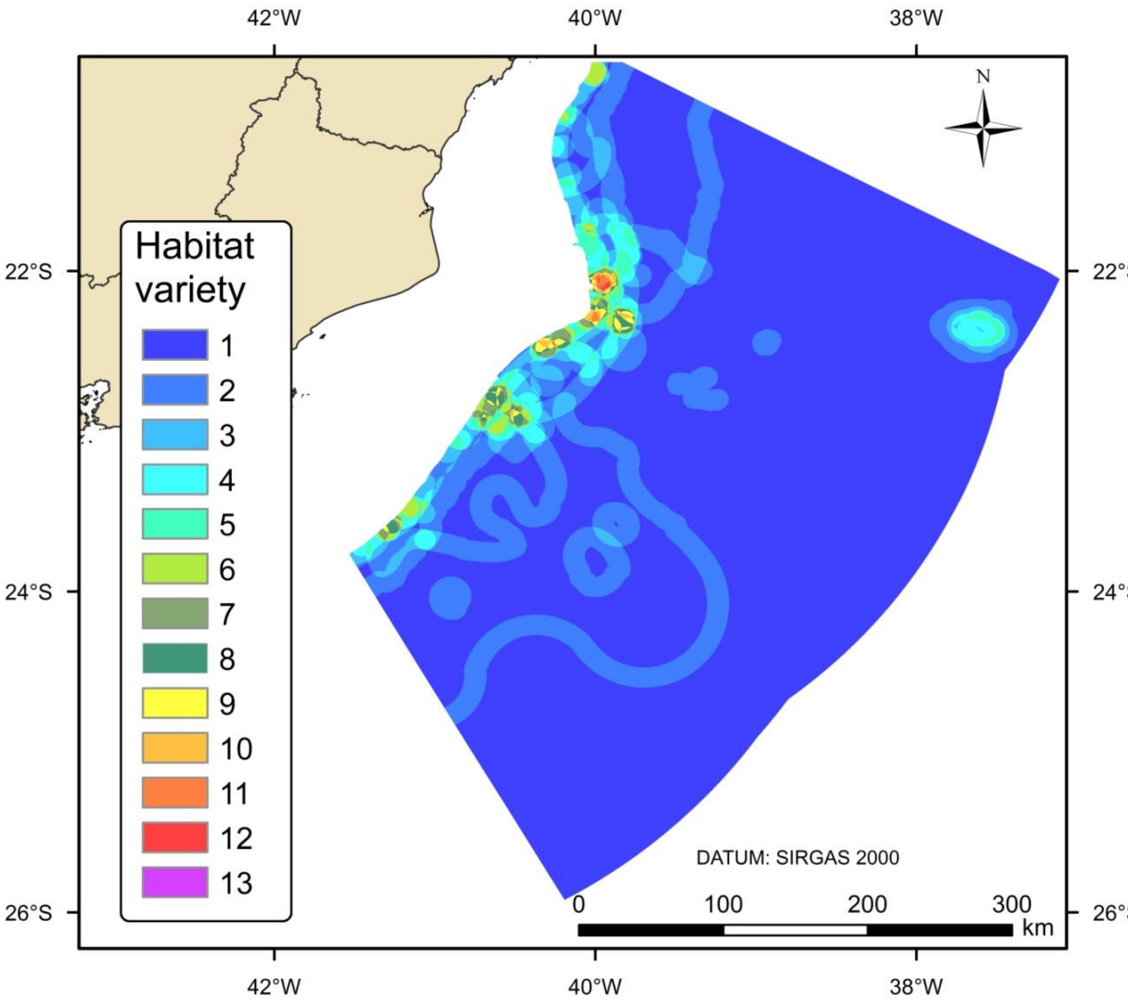

Figure S3: Habitat variety map (number of different habitat types within a 7 km radius) indicates that habitat heterogeneity is bigger in the upper and middle slope (200 - 1500 m).

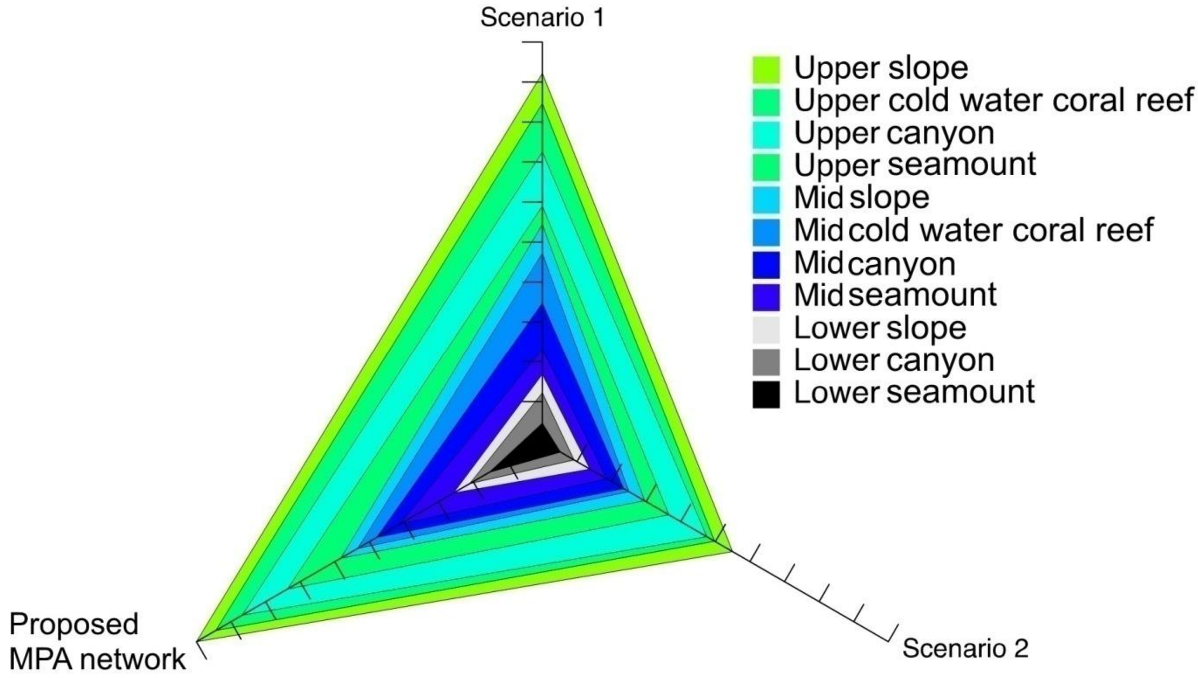

Figure S4: Comparison of habitat protection between the proposed MPA network and best solutions obtained in scenarios 1 and 2 (absolute values are presented in Table 5). Scale of values in each axis is proportional to the biggest values obtained for each habitat.

Table S5: Habitat representation on the proposed MPA network. *Habitat X431 corresponds to seamount summit, with depth <200 m.

Upper slope (200 - 500 m)			**Middle slope (500 - 1500 m)**			**Lower slope (>1500 m)**		
Habitat code	**Area within MPA network (km^2)**	**Represen-tation on MPA network (%)**	**Habitat code**	**Area within MPA network (km^2)**	**Represen-tation on MPA network (%)**	**Habitat code**	**Area within MPA network (km^2)**	**Represen-tation on MPA network (%)**
1111	23.653	41.0	**2111**	0.072	100	**3121**	13.987	39.7
1112	11.949	38.6	**2112**	2.147	100	**3122**	40.442	32.3
1113	5.257	31.8	**2121**	82.137	50.5	**3131**	27,274.473	30.4
1121	86.666	39.3	**2122**	7.317	43.3	**3132**	8,963.899	30.6
1122	34.056	56.4	**2131**	153.542	32.0	**3133**	1,223.243	31.5
1123	26.957	39.7	**2132**	1,404.523	31.3	**3321**	10.413	100
1131	30.531	70.2	**2133**	876.119	31.5	**3331**	6.487	40.3
1132	285.772	33.8	**2241**	123.801	31.8	**3332**	55.598	33.2
1133	133.479	32.0	**2242**	81.321	34.8	**3333**	87.040	35.6
1241	17.747	49.9	**2243**	50.843	54.2	**3431**	658.527	100
1242	4.939	56.4	**2321**	61.041	100			
1243	7.333	45.7	**2331**	18.474	100			
1311	1.713	100	**2332**	142.732	32.4			
1321	4.849	100	**2333**	63.168	49.5			
1332	53.980	83.4	**2431**	179.609	100			
1431	61.509	100						
X431*	83.414	100						

-------------- *Fim do manuscrito* ------------------

IV. CONCLUSÃO

A partir dos resultados obtidos no presente estudo, conclui-se que a implementação de uma rede de áreas protegidas para conservação da biodiversidade bentônica na porção profunda da Bacia de Campos pode ser conciliada com o atual uso da região pela indústria petrolífera. Ainda, o *design* ora proposto para a rede de áreas protegidas, fundamentado em representatividade de habitats bentônicos e mínima interferência nas áreas atulamente concedidas para exploração e produção de petróleo e gás, pode ser aprimorado com a participação dos atores sociais envolvidos com a região (sobretudo representantes das cadeias produtivas da pesca e do petróleo, além do poder público), seguindo-se as premissas do planejamento sistemático de conservação. Os resultados obtidos no presente estudo podem, ainda, ser utilizados como base para o desenvolvimento de futuras pesquisas.

V. REFERÊNCIAS

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VI. ANEXOS

Em anexo são apresentadas em alta resolução todas as 10 figuras que constam no capítulo único desta dissertação.