



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

**UNIVERSIDADE FEDERAL DO ESPÍRITO SANTO
CENTRO DE CIÊNCIAS HUMANAS E NATURAIS
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**

VITÓRIA

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Dissertação apresentada ao Programa de Pós-Graduação em Oceanografia Ambiental da Universidade Federal do Espírito Santo, como requisito parcial para obtenção do título de Mestre em Oceanografia Ambiental.

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 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 concedidas 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 utilizada como ponto de partida para sua efetiva criação pelas autoridades brasileiras, preferencialmente 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, conseqüentemente, 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 exploração de petróleo e gás cada vez mais para áreas mais profundas; atualmente já existem sistemas de produção em operação em lâmina d'água 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 indústria 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 ecossistemas do mar profundo (Mariano & La Rovere, 2007). Ainda, o licenciamento ambiental das atividades de exploração e produção de petróleo em águas marinhas sob jurisdição brasileira só foi iniciado 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 petróleo 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

empreendimentos 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 objetivos 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 habitats 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.

1 **Biodiversity conservation on the deep-sea oil fields of SW Atlantic:**
2 **supporting a marine protected area network**
3

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19 interest

20
21 **Abstract**

22 This study aims to identify areas of interest for the conservation of benthic biodiversity in the deep
23 portion (depth > 200 m) of the Campos Basin, on southeastern Brazilian margin, which is the main
24 oil and gas exploitation area of Brazil. We have employed benthic habitats as a proxy for benthic
25 biodiversity distribution, setting the representation of 30% of the area of all benthic habitats in the
26 study area as the conservation goal. Habitats characterization was developed from a nested
27 hierarchical scheme, utilizing abiotic surrogates that strongly influence biodiversity distribution in
28 the deep sea: depth; geomorphology; sediment grain size; and sediment total organic carbon. As
29 result, 42 habitat types were mapped in the study area: 6 characterized by cold water coral reef; 11 by
30 submarine canyon; 4 by seamount; and 21 by sedimentary continental slope. Marxan software was
31 used to support the design of a marine protected area (MPA) network with minimal overlap to areas
32 leased to the oil industry, applying three scenarios: 1 - without spatial constraints for location of
33 MPAs; 2 - restricting MPAs location to non-leased areas; 3 - restricting the overlap of MPAs within a
34 5 km buffer around oil production platforms. Also, in scenario 3 benthic macrofaunal diversity was
35 used as a secondary driver for the location of MPAs, in order to favor the selection of higher diversity
36 areas. In scenario 1 it was possible to achieve the 30% representation target for all 42 habitats, but
37 MPAs overlap with leased areas is 60% of the total leased areas within deep Campos Basin. In
38 scenario 2 there was no overlap at all, but 15 habitat were represented below the 30% target. In
39 scenario 3 all habitats achieved the 30% representation target while the overlap with leased areas was

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

44

45 **1 Introduction**

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

57

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

71

72 Brazil has an extensive and a resource rich continental margin, with over 93% of the country's oil and
73 76% of natural gas production being exploited from offshore fields. Campos Basin, in the SE
74 Brazilian margin, is the main production region, where exploitation began in the mid 1970's. In the
75 last decades, deep sea ecosystems in Campos Basin and in many other deep sea basins off Brazilian
76 margin are becoming increasingly threatened by the increasing industry's operational depth limit
77 (which to date is already higher than 2000 m). Additionally, Brazilian regulations failed to recognize
78 and manage the diversity of deep sea habitats prior to offering exploratory blocks at bidding rounds
79 (Mariano and La Rovere, 2007), which resulted in leased areas in close proximity or with a high
80 degree of overlap with many deep sea habitats of high biological and ecological relevance. A number
81 of deep sea ecosystems of biological interest are present on Campos Basin within leased oil and gas
82 fields and exploratory blocks, including submarine canyons and cold water coral reefs (Kitahara,
83 2007; Pires, 2007; Kitahara et al., 2009; Cordeiro et al., 2012). Cold-water coral reefs are specially
84 common along Campos Basin (21° S to 24° S) in depths between 500 m and 1200 m (Arantes et al.,
85 2009), with some reef formations reaching up to 900 m in length and 30 m in height. Additionally,
86 there is evidence for highly diverse communities associated with slope sediments on the Brazilian
87 margin, with marked bathymetric and regional differences associated to different water masses and

88 productivity gradients (Costa et al, 2015; Bernardino et al., 2016). However, although there is
89 significant scientific knowledge of Campos Basin's deep sea ecosystems and its oceanographic
90 conditions, in part due to the long term industrial activities, there is no effective protection or
91 management of those ecosystems and their biodiversity at a basin scale.

92

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

108

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

116

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

127

128 **2 Methods**

129 **2.1 Study Area**

130 Campos Basin is located on the SE Brazilian margin under a tropical oligotrophic productivity
131 regime (Gonzales-Silveira et al., 2004) with an area of 135.720 km² of deep sea habitats (depth >200
132 m). The slope of Campos Basin is under the western boundary current of the South Atlantic
133 Subtropical Gyre (Stramma & England, 1999). The slope in the study region is influenced by four

134 main water masses with distinct flow directions: (i) the South Atlantic Central Water (SACW; T= 18–
135 6 °C) flowing northward between 300 and 550 m depth; (ii) Antarctic Intermediate Water (AAIW, T=
136 6–2 °C) flowing northward between 550 and 1200 m depth; (iii) North Atlantic Deep Water (NADW,
137 T= 4–2 °C) flowing southward between 1200 and 3500 m; and (iv) Antarctic Bottom Water (AABW,
138 T< 2 °C) flowing northward below 3500 m (De Madron and Weatherly, 1994). Campos Basin is
139 subject to upwelling conditions (Aguiar et al., 2014; Palóczy et al., 2014) and to a intense mesoscale
140 activity due to meanderings, eddies and vortex formations under influence of the Vitória-Trindade
141 seamount chain (20 °S) (Hogg & Owens, 1999), the Cabo de São Tomé (22 °S) and the Cabo Frio (23
142 °S) (Fernandes et al., 2009).

143

144 Over 60% of Brazil's hydrocarbon production comes from offshore fields located in the slope of
145 Campos Basin, with recent reservoirs discovered on pre salt layers at water depths of over 2000 m.
146 Exploration and production on the deep Campos Basin started in early 1980's, with no environmental
147 regulation for the offshore operations at that time. By mid 1990's, Brazil's government began to
148 regulate the industries, demanding Environmental Impacts Assessments (EIA) and long term
149 monitoring. Currently, the continental slope on the deep Campos Basin is densely occupied by leased
150 oil/gas fields (46) and exploratory blocks (8), and have over 50 floating platforms (including
151 stationary production units and drilling rigs) and nearly 1500 drilled wells. The total leased area on
152 depths >200 m is 11,137.7 km², covering over 47% of the bathyal region between 200 and 1500 m.

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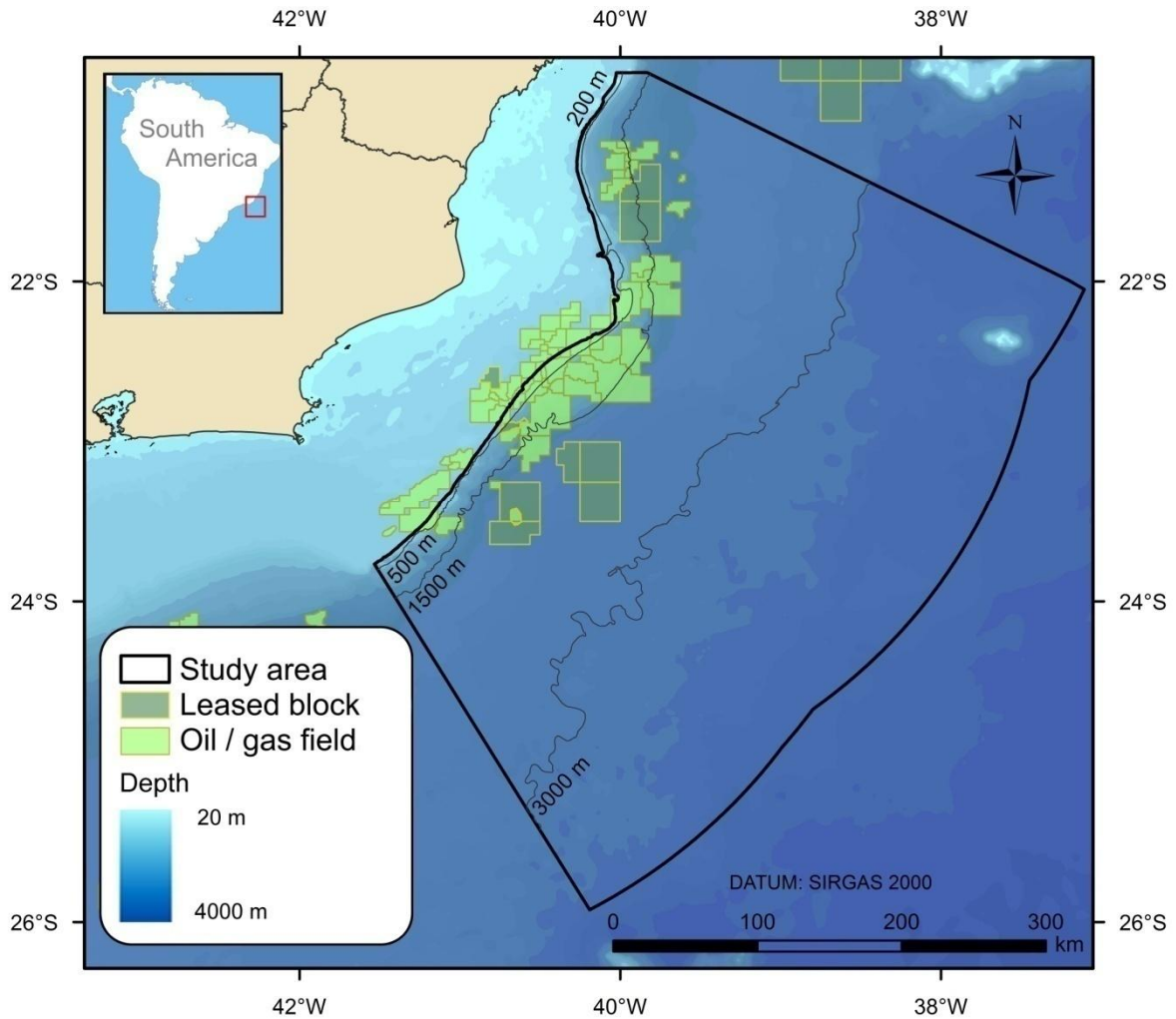
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 177 Figure 1: Map of deep Campos Basin (study area), detailing the current leased areas (exploratory
 178 blocks and oil/gas production fields). The northwestern boundary of the study area is the 200 m
 179 isobath and southeastern boundary is the Brazilian Exclusive Economic Zone limit.
 180

181 **2.2 Dataset**

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

197 areas as on September 2015.

198

199 **2.3 Habitat mapping**

200 Benthic habitats can be interpreted as areas of the seabed with singular combinations of physical,
201 chemical and biological variables (Lecours et al., 2015). As Systematic Conservation Planning
202 demands quantitative inputs to support quantitative goals, we have used benthic habitats as proxies
203 for benthic assemblages, thereby setting habitat area as the conservation metric. The habitat
204 characterization was based on abiotic surrogates for biological communities (Roff et al., 2003; Harris
205 et al., 2008; Last et al., 2010; Huang et al., 2011; Douglass et al., 2014). We employed a habitat
206 classification scheme fundamentally based on the hierarchical framework presented by Last et al.
207 (2010). This framework relies on a top-down approach, with nested levels of classification, each level
208 reflecting the processes that drives the biodiversity distribution at the respective spatial scale.

209

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

221

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

Level 1	Level 2	Level 3	Level 4
Bathymetric zones	Geomorphic features	Sediment grain size	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	

224

225 Bathymetric zones was assigned to the first classification level (Table 1, Figure 2). The 3 classes
226 within this level were selected to represent bathymetric changes in biological communities and thus
227 include major transitions of faunal assemblages along the margin (Carney, 2005; McClain & Hardy,
228 2010; Costa et al., 2015). The selected bathymetric zones also match the range of major water masses
229 along the slope that may drive benthic assemblage composition (Stramma & England, 1999; Arantes
230 et al., 2009; Bernardino et al., 2016).

231

232 The second classification level was represented by geomorphic features (Table 1, Figure 2),
233 representing large scale (>100 meters) geomorphic and structural seafloor heterogeneity on Campos
234 Basin. For this level only conspicuous features that notably change biological assemblages were
235 considered (a proxy for biological uniqueness, Clark et al., 2014), as ground truthing was not
236 available for all the interpreted geomorphic features in the available dataset. Therefore, only

237 submarine canyons (Schlacher et al., 2010), cold water coral reefs (Kitahara, 2007) and seamounts
238 (Taranto et al., 2012) were included on the level 2 GIS layer, while the remaining slope areas were
239 conservatively classified as sedimentary slope. The cold water coral reef dataset was originally
240 available in a resolution of meters, and therefore it was processed in a GIS environment prior to its
241 inclusion on the level 2 data layer. In order to use the cold water coral reef location data at a
242 resolution compatible with the study area scale, we first created a 200 m buffer around all polygons
243 representing coral reefs and then all patches (polygons formed by the eventual overlapping of the 200
244 m buffers) with area $< 1 \text{ km}^2$ were removed from the map, so that the final level 2 GIS layer only
245 represented larger reefs or large areas of highly connected small reefs. The removed patches
246 accounted for only 9% of the total area of patches generated in the first step of geoprocessing.
247 Considering that conservation planning is area based, this processing was intended to direct
248 conservation efforts towards the most connected areas of cold water coral reef occurrence.

249

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

262

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

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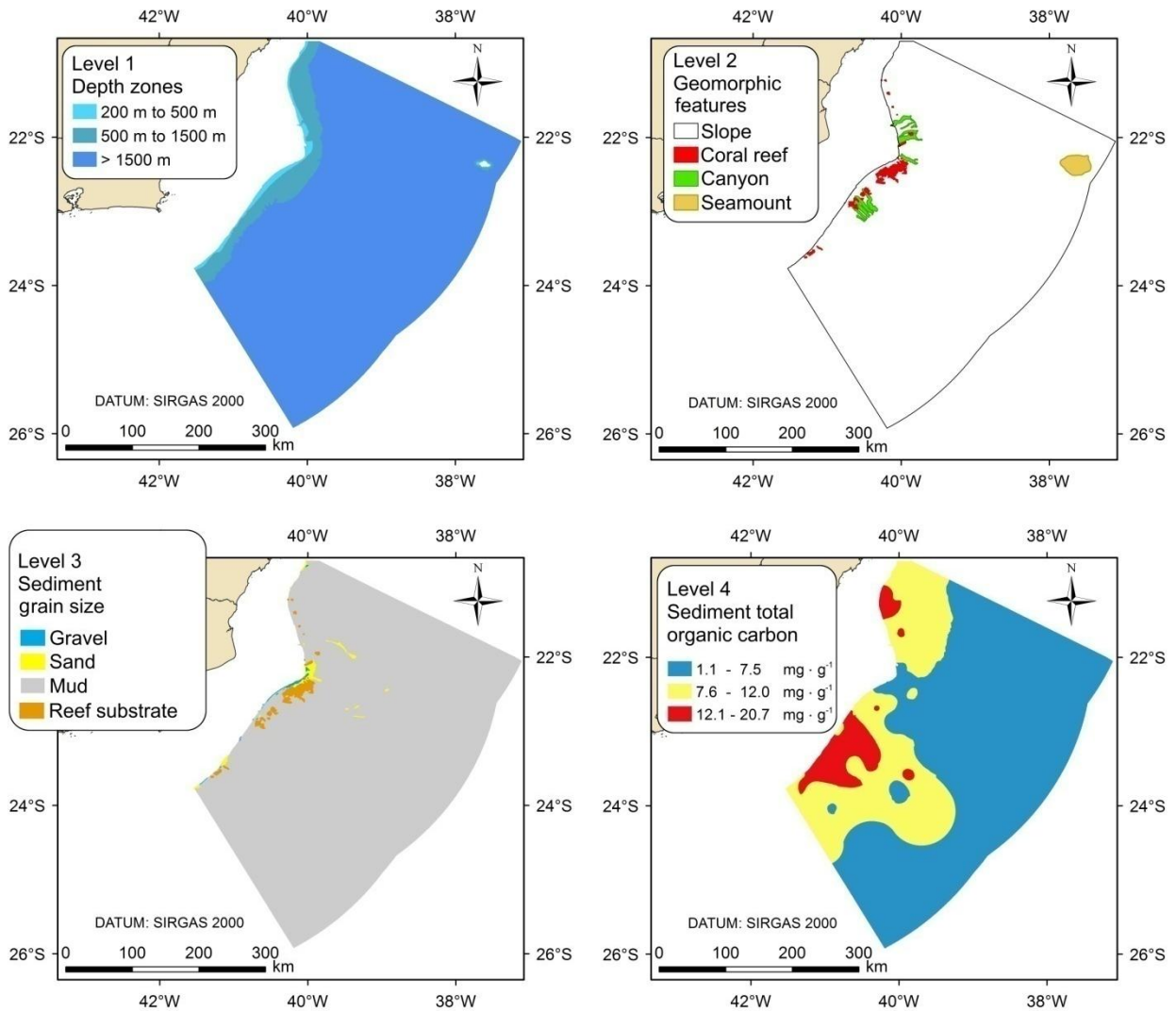
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 281 Figure 2: Representation of the variables employed on each level of the habitat classification scheme
 282 used in this study. Upper left: Level 1 - Bathymetric zones; Upper right: Level 2 - Geomorphic
 283 features; Lower left: Level 3 - Sediment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

284

285 **2.4 Identification of areas of interest for conservation (MPA network design)**

286 In order to be politically acceptable, the conservation of deep sea ecosystems on Campos Basin must
 287 take into account the existing oil and gas industrial activities in the area (Kark et al., 2015; Cordes et
 288 al., *in press*). Therefore, we have adopted to use the Systematic Conservation Planning (SCP)
 289 framework as the basis for the identification of areas of interest for conservation (Margules &
 290 Pressey, 2000; Leslie, 2005; UNEP-WCMC, 2008; Pressey & Bottrill, 2009). Therefore, the
 291 outcomes of this study should be not only scientifically consistent, but it should also be politically
 292 acceptable. The SCP focus on representativeness and long term persistence of biodiversity, but the
 293 tradeoffs between conservation goals and productive and social costs are addressed in the protected
 294 area design process. In order to keep conflicts at the lowest possible level, the conservation targets
 295 should be met with the lowest possible interference with other concurrent space or resources uses. In
 296 the study area, we considered only oil and gas stakeholders directly competing for the allocation of
 297 marine space, as there were no available datasets to support the inclusion of fisheries on the present
 298 study. Nevertheless, deep bottom fisheries (i.e. trawling, gillnet and long line) are not the main

299 source of impact on benthic habitats in the study area, given the spatial coverage of impacts
300 associated with seabed infrastructure of the oil industries and drill cuttings in the deep Campos Basin.
301 Also, the great majority of fishing effort is directed to the capture of pelagic fish stocks (Perez et al.
302 2009) and represent little threat to deep sea benthic habitats.

303

304 The conservation target was set to 30% of the area of each benthic habitat, based on the available
305 guidelines (Soulé & Sanjayan, 1998; Agardy et al., 2003; Green et al., 2014), and also given that the
306 10% representation goal of the CBD's Aichi target might stand below the necessary amount to
307 maintain the integrity of ecological processes. Applying the same target for all habitat type may not
308 represent the optimum protection for each associated assemblage due to broad biological and
309 ecological variability and due to variations in impact or stress levels (Johnson et al., 2014), but this
310 precautionary approach may offer protection to a variety of threatened habitats within the study area
311 (Bridge et al., 2016) and should be applied until more sampling and ecological studies become
312 available to support a better management strategy.

313

314 Decision support software Marxan v.2.4.3 (Game & Grantham, 2008; Ball et al., 2009) was used to
315 provide MPA design solutions that meet the conservation targets with minimal total area
316 requirements (Leslie et al., 2003). For the Marxan analysis, the study area was divided into 5 km²
317 hexagon shaped planning units (PUs), resulting in a total of 27,549 PUs. The PUs along the borders
318 of the study area were clipped to produce a perfect fit to the study area. The PUs cost was set as
319 proportional to its area and Marxan analysis was undertaken, after the calibration of the boundary
320 length modifier, using 10⁷ iterations on each run and 1000 runs for each scenario. The frequency of
321 PUs selection (to integrate a MPA) along the 1000 runs of each scenario is a measure of PU
322 irreplaceability for an efficient reserve design and can be considered a key Marxan output to support
323 decision making (Game & Grantham, 2008).

324

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

339

340 The MPAs location (site selection) in the third scenario was further refined based on a dataset of
341 benthic biodiversity (i.e. soft sediment macrofaunal diversity based on Hulbert's rarefaction index).
342 The cost of all PUs was scaled with macrofaunal diversity, favoring MPA site selection towards
343 higher diversity areas. Mean Hulbert Rarefaction diversity (ES₂₅) was calculated for 56 triplicate box
344 core samples and then interpolated by the inverse distance weighted method on ArcGIS 10.1, to

345 create a *shapefile* covering the study area. ES₂₅ values ranged from 3.6 to 34.9 (mean = 23; SD =
346 8.9), and the study area was divided into five ES₂₅ classes (supplementary material - Figure S2).

347

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

360

361 **3 Results**

362 **3.1 Benthic habitats map**

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

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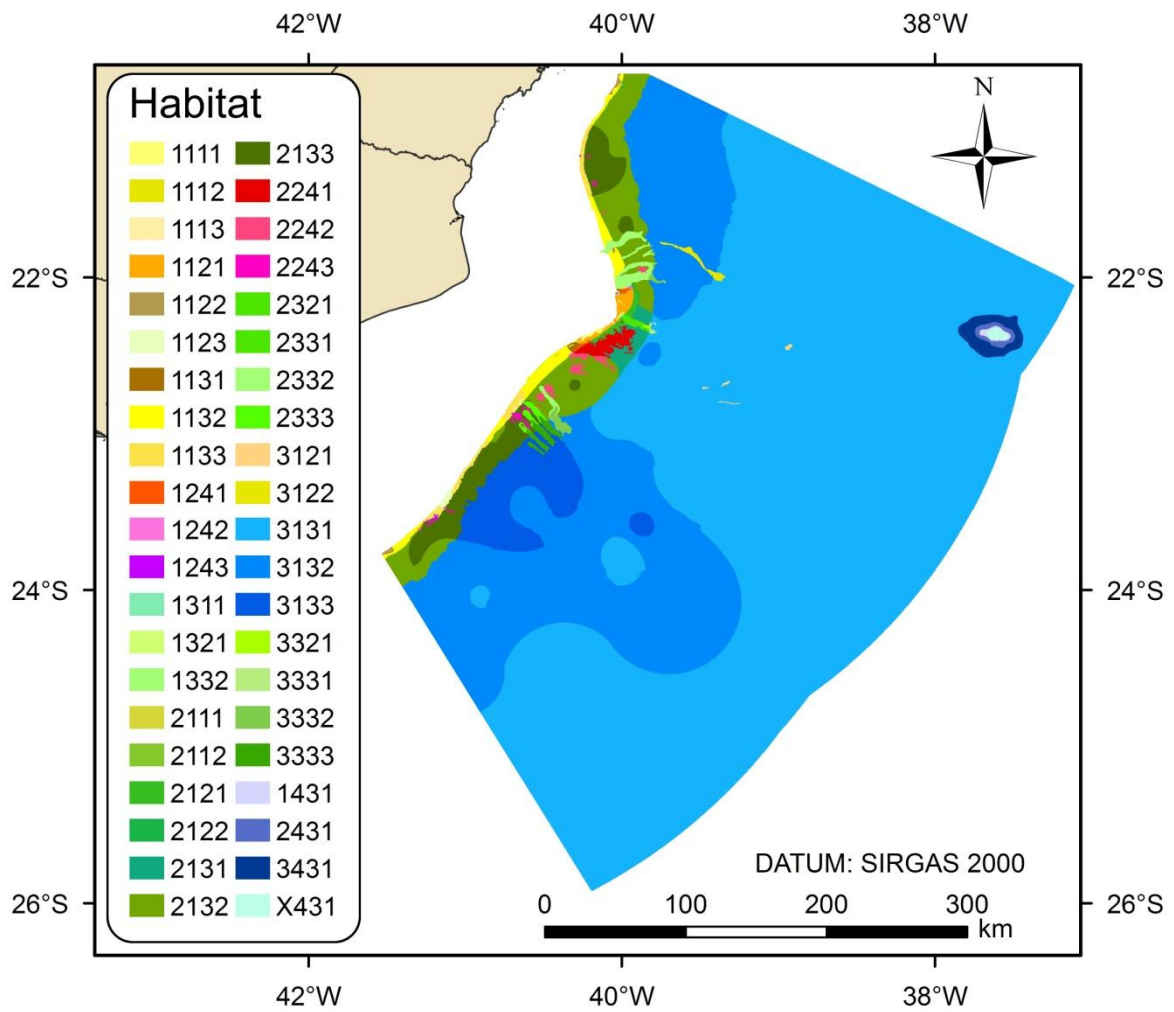
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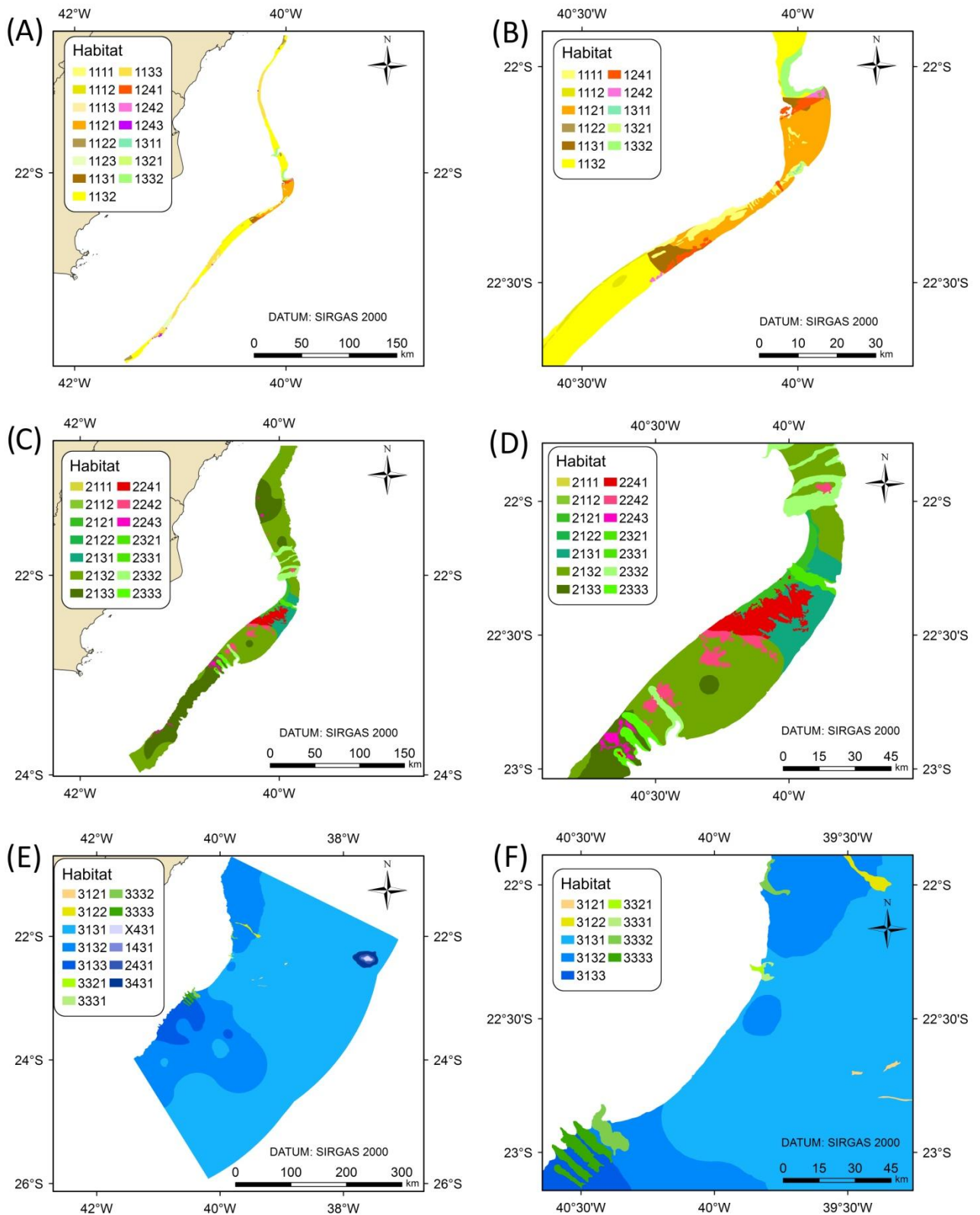
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 388 Figure 3: Benthic habitats map. Each habitat is a sole combination of classes in the 4 levels of the
 389 habitat classification scheme, represented by a four digit code (see Table 2).
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Figure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

408
409

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
	slope [1]*	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
	slope [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]*	1321	1	4.849	98.2
			mud [3]*	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
			low [1]*	2121	4	162.531	69.5
	slope [1]*	sand [2]*	medium [2]*	2122	3	16.916	81.0
			low [1]*	2131	6	480.085	75.7
			medium [2]*	2132	12	4,494.057	47.3
	slope [1]*	mud [3]*	high [3]*	2133	7	2,779.251	25.9
			low [1]*	2241	12	389.471	95.2
			medium [2]*	2242	24	233.780	91.2
	cold water coral reef [2]*	reef substrate [4]*	high [3]*	2243	16	93.831	55.8
			sand [2]*	2321	1	61.041	32.8
			low [1]*	2331	1	18.476	61.3
	canyon [3]*	mud [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

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417 Table 2 (continued): Benthic habitats map summary. * Digits in brackets represent each level on the
 418 habitat four digit code: first digit represents level 1 and so on. An additional bathymetric zone (<200
 419 m) was included to create a habitat type comprising the seamount's summit, in order not to leave a
 420 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
	canyon [3]*	mud [3]*	high [3]*	3133	2	3,882.548	26.4
			low [1]*	3321	1	10.413	0.0
			medium [2]*	3331	2	16.085	0.0
			high [3]*	3332	6	167.254	54.3
	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

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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 Bathymetric zones	Total area (km ²)	Overlap to leased areas (%)	Level 2 Geomorphic 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
						gravel	1.713	100.0
						sand	4.849	98.2
			canyon	71.294	16.9	mud	64.732	8.6
						seamount	61.509	0.0
						mud	61.509	0.0
						gravel	2.219	0.0
500 - 1500 m	9,480.038	46.3	slope	7,935.059	42.0	sand	179.447	70.6
						mud	7,753.393	41.4
						reef substrate	717.082	88.7
			cold water coral reef	717.082	88.7	sand	61.041	32.8
						mud	587.247	67.8
						seamount	179.609	0.0
			canyon	648.288	64.5	mud	179.609	0.0
						sand	160.472	0.0
						mud	122,994.240	4.5
						sand	10.413	0.0
>1500 m	124,251.361	4.7	canyon	438.122	68.6	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

444

445 3.2 Areas of interest for the conservation of benthic biodiversity (MPA network design)

446 The three scenarios for MPA design resulted in similar requirements for the total area to be protected,
 447 but with variable success on the overlap with current oil and gas activities in Campos Basin. In
 448 scenario 1, where MPAs could be freely positioned, the 30% representation target was successfully
 449 met for all habitats in all 1000 generated solutions, but every solution presents a high degree of
 450 overlap of MPAs to the leased areas. The best ranked solution (according to Marxan's objective
 451 function) overlaps over 60% of the total of leased areas within the study area (Figure 5). The total
 452 area for the MPA network on the best solution is 43,316.24 km², which corresponds to 33.2% of the
 453 deep Campos Basin area. This MPA network cover 53.6% of the upper slope; 50.5% of the middle
 454 slope and 30.1% of the lower slope. In scenario 1 the majority of the PUs with higher selection
 455 frequency area located on the central region of the Campos Basin (Figure 5), driven mainly by the
 456 occurrence rare and patchy habitats in this region (i.e. high habitat heterogeneity). In this scenario,
 457 only 0.4% of the total PUs can be considered highly irreplaceable (selection rate \geq 80%) for an
 458 efficient MPA network design.

459

460 In Scenario two, no solutions were able to meet the 30% representation target for all habitats, given

461 that MPAs location was restricted to non-leased areas. On the best solution 15 habitats were
 462 underrepresented (Table 4), and least 14 were underrepresented in all solutions. In this scenario there
 463 was an increase in the proportion of highly irreplaceable PUs (i.e. selection rate $\geq 80\%$) compared to
 464 the first scenario. Scenario two had over 4 times more highly irreplaceable PUs if compared to
 465 scenario one, and 175 PUs (0.6%) had selection rates of 100% (figure 5). The total area for the MPA
 466 network on the best solution for scenario two is 40,735.18 km² (figure 5), which represents 30% of
 467 the deep Campos Basin area. This MPA network cover 34.3% of the upper slope; 28.4% of the
 468 middle slope and 30% of the lower slope, with no overlap to leased areas.

469

470 Table 4: Fifteen habitats miss the 30% representation target on the best solution for scenario 2, given
 471 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	
cold water coral reef		reef substrate	mud	low	2131	24.25
			low	2241	4.56	
	canyon	mud	medium	2242	9.28	
			high	3333	12.50	

472

473 In the third scenario, given that MPA positioning was restricted only within a 5 km buffer around oil
 474 production platforms, 93.6% of the solutions were able to met the 30% representation target for all
 475 habitats, and all 1000 solutions presented at least 29% of representation for all habitats. On the best
 476 solution, MPAs overlap with leased areas is only 5.5% of the total area leased within deep Campos
 477 Basin (Figure 5). In this scenario 1.6% of the PUs have selection rate $\geq 80\%$, and these PUs may
 478 represent extremely important areas for conservation (Figure 5). The MPA network on the best
 479 solution for this scenario has a total area of 40,924.89 km² (30.1% of the deep Campos Basin area),
 480 and cover 34.3% of the upper slope, 31.2% of the middle slope and 30% of the lower slope.

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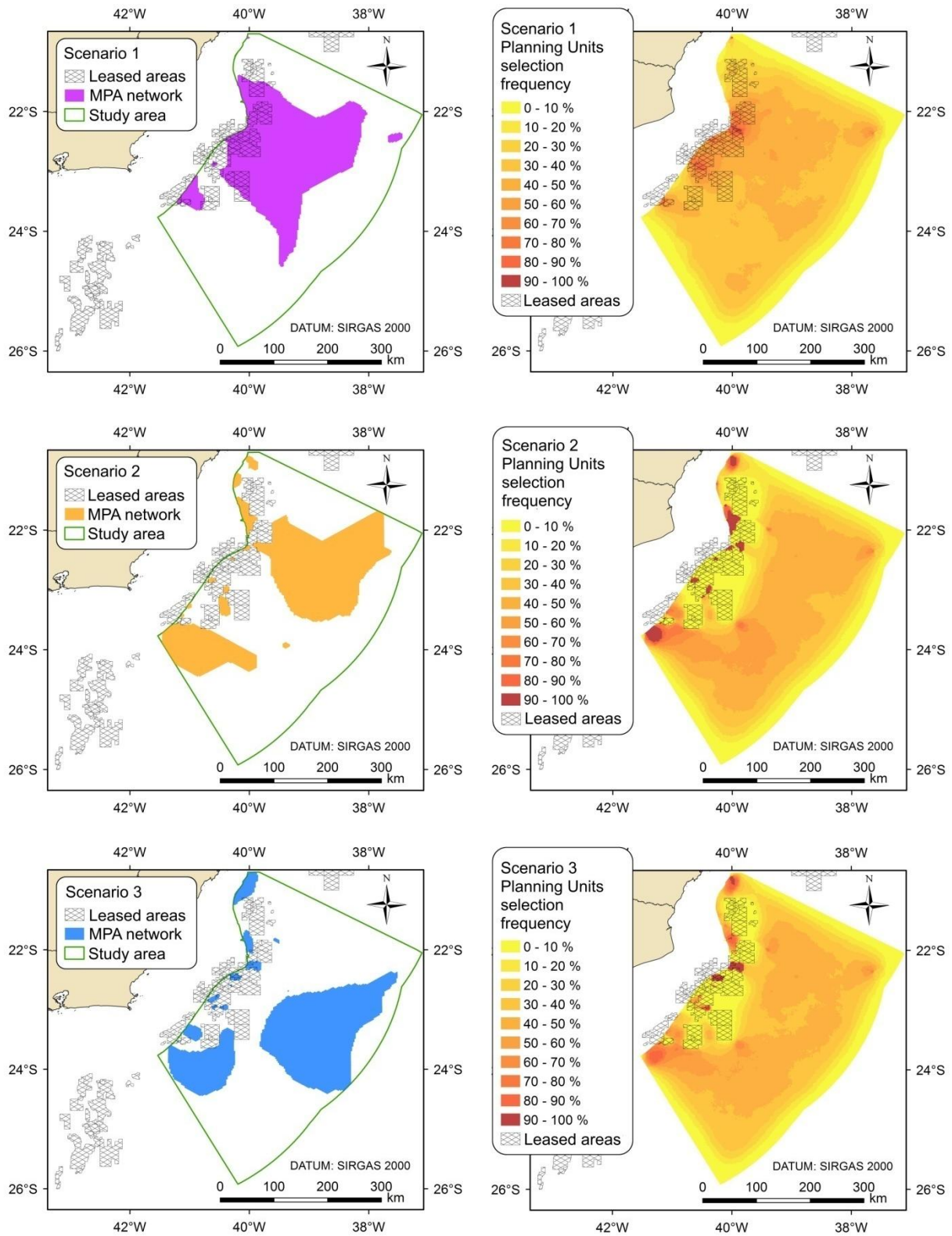
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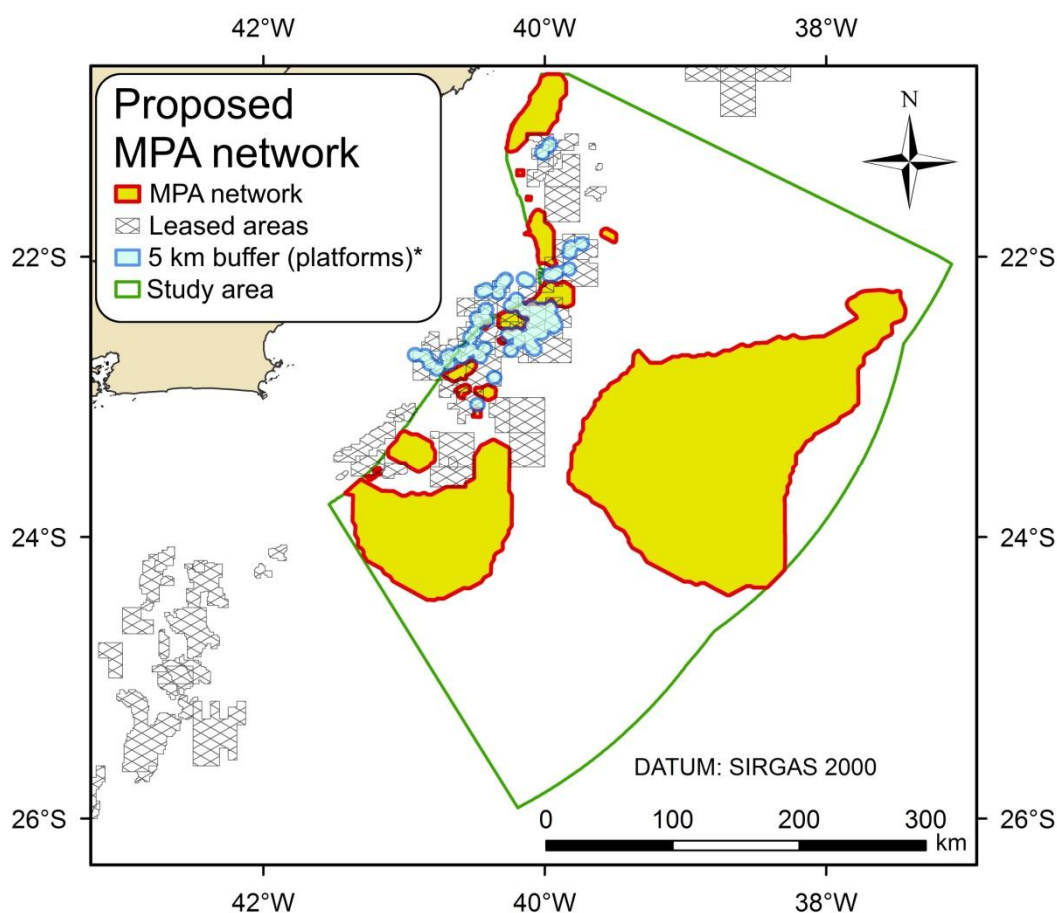


487
 488 Figure 5: Results for each of the three modeled scenarios: (Left) MPA network on the best solution;
 489 (Right) frequency distribution of PUs selection.
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492 The 50 km limit for maximum distance between nearest MPAs in the network was met by the best
 493 solution of scenario 3. Thus, we built a proposition for a MPA network based on that result, in which
 494 we have enhanced the representation of sensitive habitats associated to cold water coral reef and

495 seamount. Three additional MPAs were included on the network in order to protect coral reef habitats
 496 that don't overlap with leased areas and remained unprotected. The Almirante Saldanha seamount
 497 was fully included on the largest MPA on the network, which already comprised 30% of the
 498 seamount. This proposition of a MPA network (figure 6) comprises 18 individual MPAs, with a total
 499 area of 42,454.76 km² (31.28% of the study area). The maximum distance between nearest MPAs in
 500 the proposed network is 42.33 km. but this distance is lower (15.22 km) for part of the network on
 501 the upper and middle slope (depth 200 to 1500 m). A comparison of habitat protection and overlap to
 502 leased areas between the proposed MPA network and the best solution for scenarios one and two is
 503 shown on table 5 and represented graphically on supplementary material (Figure S4). Representation
 504 of each individual habitat in the proposed MPA network is shown on supplementary material (Table
 505 S5).

506



507
 508 Figure 6: Proposition of a MPA network based on habitat representativeness and low overlap (5.5%)
 509 with areas leased to the oil industry. * The 5 km buffer was set only for oil/gas production units.

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

Overlap of MPAs to leased areas		Scenario 1		Scenario 2		Scenario 3 (Proposed MPA network)	
		60%		0%		5.5%	
Level 1 - bathymetric zones	Level 2 - geomorphic features	Area on MPA network (Km ²)	Representation (%)	Area on MPA network (Km ²)	Representation (%)	Area on MPA network (Km ²)	Representation (%)
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

517

518 4 Discussion

519 This study identified a number of biologically relevant and vulnerable deep sea habitats distributed
 520 along the continental slope of Campos Basin, many of them located within current leased areas for
 521 the oil and gas industry. The leased areas are concentrated over the upper and middle continental
 522 slope, mostly over the central region of Campos Basin, with a significant overlap with several unique
 523 ecosystems of high biodiversity, including cold water coral reefs, submarine canyons and slope
 524 sediments. Deep sea coral reefs on Campos Basin are structured by typical cold water reef building
 525 species, including *Lophelia pertusa*, which may harbor several associated species with no
 526 representation on non-coral habitats (Cordes et al., 2008; Arantes et al., 2009; Lessard-Pilon et al.,
 527 2010). The submarine canyons also may host a distinct biodiversity over the margin and sustain
 528 important habitats for fisheries (De Leo et al., 2010; De Leo et al., 2014). Although the degree of
 529 biological uniqueness on deep sea communities in Campos Basin is still uncertain, some of the
 530 identified habitats meet several criteria (e.g. biological relevance, uniqueness, threat, etc.) to be
 531 considered Ecologically and Biologically Significant Areas (EBSA's) (Clark et al., 2014; Dunn et al.,
 532 2014), and some can be considered critical habitats for marine industries (Martin et al., 2015), and
 533 therefore should be targeted for protection. The mapped habitats were identified based on an
 534 extensive but still limited dataset, and mostly by seabed geophysical surveys carried by the industry
 535 over areas of commercial interest. Although geophysical roughness may have low performance as a
 536 surrogate for diversity (Schlacher et al., 2009), the mapped EBSA's represent a conservative picture
 537 of the heterogeneity and diversity within the deep Campos Basin. The sedimentary and organic
 538 carbon surrogates were also conservatively applied towards habitat identification, but these variables
 539 are markedly associated with benthic diversity and assemblage composition over the slope
 540 (Bernardino et al., 2016).

541

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

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

562

563 The Systematic Conservation Planning aims for a representation of the whole set of biodiversity
564 within a given area and, therefore, some areas may be excluded from protection provided that
565 ecological processes are not dramatically affected and that the biodiversity it contains can be
566 protected elsewhere. However, our results indicate that some habitat types, including 5 of the 6
567 identified cold water coral reef habitats, would not reach a minimum of 30% representation on a
568 MPA network if protected exclusively outside current the leased areas. Upper and middle slope soft
569 bottom habitats were also significantly occupied by leased areas (Table 3). However, the proposed
570 MPA network, with a minimum of 30% of protection for all habitats, has minimal overlap with the
571 leased areas, using less than 6% of the leased areas within deep Campos Basin to reach the
572 conservation goal. The highly irreplaceable areas for conservation, indicated by the planning units
573 with high selection frequency (>80%) in scenario three (figure 5), represent extremely important
574 areas for establishing a MPA network, as they support the co-occurrence of benthic biodiversity
575 conservation with the current offshore industrial activities. These results suggests that an ecosystem
576 based biodiversity conservation plan, with consistent habitat representation (30%), can be
577 implemented without disrupting current industrial activities in the deep Campos Basin. Although the
578 30% representation target applied in this study may seem high if compared to the CBD's guidelines,
579 the conservation of larger areas may also ensure protection of unmapped fish stocks and safeguard
580 vulnerable deep sea habitats against other sources of impacts and environmental change (Roberts et
581 al., 2006a; Davies et al., 2007; Armstrong et al., 2014).

582

583 While negotiating improvements in the design of the proposed MPA network with stakeholders,
584 decision makers should give some attention to the tradeoffs involving coral reef habitats. Although
585 cold water coral reefs ecosystem functions in Campos Basin are yet to be fully unveiled, it is evident
586 that they are complex and vulnerable tridimensional habitats that support high biodiversity (Roberts
587 et al., 2006b). Representation of cold water coral habitat types on the proposed MPA network varies
588 from 31.8% to 56.4%, surpassing the initial 30% representation target. However, as stated before, the
589 high resolution geophysical surveys did not cover the entire study area, and population variability and
590 connectivity patterns for coral species is unknown in Campos Basin. Furthermore, most cold-water
591 coral habitats on Campos Basin are concentrated within the upper and middle slope, in areas with
592 historical industry activity, densely occupied by leased areas and prone to have new exploratory

593 blocks offered in future bidding rounds. To address this situation, it is recommended to incorporate
594 new areas within the depth range of cold water coral reef habitats occurrence (200 to 1500 m) to the
595 future MPA network in deep Campos Basin, as broadly as possible. On the other hand, the oil
596 industries are likely to offer some resistance to the expansion of the MPA network in the mentioned
597 depth range, which may contain still undiscovered hydrocarbon reservoirs.

598

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

617

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

638

639 **Authors contribution statement:** GA and AB contributed to this manuscript analyzing datasets,
640 writing and editing the text, creating and editing figures and tables.

641

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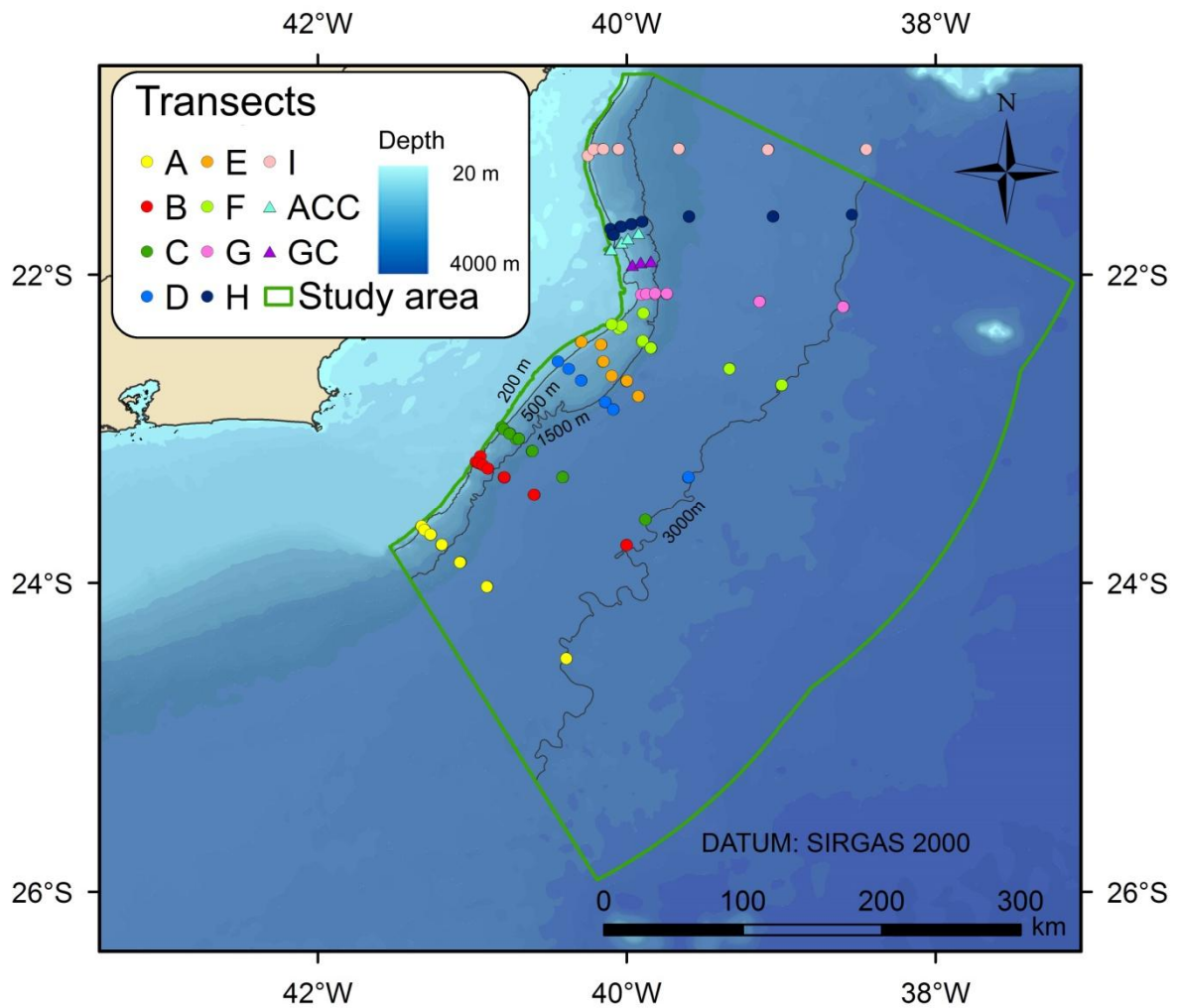
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 993 Figure S1: Sampling grid of the 'Habitats' project on the deep Campos Basin. On each transect
 994 samples were taken in real triplicate in depths of 400 m, 700 m, 1000 m, 1300 m, 1900 m, 2500 m
 995 and 3000 m. Canyon samples were taken in the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

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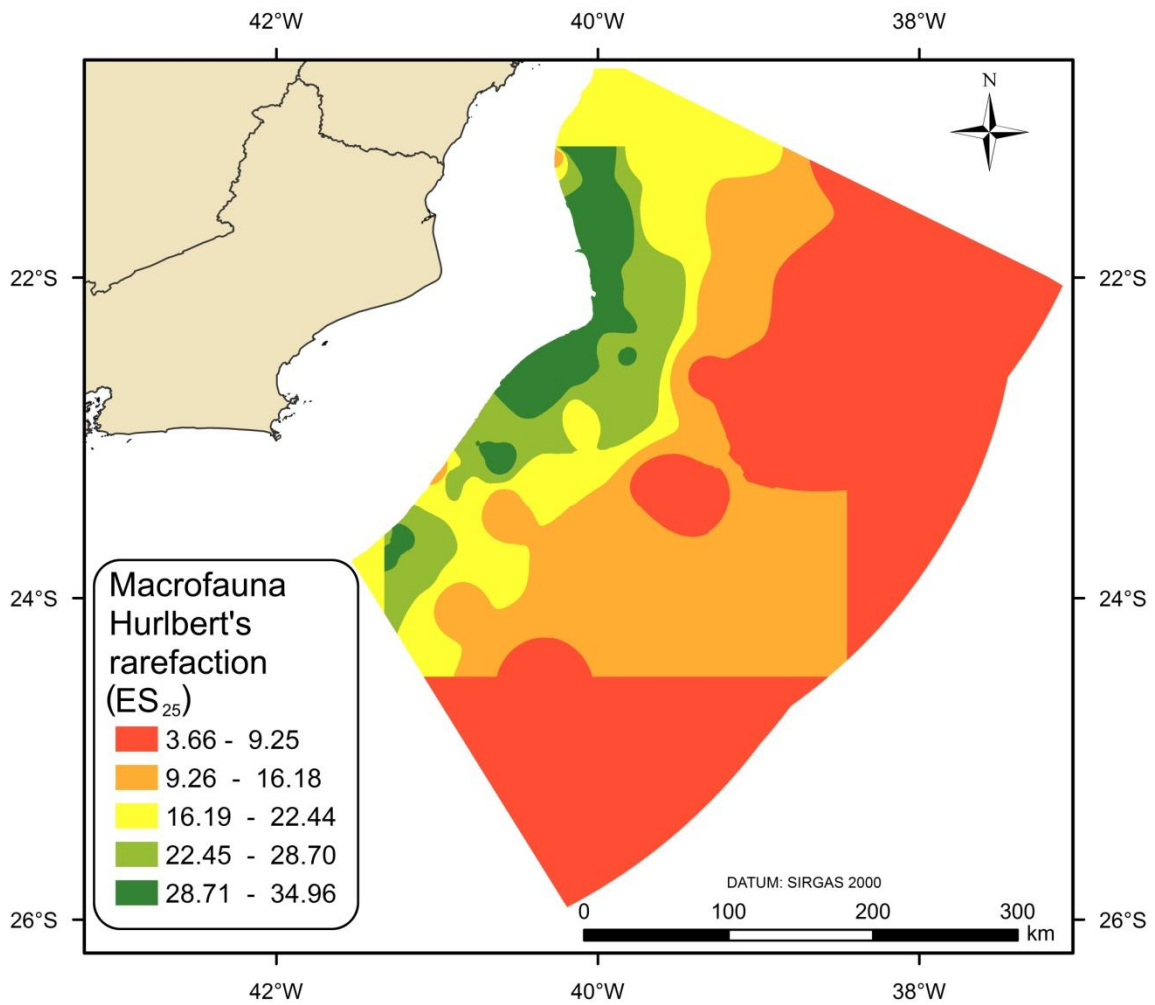
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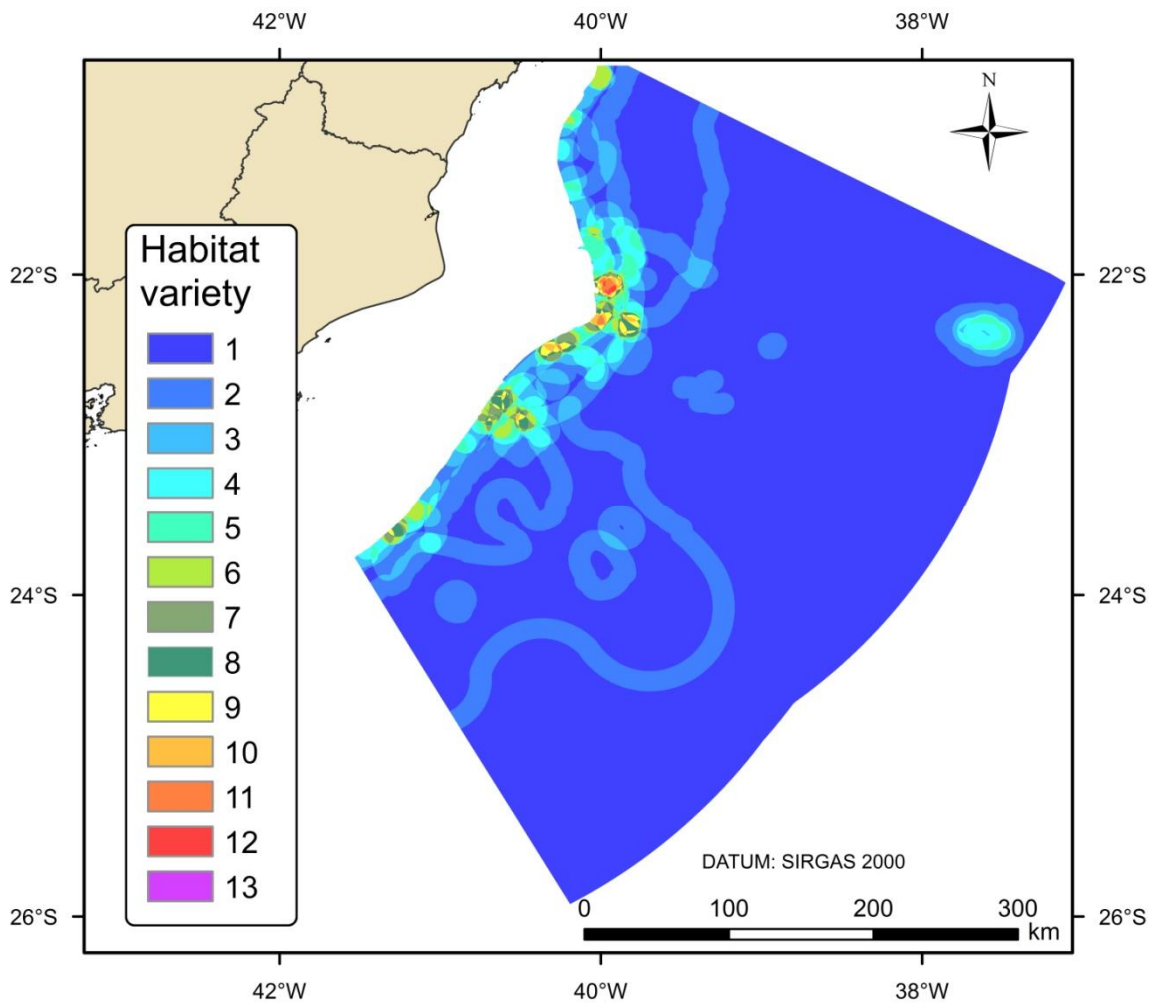
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 1007 Figure S2: Benthic macrofauna diversity (Hurlbert's rarefaction curve index). 'Edges' of the study
 1008 area were not covered by resulting interpolated surface, thus being conservatively assigned as middle
 1009 class (ES_{25} 16.19 - 22.44) if comprising the upper or middle slope (depth 200 to 1500 m) or lower
 1010 class (ES_{25} 3.66 - 9.25) if comprising only the lower slope (depth >1500 m).
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 1023 Figure S3: Habitat variety map (number of different habitat types within a 7 km radius) indicates that
 1024 habitat heterogeneity is bigger in the upper and middle slope (200 - 1500 m).
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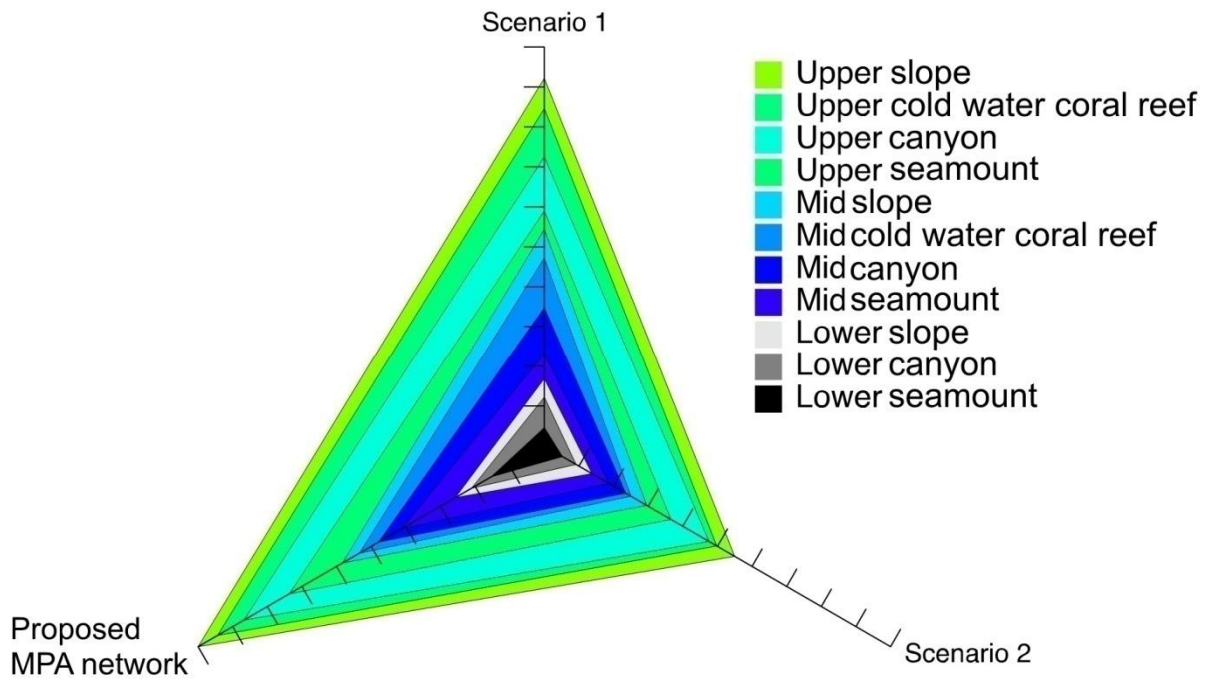
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1034 Figure S4: Comparison of habitat protection between the proposed MPA network and best solutions
 1035 obtained in scenarios 1 and 2 (absolute values are presented in Table 5). Scale of values in each axis
 1036 is proportional to the biggest values obtained for each habitat.

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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)	Representation on MPA network (%)	Habitat code	Area within MPA network (km ²)	Representation on MPA network (%)	Habitat code	Area within MPA network (km ²)	Representation 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						

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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 atualmente 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.

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VI. ANEXOS

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