FISHING IMPACT ON DEEP-SEA COLD-WATER CORAL COMMUNITIES OF THE AZORES: CONTRIBUTION TO DESCRIPTOR 6 OF THE MARINE STRATEGY FRAMEWORK DIRECTIVE

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Faculdade de Ciências da Universidade do Porto
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2021

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Todas as correções determinadas pelo júri, e só essas, foram efetuadas.

O Presidente do Júri,

Porto, ______/______/_________

MSC

AKNOWLEDGMENTS

Em primeiro lugar, ao meu orientador Telmo Morato, pela minha inclusão e acolhimento, exigência, e conhecimento partilhado, sem os quais esta dissertação nunca teria sido concluída. Um sincero obrigado por me ter aberto as portas sem hesitar e me fazer também um pouco parte deste grupo.

À minha coorientadora Joana Xavier por toda a sua disponibilidade, fornecendo sempre apoio e feedback essenciais. Um obrigado por toda a simpatia, prontidão e encorajamento.

Ao Carlos Carrió, pela sua presença, disponibilidade e acompanhamento constantes e esclarecimento de (muitas) dúvidas.

À Marina Carreiro Silva e ao Luís Rodrigues pelo apoio e pareceres fornecidos por variadas ocasiões.

Aos meus pais por, uma vez mais, continuarem a possibilitar-me a perseguição das oportunidades para fazer aquilo que sempre quis, e tornarem um pouco mais alcançáveis os objetivos que procuro.

A todos os amigos que Coimbra fez.

À Kally, por tudo. Se há 5 anos me ensinaste quais as 9 ilhas dos Açores, hoje agradeço-te estar a conhecê-las contigo.

ABSTRACT

The Marine Strategy Framework Directive (MSFD) was adopted by the European Union in 2008, providing an ecosystem-based approach, with objective criteria and methodologies for determining Good Environmental Status (GES) and which enable the protection of the marine environment. The MSFD comprehends 11 qualitative descriptors, of which Descriptor 6 (D6) represents "sea-floor integrity", considered an inherently challenging descriptor, particularly when it addresses ecosystems such as those found in the deep-sea, for which knowledge is limited.

This extensive biome is nowadays known for its heterogeneity, which promotes a species-rich environment and where distinct physical and biological processes occur, contributing to its uniqueness. Nevertheless, many inherent traits of this ecosystem – patch-like features and pin-point-exerted pressures, for instance - make its study and assessments substantially challenging.

The Azores archipelago is an area of high Blue Growth potential where, however, a clear lack of information regarding its deep-sea ecosystems hinders their preservation and management substantially. This gap has led to considerable scientific efforts in the last years to better describe its functioning and the anthropogenic impacts present. As a result, many new distinct benthic habitats such as coral gardens, hydrothermal vents and sponge aggregations harbouring several species that rely on the services provided by said habitats have been described. Cold-water corals (CWCs), in particular, occur frequently and are thought to drive fish species distributions, including important commercial species, therefore supporting deep-sea fisheries. However, their life traits suggest high vulnerability and low recovery capacity when human-induced pressures are present, such as deep-sea fishing, being often considered as Vulnerable Marine Ecosystem indicators.

A permanent ban on bottom trawling was implemented in 2005 in the archipelago, after reports of impacts of this fishing activity on benthic communities, including CWCs. Nowadays, Azores' fishing fleet is mainly artisanal and composed of small-scale fishing vessels, mostly performing bottom longline and handline fishing. CWCs are common bycatch targets of bottom longline fishing in the Azores with traits such as structural complexity having been linked with CWCs' higher susceptibility to damage. This selective effect could trigger potential community shifts, favouring smaller, opportunistic species. However, the real level of impact on these communities is argued to be much higher. Therefore, a better understanding of the impacts caused by these fishing techniques in the deep-sea communities of the Azores is of utmost importance. The application of the

MSFD framework including D6 assessments, along with successful evaluations of GES in this subregion still need higher data resolution to be acquired, more efforts regarding habitat mapping and more comprehensive studies involving structuring species.

This work aimed to formulate and test indicators and standardized methods suitable for GES evaluations, specifically contributing towards future assessments of D6 in the Azores. CWCs were used as VME indicator taxa to describe and assess the condition of benthic communities.

The Gigante Seamount complex was chosen as the study area and thirteen different CWC species identified as relevant habitat-builders in the Azores selected for analysis. Two separate scales were created to objectively apply the indicators formulated: percentage of coral structure physically affected, and percentage of coral covered by epibenthic organisms, using video footage of the seabed to provide *in situ* observations and assessments.

A total of 11524 colonies were annotated and 7066 partially or fully assessed throughout 13 video transects observed and nearly 27.000m^2 of seafloor covered. Despite this extensive data gathering process, few observations were made for the majority of the selected CWC species, limiting the analyses performed. Nevertheless, differences between species, structural complexities and areas assessed were detected, supporting the idea that our indicators and methodologies are sensitive and adequate to perform GES assessments regarding D6. Previously reported correlations such as between species' structural complexity and their susceptibility to impacts, cannot, however, be backed up due to the ambiguity of our results concerning this issue. Regarding the hypothesized correlation between coral condition and fishing effort, there is still a need for further clarification on the matter. No indicator, regardless of the area assessed - other than epibiosis level in Gigante Seamount area -, proved a correlation with fishing effort, a conclusion probably hampered by a lack of sampling units and diversity of observations.

With the present study, we contribute towards the application of suitable GES indicators and methodologies that facilitate future assessments of CWC deep-sea ecosystems, always considering D6 and the MSFD as the guiding framework that upholds the maintenance of seafloor integrity and the protection of the marine environment.

Keywords

Cold-water corals; Deep-sea fisheries; Seabed integrity; Fishing effort; Structural complexity; Management and conservation

RESUMO

A Diretiva-Quadro Estratégia Marinha (DQEM) foi adotada pela União Europeia em 2008, providenciando uma abordagem ao nível do ecossistema, com critérios e metodologias para a determinação do Bom Estado Ambiental (BEA), apoiando a proteção do meio marinho. A Diretiva considera 11 descritores qualitativos, entre os quais o Descritor 6 (D6) representa a “integridade dos fundos marinhos”, sendo considerado um descritor inerentemente desafiante, em particular quando se refere a ecossistemas como os que encontramos no mar profundo, sobre os quais o conhecimento é limitado.

Este extenso bioma é atualmente conhecido pela sua heterogeneidade, que promove um ambiente rico em espécies, onde processos físicos e biológicos distintos ocorrem, contribuindo para a sua singularidade. Não obstante, muitas características inerentes a este bioma – os seus ambientes pontuais e pressões exercidas localmente, por exemplo – tornam o seu estudo e avaliações substancialmente mais difíceis de realizar.

O arquipélago dos Açores é uma área com alto potencial para Crescimento Azul onde, no entanto, a falta de informação relativa a este bioma compromete bastante a sua preservação e manutenção. Esta falha tem levado a esforços científicos consideráveis nos últimos anos de forma a descrever melhor o seu funcionamento e os impactos antropogénicos que nele atuam. Consequentemente, diversos novos habitats bentónicos tais como jardins de corais, fontes hidrotermais e agregações de esponjas, que albergam diversas espécies que dependem dos serviços por estes providenciados, têm vindo a ser descobertos. Os corais de águas frias ocorrem frequentemente nas águas dos Açores e pensa-se que influenciam as distribuições de espécies de peixes, incluindo algumas de valor comercial importante, suportando assim, também, pescarias de mar profundo. No entanto, as suas características de história de vida sugerem alta vulnerabilidade e baixa capacidade de recuperação quando pressões humanas estão presentes, tal como a pesca em mar profundo, sendo muitas vezes considerados indicadores de Ecossistemas Marinhos Vulneráveis.

A proibição permanente da pesca de arrasto de fundo foi implementada em 2005 no arquipélago, após descrições do impacto desta atividade pesqueira em comunidades bentónicas, incluindo corais de águas frias. Hoje em dia, a frota pesqueira dos Açores é maioritariamente artesanal e caracterizada por embarcações de pesca a pequena escala, na sua maioria usando palangre de fundo ou linhas de mão. Os corais de águas frias são normalmente alvos de captura acessória por parte de palangre de fundo nos

Açores, tendo características como a complexidade estrutural dos mesmos sido associadas à uma maior suscetibilidade a dano. Este efeito seletivo poderá levar a alterações ao nível da comunidade, favorecendo espécies mais pequenas e oportunistas. No entanto, o impacto real nestas comunidades é considerado ser substancialmente mais alto. Assim, uma maior compreensão dos impactos causados por estas técnicas de pesca nas comunidades de mar profundo dos Açores é da maior importância. A aplicação da DQEM, incluindo avaliações do D6, juntamente com determinações do BEA nesta área requerem ainda maior resolução de dados, mais esforços de mapeamento de habitats e estudos mais compreensivos referentes a organismos estruturantes.

Este trabalho pretendeu formular e testar indicadores e métodos adequados para avaliações do BEA, especificamente contribuindo para levantamentos futuros do Descritor 6 nos Açores. Corais de águas frias foram usados como indicadores de Ecossistemas Marinhos Vulneráveis para descrever e estimar a condição das comunidades bentónicas.

O complexo do monte submarino Gigante foi escolhido como área de estudo e treze diferentes espécies de corais de águas frias identificadas como "construtores de habitat" relevantes nos Açores foram selecionadas para análise. Duas escalas distintas foram criadas para aplicar objetivamente os indicadores formulados: percentagem de estrutura do coral fisicamente afetada e percentagem da estrutura do coral coberta por organismos epibiontes, usando imagens de vídeo do fundo marinho para permitir observações e avaliações *in situ.*

Um total de 11524 colónias foram anotadas e 7066 avaliadas parcial ou na sua totalidade, ao longo de 13 transeptos de vídeo e cerca de 27.000m^2 de fundo marinho apreciado. Apesar deste extenso processo de colheita de dados, poucas observações foram feitas para a maioria das espécies de corais selecionadas, limitando a maioria das análises efetuadas. Não obstante, diferenças entre espécies, complexidades estruturais e áreas avaliadas foram detetadas, dando suporte à ideia de que os nossos indicadores e metodologias são sensíveis e adequados para avaliações do BEA referentes ao D6. Correlações anteriormente reportadas tais como entre a complexidade estrutural das espécies e a sua suscetibilidade a impactos não pode, no entanto, ser corroborada devido à ambiguidade dos nossos resultados relativamente a este tema. No que diz respeito à correlação hipotética levantada entre a condição dos corais e esforço de pesca, há ainda a necessidade de a clarificar futuramente. Nenhum indicador, independentemente da área avaliada – excluindo dano por epibiose no monte submarino

Gigante – provou estar correlacionado com o esforço de pesca, uma conclusão provavelmente motivada pela falta de unidades amostrais e diversidade de observações.

O presente estudo contribui para a aplicação de indicadores do BEA adequados e de metodologias que facilitem avaliações futuras de ecossistemas de mar profundo, tendo sempre em consideração o D6 e a DQEM como a abordagem a seguir para apoiar a proteção e conservação da integridade dos fundos e meio marinhos.

Palavras-chave

Corais de águas frias; Pescarias demersais; Integridade do fundo marinho; Esforço de pesca; Complexidade estrutural; Gestão e Conservação

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LIST OF ACRONYMS AND ABBREVIATIONS

MSFD	Marine Strategy Framework Directive
GES	Good Environmental Status
EU	European Union
ICES	International Council for the Exploration of the Sea
JRC	Joint Research Centre
EEZ	Economic Exclusive Zone
D6	Descriptor 6
TG	Task group
CWC	Cold-water corals
VME	Vulnerable Marine Ecosystem
FAO	Food and Agriculture Organization
VMS	Vessel Monitoring System
RMS	Root mean square
OFOP	Ocean Floor Observation Protocol

CHAPTER I. GENERAL INTRODUCTION

1.1. PROTECTION OF THE MARINE ENVIRONMENT ACROSS EUROPE: THE MSFD APPROACH

A sustainable management of the marine environment relies on continuous scientific and policy efforts that endorse it. The transboundary nature of the marine environment renders its management and the assessments performed quite demanding; therefore, holistic and consistent research is of major importance, ensuring that the best and most recent data is used to successfully carry out ecosystem-based approaches, applying objective indicators as well as practical methodologies to implement them.

The European Commission adopted, in 2008, the Marine Strategy Framework Directive (MSFD; Directive 2008/56/EC), which aimed to promote the effective protection of the marine environment across Europe (European Commission, 2008). The MSFD requested Member States to take all the necessary measures to achieve or maintain Good Environmental Status (GES) in the marine environment by 2020. Additionally, the MSFD reflected the EU need for an objective application of an ecosystem-based approach towards the protection of the marine environment, as well as a shift from the protection of specific habitats and species to a more holistic framework.

In 2010, the Decision 2010/477/EU (European Commission, 2010) was adopted, providing Member States with a framework to implement the MSFD and, consequently, for monitoring GES through continuous data gathering. This framework was revised in 2017 (Decision 2017/848/EU) with the adoption of better-defined criteria and methodological standards, as well as methods for monitoring, assessing, and establishing threshold values of GES (European Commission, 2017). Additionally, the International Council for the Exploration of the Sea (ICES) and the Joint Research Centre (JRC) were also contracted to provide scientific support to the Commission. Within this framework, 11 qualitative Descriptors (D) were formulated for determining GES of specific marine regions or subregions (Fig. 1):

- Descriptor 1. Biodiversity is maintained;
- Descriptor 2. Non-indigenous species do not adversely alter the ecosystem;
- Descriptor 3. The population of commercial fish species is healthy;
- Descriptor 4. Elements of food webs ensure long-term abundance and reproduction;
- Descriptor 5. Eutrophication is minimised;
- Descriptor 6. The sea floor integrity ensures functioning of the ecosystem;

- Descriptor 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem;
- Descriptor 8. Concentrations of contaminants give no effects;
- Descriptor 9. Contaminants in seafood are below safe levels;
- Descriptor 10. Marine litter does not cause harm;
- Descriptor 11. Introduction of energy (including underwater noise) does not adversely affect the ecosystem;

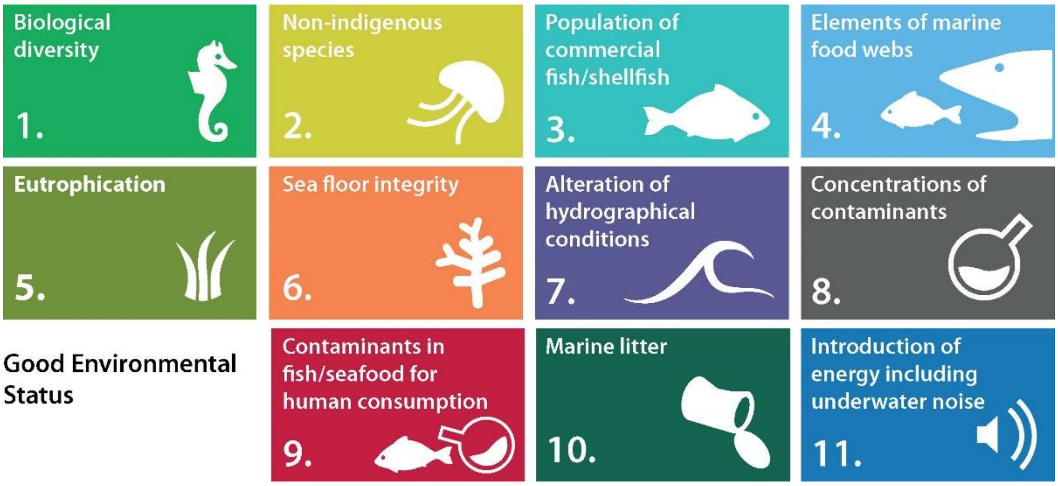


Figure 1. MSFD Descriptors for determining Good Environmental Status. Source: extracted in 2021 from EMODnet, available at https://www.emodnet-chemistry.eu/about/why.

In order to assess each Descriptor as uniformly as possible between Member States, the Decision 2017/848/EU laid out several primary and secondary criteria (criterions) for each one. Still, it acknowledges the possibility of Member States to decide whether to apply or not, or even to complement certain criteria, provided with justification. The MSFD also encouraged Member States to develop regional strategies which, while being specific to their waters, also reflected the desired holistic interpretation of the marine region and sub-regions concerned.

Despite the recognition that the MSFD has been a fundamental driver for a better understanding of the marine environment - including the pressures and impacts they are subject to - the European Commission’s recent progress report on the implementation of the MSFD (COM/2020/259; European Commission, 2020a) identified some consistency issues. These concerned either the methodologies and indicators used or the lack of coherence between Member States on the reported information. The Commission Staff Working Document (SWD/2020/61; European Commission 2020b) further elucidated these issues and the limited progress made by some Member States. By 2019, only 14 Member States had their reports submitted, also reflecting different commitment levels between them. Some of the inconsistencies may have resulted from the fact that well-defined criteria and methodological standards were only adopted in 2017.

Furthermore, despite the MSFD comprehending all marine waters included in Member States Economic Exclusive Zones (EEZs), its implementation seems to be narrower, rather focusing on coastal and shallow-water habitats when compared to the deep-sea. Regardless of the extension that this biome covers, it appears as though its relevance is overlooked, even though clear ecological links between coastal and deep-sea environments occur (e.g. Snelgrove et al., 2018). This apparent neglect could potentially lead to a lack of GES assessment, management and conservation of these ecosystems. Therefore, an extension of the MSFD implementation is needed for the deep-sea, otherwise, this framework will continue, counterintuitively, disregarding and undermining ecosystem-based approaches to the marine management.

1.2. DEEP-SEA ECOSYSTEMS AND DESCRIPTOR 6 ASSESSMENT

The deep-sea, considered to encompass waters below 200 m, is the largest biome in the world but one of the least studied. By the end of the last century, the concept of the deep-sea being characterized as a habitat of low biodiversity with limited production, no seasonality, or environmental changes, buffered from the atmosphere, upper ocean, and coastal ecosystem drivers (Glover et al., 2011) gradually shifted towards the notion that it is instead an extremely rich environment, with unique biotic and abiotic, structural and functional traits (Stuart et al., 2003; Ramirez-Llodra et al., 2010).

Changes in the physical environment and biological processes below 200m lead to markedly altered faunal composition and life-history traits (Gage & Tyler, 1991; Ramirez-Llodra et al., 2011; Levin & Sibuet, 2012; Danovaro et al., 2014). Great geomorphologic, geochemical and biogenic heterogeneity along its large extension promotes a species-rich environment, with its numerous distinct habitats and features such as seamounts, trenches, ridges, hydrothermal vents, coral gardens and sponge aggregations harbouring said biodiversity (Ramirez-Llodra et al., 2010; Levin & Sibuet, 2012). However, ever increasing anthropogenic stressors are known to act upon this environment, with bottom-contacting fisheries representing one of the most significant threats to these habitats (Koslow et al., 2000). This reinforces the need to better understand the consequences of these pressures, thus endorsing an effective protection of this extensive, rich ecosystem.

Assessments performed in these habitats mainly involve the characterization of the MSFD Descriptor 6 (D6 - The sea floor integrity ensures functioning of the ecosystem), along with suitable indicators (Kazanidis et al., 2020) specific for each of the constituent criteria of this Descriptor: spatial extent and distribution of physical loss of the natural seabed (D6C1), spatial extent and distribution of physical disturbance pressures on the seabed (D6C2), spatial extent of each habitat type which is adversely affected (D6C3), extent of loss of the habitat type (D6C4) and extent of adverse effects from anthropogenic pressures on the condition of the habitat type (D6C5) (European Commission, 2017). It is also worth mentioning that criteria D6C1, D6C2 and D6C3 only address elements such as physical loss and physical disturbance and their impacts, whereas D6C4 and D6C5 concern overall assessments of D6. Furthermore, evaluations concerning D6C4 and D6C5 take into consideration the assessments performed for D6C1, D6C2 and D6C3, along with other criteria which compose other Descriptors. The task group (TG) assigned to D6, composed by independent experts and coordinated by JRC and ICES (Rice et al., 2010), considers the assessment of this descriptor fundamentally challenging, mostly due to the “patchy” nature of the already mentioned benthic ecosystem features. It also underlines that not only the existing anthropogenic pressures act upon the marine environment in a pin-point manner but also, despite this, the ecological effects that said pressures trigger can be transported through a much larger spatial scale by abiotic and biotic phenomena. Such challenges naturally render the assessments of this ecosystem much more difficult. When addressing less studied ecosystems, such as the deep-sea, these issues become more evident, since the implementation of these marine policies becomes further hindered by a lack of information and coarser temporal and spatial resolution of available data. Such gaps ultimately limit conservation planning approaches and new policies supporting sustainable exploitation of deep-sea resources.

Therefore, in an attempt to deal with these challenges, this TG emphasises the importance of using a three-step approach: 1) identify the ecological features of particular importance, 2) identify anthropogenic pressures known or likely to be degrading the environment condition and 3) the use of appropriate attributes and, within these, indicators to adequately assess D6, against previously defined GES standards and along with significant, applicable scales that describe the seafloor condition and pressures.

Nevertheless, information regarding most of these benthic habitats remains scarce, making the application of the MSFD framework and evaluation of D6 still limited, to which also contributes a lack of standardized methodology to perform GES assessments.

1.3. THE AZORES DEEP-SEA ECOSYSTEMS

Among the sites which still requires a comprehensive knowledge about their deep-sea ecosystems is the Azores archipelago, included in the MSFD sub-region of Macaronesia (Fig. 2). The Azores is seen as an area of increasing Blue Growth opportunities in the deep-sea, particularly regarding deep-sea fisheries, biotechnology and deep-sea minerals (Morato et al., 2020a). The Blue Growth strategy was adopted by the European Commission in 2012 (COM/2012/494), which aimed to promote a marine-based development while ensuring its protection and preservation. The Azores' potential in this front further stresses the need to balance this growth with the preservation of deep-sea ecosystems. As a result, considerable scientific efforts have been made to better understand and more comprehensively characterize deep-sea ecosystems of the Azores and their human-caused impacts (Morato et al., 2008, 2020b). Several research projects and collaborations from local to international scale currently support this cause, which has led to more comprehensive knowledge and several discoveries being made in recent years, such as first reports of species and ecological associations, for instance (de Matos et al., 2014; Pham et al., 2015; Carreiro-Silva et al., 2017; Gomes-Pereira et al., 2017; Xavier et al., 2021).

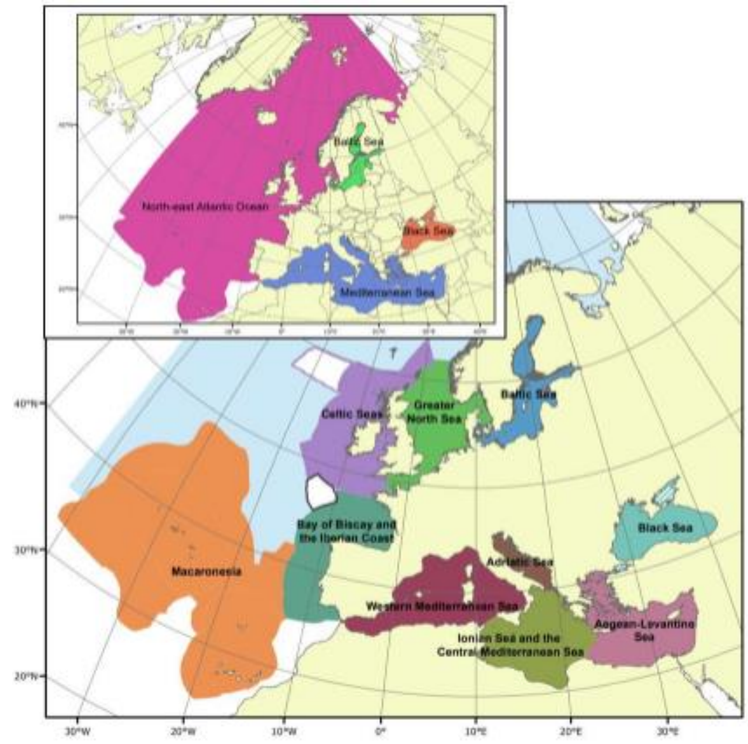


Figure X. MSFD regions and sub-regions. Source: extracted in 2021 from EMODnet, available at https://www.emodnet-chemistry.eu/about/why.

As a result, this archipelago harbours many distinct benthic habitats such as hydrothermal vents, coral gardens, and sponge aggregations, for instance (Tempera et al., 2013; Dominguez-Carrió et al., 2020), to which are often associated greater species richness and abundance, when compared with surrounding areas. In particular, habitat-forming organisms such as cold-water corals (CWC) and sponges promote higher biodiversity by increasing habitat heterogeneity due to their three-dimensional structure, providing nursery areas and protection for several species and creating ecological associations (Buhl-Mortensen et al., 2010; Braga-Henriques et al., 2011; Beazley et al., 2013; Henry et al., 2013; Pham et al., 2015; Carreiro-Silva et al., 2017; Gomes-Pereira et al., 2017; Ashford et al., 2019). These habitat builders can either form coral reefs, dense coral aggregations – coral gardens – or sponge aggregations (OSPAR, 2010). CWCs can serve as habitat for several fish among which are included commercially important species, such as *Helicolenus dactylopterus* (Delaroche, 1809) and *Pontinus kuhlii* (Bowdich, 1825), as Pham et al. (2014) reported in the Azores. Here, CWCs are often part of the bycatch resulting from bottom longline fishing, which further suggests a relationship between these habitats and commercial fish species distribution, although this cannot be implied merely based on this co-occurrence (Sampaio et al., 2012; Pham et al., 2014, 2015).

1.4. COLD-WATER CORALS AND IMPACTS OF FISHERIES

CWCs are considered important Vulnerable Marine Ecosystem (VME) indicators, considering FAO's developed criteria for defining one (FAO, 2009; 2016): 1) uniqueness or rarity, 2) functional significance of the habitat, 3) fragility, 4) life-history traits that make recovery difficult and 5) structural complexity. Therefore, CWCs can constitute useful tools to generate assessments of GES within the MSFD framework and, in particular, D6.

CWC species that occur in the Azores include members of the taxa Scleractinia (Bourne, 1990; stony corals), Alcyonacea (Lamouroux, 1812; gorgonians and soft corals), Pennatulacea (Verrill, 1865; seapens), Antipatharia (black corals), and Stylasteridae (Gray, 1847; hydrocorals), including 23 endemic species (out of 164) such as *Errina dabneyi* (Portualès, 1871) (Braga-Henriques et al., 2013).

Life-history traits of CWCs – high longevity and slow growth and reduced recruitment rates (e.g., Brooke & Young, 2009; Roark et al., 2009; Sabatier et al., 2012; Carreiro-Silva et al., 2013; Lacharité & Metaxas, 2013) – suggest that these habitats have a very low recovery capacity in response to disturbances (Pham et al., 2014; Clark et al., 2016,

2019) and are, therefore, likely to be affected by deep-sea fishing pressure. This is also backed by anecdotal reports of fisherman describing a reduction of black corals (*Leiopathes* spp., Haime, 1849) bycatch after years of deep-sea fishing activity. This susceptibility to disturbances further supports their use as VME indicators concerning GES assessments of D6.

Due to overexploitation of many fish stocks, deep-sea fisheries have shifted into deeper offshore waters, harvesting new target species and increasing the depth range in which previously exploited species were caught (Koslow et al., 2000; Morato et al., 2006; Watson & Morato, 2013; Clark et al., 2007; Diogo et al., 2015). The impacts of these anthropogenic activities are varied and intense, triggering direct effects on benthic communities through physical disturbance of the seabed and removal of previously mentioned habitat-building organisms, thereby reducing their coverage, diversity and abundance, concomitantly affecting associated organisms (Watling & Norse, 1998; Collie et al., 2000; Koslow et al., 2000; Hall-Spenser et al., 2002; Watson & Morato, 2004; Maynou & Cartes, 2012; Ragnarsson et al., 2017). In the long term, fisheries production can become haltered due to these negative impacts.

The impacts of fisheries in benthic ecosystems of the Azores have received considerable policy attention, raising the question of whether these are in GES. This awareness has led to the permanent ban of all bottom fishing activities in 2005, including bottom trawling, gill nets, and trammel, covering most of the Azores waters (European Council Regulation EC No. 1568/2005). Bottom trawling, specifically, is responsible for high bycatch and discard rates (Kelleher, 2005; Pham et al., 2013; Zeller et al., 2018).

Nowadays, fishing activity in the Azores is characterized as artisanal and small-scale, using passive and more selective fishing gears and reduced vessel size (Carvalho et al., 2011). These types of fisheries are usually less capital and fuel-intensive than large-scale activities, also being considered more sustainable than their larger counterpart (Sumaila, 2010; Carvalho et al., 2011; Suuronen et al., 2012; Pham et al., 2014). Approximately 90% of the fishing fleet is comprised of vessels of less than 12m (small-scale fishing sector), which is responsible for 52% of total landings in the Azores (Carvalho et al., 2011). Bottom longline gears and handlines are the most representative of the fishing techniques used by the Azorean fleet (47% of all fishing vessels) (Fig. 3), which target many of the same deep-sea demersal fish species, but mostly blackspot seabream (*Pagellus bogaraveo;* Brünnich, 1768), with other species including the blackbelly rosefish (*Helicolenus dactylopterus*), wreckfish (*Polyprion americanus*; Bloch & Schneider, 1801), European conger (*Conger conger*; Linnaeus, 1758), and alfonsinos (*Beryx* spp.; Cuvier, 1829) (Diogo et al., 2015; Fauconnet et al., 2019). These fishing gears are considered size and species selective and their bycatch and discard rates are much lower than bottom trawling (Pham et al., 2013, 2014).

Impacts of fishing activities on CWC communities have also been widely recognized, mostly the ones associated to bottom trawling (Koslow et al., 2000; Hall-Spencer et al. 2002; Wheeler et al., 2005; Althaus et al., 2009; Clark and Rowden, 2009; Benn et al., 2010; Murillo et al., 2011), with reports of clear damage to the seabed, associated decreased coral abundances, damaged colonies, and other significant impacts. Studies revealing the impacts of other fishing gears in these habitats - such as bottom longlines and gillnets – remain scarce, despite some occasional efforts (Muñoz et al., 2011; D'Onghia et al., 2012) reporting bycatch of CWC. In the Azores, in particular, CWC bycatch has been previously documented (Sampaio et al., 2012; Pham et al., 2014). Pham et al. (2014) stated that nearly 45% of longline sets were responsible for bycatch of epibenthic organisms, even though bycatch levels of CWCs were, on average, low (0,32 CWCs/1000 hooks). Nevertheless, there is a need for further research, as information on the matter is still unclear. Considering possible threats from bottom longlines and handlines, as these are the most used fishing gears in the Azores, as previously stated.

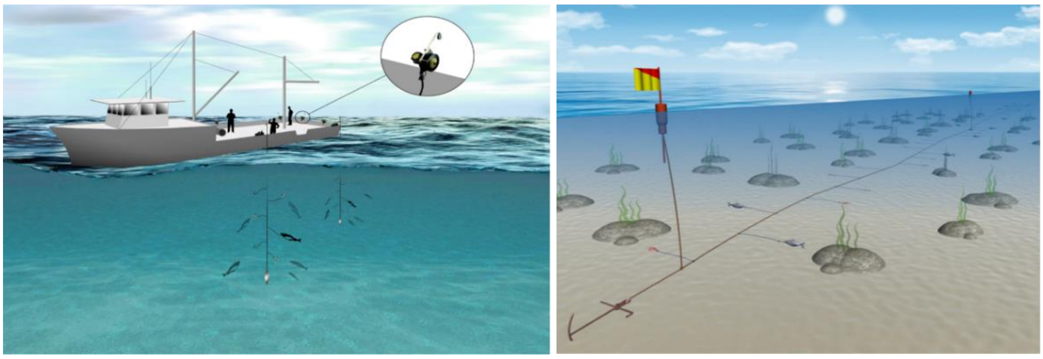


Figure X. Schematic representation of the most used fishing techniques in the Azores: handline (left) and bottom longline (right). Extracted from He et al., (2021) *Classification and illustrated definition of fishing gears*

Longlining can cover deeper and topographically complex areas - which are suitable habitats for CWCs and where bottom trawling is hardly performed (Wareham & Edinger, 2007). In fact, these fishing gears can be deployed until depths of 1200m, with its fishing effort being concentrated around areas between 200 and 700m (Pinho & Menezes, 2009). This could mean that intensive longline fisheries have the potential to, over time, trigger significant and specific effects in new, previously untargeted fishing grounds. Among these effects is a possible association between coral structural complexity and its likeliness of bycatch, with branched three-dimensional CWCs comprising most bycaught corals (Sampaio et al., 2011; Pham et al., 2014): larger and more complex CWC colonies are more easily entangled on fishing lines, contributing to their higher bycatch rate. This association raises some concerns given their particularly low recovery capacity. Still, although CWC longline bycatch by itself is not negligible, it underestimates the actual level of impact on these communities. Only part of the effects caused by longlines on CWCs is represented in bycatch since not every coral damaged by the gear is brought to the surface and thus accounted for as bycatch, possibly getting lost in the water column before reaching the deck or not getting caught at all (Wareham & Edinger, 2007; Heifetz 2009). Partial tissue damage in these organisms caused by fishing lines could also lead to harmful parasitic relationships by other corals or epibiont zoanthids (Mortensen et al., 2005; Carreiro-Silva et al., 2011; Bo et al., 2014a, b; Angiolillo et al., 2015). These can infect the colony and cause the elimination of the host's tissue, overgrowing it and ultimately resulting in mortality. Pham et al. (2014) showed that longlines had a negative impact on CWC communities, besides that of bycatch, underlying the selective negative effects of this fishing activity, since it mostly targets structurally complex organisms, potentially leading to shifts in community structure and functioning. Removal of these more vulnerable organisms could benefit assemblages composed of smaller, rapid growth, opportunistic species, which can easily recolonize areas after disturbances (Jennings & Kaiser et al., 1998; Clark & Koslow, 2007). However, differences between impacts on CWCs communities caused by longlining and bottom trawling are clear. Pham et al. (2014) predicted that a single bottom trawl could produce the same impacts as 296 to 1.719 longlines, which might suggest that sustainability of deep-sea fisheries can be achieved if bottom longline activities are properly regulated.

Although there are indications of the impacts caused by longline activities on these deep-sea habitats, further research is needed to better describe and comprehensively understand these issues. Assessing possible threats from these anthropogenic activities is important, as studies on this matter will help developing assessments of GES regarding D6 and will contribute to better understandings of the adverse effects they can trigger in CWC-formed habitats.

The Azores MSFD initial evaluation, produced in 2014 (SRRN, 2014), underlined the challenges found in the application of the MSFD framework and evaluation of D6 in this sub-region of the Azores. GES evaluation was undertaken, nevertheless: CWCs and hydrothermal vents were assessed based on the 2010 Commission Decision criteria (later revoked by the 2017 Commission Decision) and, in both cases, GES was achieved, despite low confidence levels, to which contributed the lack of available information on different issues, hindering the evaluation. Difficulties in the assessment of impacts were also expressed.

Contrasting with these limited assessments are other more extensively studied areas, such as the Mediterranean Sea, for example, with several papers addressing its specific 1) benthic communities and relevant ecological features, 2) anthropogenic pressures and 3) developed indicators, indices and methodological approaches (Cartes et al., 2013; Mytilineou et al., 2014; Bo et al., 2014a, b, 2015; Cau et al., 2015; Grynió et al., 2016; Gori et al., 2017; Enrichetti et al., 2019a, b, c). Consequently, assessments whose objectives are aligned with the MSFD and D6 framework are more easily and comprehensively performed in these regions, therefore more effectively contributing towards the preservation of seafloor integrity.

Successful evaluations of GES in the deep-sea of the Azores will still require higher temporal and spatial resolutions regarding the mapping and description of benthic communities and habitats and more knowledge regarding structuring species and their vulnerability to anthropogenic pressures. Consequently, we still lack definition as to which indicators and standardized methods are most suitable and, therefore, should be applied in future assessments of GES in this sub-region’s ecosystems, including the inherently challenging evaluation of Descriptor 6.

1.5. GOALS

The present thesis aims to develop sensitive indicators and standardized methodologies that will lead to more objective GES assessments of D6, particularly addressing criteria D6C3. It will also provide assessments of the condition of benthic habitats formed by CWCs, regarded as VME indicators, using *in situ* observations. This will hopefully clarify possible reported correlations such as between species’ structural complexity and their impact status modulated by their susceptibility to disturbances, namely fishing activities (Sampaio et al., 2012; Pham et al., 2014).

With this, we hope to facilitate future assessments of deep-sea ecosystems, by providing a clearer methodology with which these can be performed, and further contribute to the application of indicators of GES relevant to CWCs deep-sea benthic ecosystems of the Azores, always aligned with the MSFD framework and its constituent descriptors.

CHAPTER II. MATERIALS AND METHODS

2.1. SELECTION OF TARGET SPECIES

Through an expert-driven process, a set of CWC species were selected as indicators of GES. The selective process considered a series of natural history traits for each candidate species based on previously published literature and expert knowledge: structural complexity (average height and branching pattern), abundance and distribution (including degree of patchiness and occurrence in the Azores), and recovery capacity after a disturbance, based on survival rates while kept in aquariums, survival rates after experiments involving transplantation of bycaught coral fragments back into their natural environment and life history traits (growth rates). Species were selected from an initial pool of CWC known to occur (Braga-Henriques, 2013) and currently considered foundation species (Dayton 1972; Braga-Henriques, 2008; Pham et al., 2015; Gomes-Pereira et al., 2017) in the Azores, after assigning each species to its specific trait. In total, 13 species, distributed across the families/orders Alcyonacea, Antipatharia and Stylasteridae were selected (Table I; Appendix I, Fig. 1,).

Table I. Selected cold-water coral species and respective biological traits matrix

	Low **Rec. Cap.**	**Medium** **Rec. Cap.**	**High** **Rec. Cap.**
High **Struct. Comp.**	*Antipathella subpinnata*	*Callogorgia verticillata*	*Dentomuricea* aff *meteor*
	Leiopathes expansa	*Paracalyptrophora josephinae*	
	Leiopathes glaberrima	*Paragorgia johnsoni*	
Medium **Struct. Comp.**	*Candidella imbricata*		*Acanthogorgia* sp.
	Errina dabneyi		*Narella bellissima*
Low **Struct. Comp.**			*Viminella flagellum*
			Narella versluysi

2.2. STUDY AREA AND SEABED VIDEO SURVEYS

Located on a highly active tectonic area, including the Mid-Atlantic Ridge and the Terceira Rift, the Azores archipelago encompasses an extensive Exclusive Economic Zone (1 million km^2). The diverse geomorphology characterizing the seafloor (Peran et al., 2016) supports the uniqueness and biodiversity that characterize this sub-region, increasing habitat heterogeneity and often enhancing productivity through upwelling and other oceanographic phenomena (Bashmachnikov et al., 2004; Morato et al., 2009).

Gigante seamount complex – which include the areas of Gigante Seamount, 127 seamount and Western-Ridge - were selected as the geomorphological units to be evaluated (Fig. 4 & 5). These were selected due to the important fishing grounds they represent for bottom longline vessels of the region and because of the considerable quantity of underwater video footage available from this area containing the target species. In fact, this geomorphological complex harbours diverse benthic communities, with distinct geomorphological features.

High-definition video footage from the deep seabed (200-800 m depth) has been recorded in the Azores region during the past two years by means of the Azor drift-cam (e.g. Morato et al., 2020c), a low-cost drifting camera system developed at IMAR-UAç (Dominguez-Carrió et al., 2021). More than 20 different underwater features have been explored with this device, including several offshore seamounts and island slopes of the central group. Overall, more than 250 deployments have been accomplished, generating more than 130 km of seabed image data. This imaging system is designed to perform linear transects over the seabed down to 1000 m depth following the drift of the support vessel. On average, each deployment generates video data for around 500 linear meters, with an average bottom time of 45 minutes. The system is equipped with two action

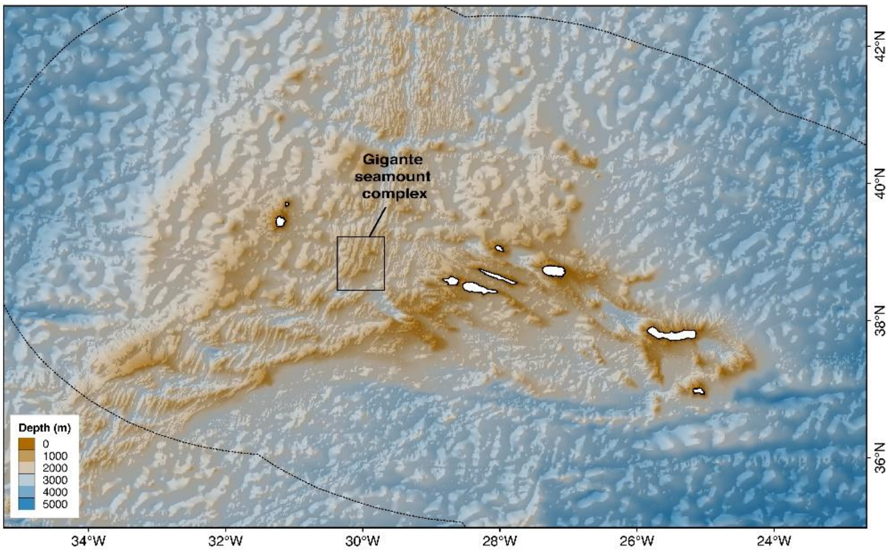
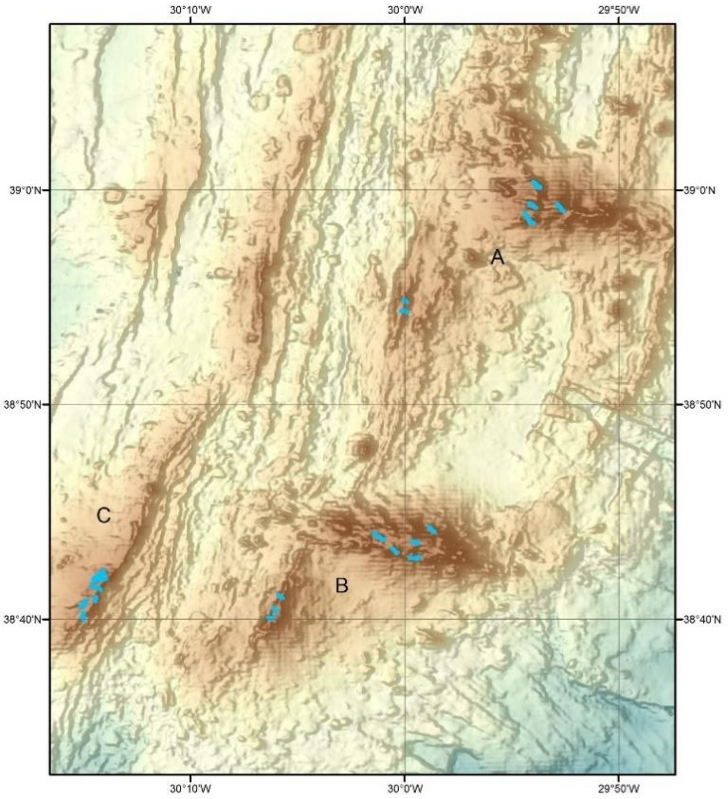


Figure 4**.** The Azores archipelago with Gigante seamount complex highlighted.



F*igure 5*. Gigante seamount complex and its areas assessed: A – Gigante Seamount; B – 127 Seamount; C – Western Ridge. Video transects analysed are highlighted in blue.

cameras placed in different angles (with a 4k action camera tilted towards the seabed for better taxonomic identification), two parallel laser beams used to scale the images and a depth/temperature sensor to obtain accurate data on the position of the system over the seabed. Having the laser beams as reference middle points, the annotation process was undertaken inside a 2m frame. For this study, we focused on 23 transects made in across our selected study areas (Fig. 5). The Gigante Seamount area comprehended an area of 6829 m^2 of seafloor observed and a total of 4322 annotations, the 127 seamount 6998 m^2 and 3863 annotations and the Western Ridge 6634 m^2, with 3339 annotations (Tab. XI).

2.3. FISHING INTENSITY

Existing maps of predicted fishing effort in the Azores, in particular those assessing bottom longline fisheries, computed from an analysis of the Vessel Monitoring System (VMS) for vessels licensed for those fishing gears were used. Fishing licences were used to assign a gear type to each VMS ping, with each record generated providing information about the vessel geographical position, date and time, speed, and fishing gear license.

Fishing effort data was gathered during a period of 17 years (from 2002 to 2018), offering information on the cumulative fishing time spent in hours per km^2 and density of VMS pings per km^2. A spatial grid composed of 100m^2 cells was used for analysis regarding fishing effort, with average values being generated for each cell.

2.4. VIDEO ANALYSES

Using *in situ* images is a valuable methodology with which to measure D6 and its constituent criteria, being a reliable way to assess the adverse effects in habitat type caused by anthropogenic pressures, in this case, particularly, by assessing the condition of CWC-formed habitats. Video images were annotated using the Ocean Floor Observation Protocol (OFOP, v. 3.3.7). Each target species and respective colony condition were annotated directly from the video footage, relating each occurrence to a specific geographical position in space (latitude/longitude) and later to a depth position. The annotation process followed a predefined guiding line, where a series of categories were used across each transect to describe it and later filter sections of the video footage unusable for annotation purposes. The mentioned categories included: “stopped at bottom”, “linear transect lasers”, “linear transect no lasers”, “moving sideways”, “moving backwards”, “erratic movement” and “off bottom”. Sections of the video footage assigned to the categories “moving backwards” and “off bottom” were discarded and the annotation process was not undertaken in these conditions. Lost fishing lines observed were also annotated. In cases of uncertainty (either related to species identification or assessment of colony condition), the safest possible decision was made (N/A), in which the presence of a coral was annotated but the species and/or condition assessment might not have been performed. Such precautionary approach was always implemented during the annotation process.

2.5. SELECTION OF INDICATORS

Physical condition and Epibiosis level of the colonies observed were used to assess the condition of the benthic habitats formed by CWCs and further develop assessments of D6 and its criteria. Physical condition referred to visible physical damage of the colony, i.e. broken/bent and/or missing branches whereas Epibiosis level described the relative portion of the colony structure affected by any visible epibiont/parasitic agent, regardless of its taxa, such as zoanthids or other corals, for instance. Two different scales were formulated to objectively apply the indicators selected and score damage/impact levels to the colonies from 1 (no damage/impact) to 5 (maximum damage/impact) (Tab. II & III). These indicators and scales were selected and formulated to contribute as an objective methodology to help measuring D6C3 - the extent of habitat adversely affected – and consequently D6C5 - the extent of adverse effects on the condition of the habitat type – and D6 itself.

Table II. Indicator scale to assess physical condition (damage) of individual colonies.

Impact level (score)	**Description**
1	Intact (0% physical damage);
2	**Bent** and/or **1 – 25%** physical damage, i.e. broken/missing branches;
3	**26 - 50%** physical damage;
4	**51 - 75%** physical damage;
5	**76 - 100%** physical damage; displaced and/or dead.

Table III. Indicator scale used to assess epibiosis level of individual colonies.

Impact level (score)	**Description**
1	Colony unaffected (0% epibiosis);
2	**1-25%** of colony colonised by epibiosis;
3	**26-50%** affected;
4	**51-75%** affected;
5	**76-100%** affected.

2.6. DATA ANALYSIS

In order to obtain comparable indicator scores across sites and assess these against fishing effort data, 50-m long sections of video footage for each underwater video transect were identified and used as sampling units. Within each sampling unit, the indicators selected were measured and their root mean squares (RMS) generated, with sections with less than 10 observations being discarded. Sampling units were statistically compared to determine whether the selected indicators were sensitive to variations in fishing intensity. A grid of 100x100 m size cells was used and an average value of fishing effort in cumulative fishing hours over a period of 17 years (2002-2018) was generated for each.

A Shapiro test was performed to check data normality and a Levene test for homogeneity of variances of our dependent variables. As neither of the assumptions were verified, the non-parametric Kruskal-Wallis and the post-hoc Dunn's test were performed to statistically compare indicators measured between species and geomorphological units. Spearman's correlations were performed to statistically test the relationships between the measured impacts and fishing effort, also testing these relationships across sites. R (version 4.0.4) and R studio (version 1.4) were used to compute these statistical tests.

CHAPTER III. RESULTS

A total of 23 transects were analysed (Tab. IV and Fig. 5 & 6), corresponding to 27.444 m^2 of seafloor assessed, throughout more than 18h of video footage. In total, 11524 colonies were annotated of which 7066 were also assessed against the impacts observed, and 313 lost fishing lines annotated.

Table IV. Approximate geographical position, number of transects analysed, transects length and depth surveyed for each Gigante seamount complex area.

Survey areas	Position (lat/long)	No. of transects	Transects length (total – average; m)	Seafloor area surveyed (m^2)	Depth surveyed (min – mean – max; m)
Gigante Seamount	38°59.58′N, 29°53.29′W	8	4621 - 577	9242	157 – 431 - 795
127 Seamount	38°43.47′N, 29°59.62′W	8	4763 - 595	9526	216 – 430 - 540
Western Ridge	38°41.14′N, 30°14.47′W	7	4338 - 620	8676	391 – 531 - 671

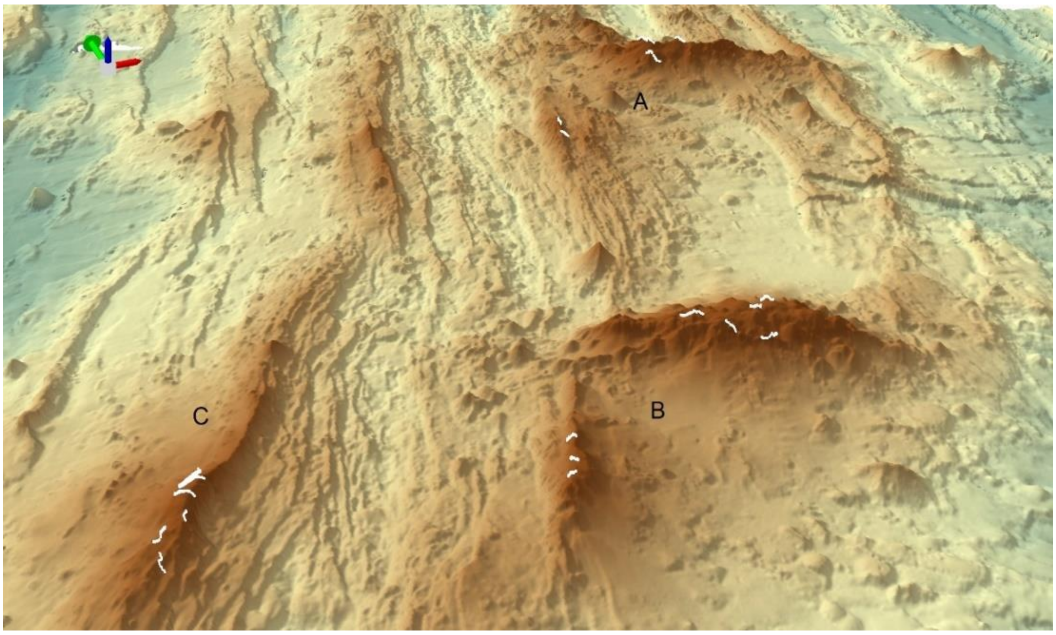


Figure 6. 3-dimensional representation of Gigante seamount complex and its areas assessed: A – Gigante Seamount; B – 127 Seamount; C – Western Ridge. Video transects analysed are highlighted in white. North is represented by the green axis.

Due to low abundances recorded for most species, only five species were recorded in sufficient number of observations: *Acanthogorgia* sp. (242), *Callogorgia verticillata* (103), *Candidella imbricata* (300), *Dentomuricea* aff. *meteor* (277) and *Viminella flagellum* (10554), with only a portion of these comprehending colonies that were fully (both indicators) or partially (one indicator) assessed (Tab. V). Regarding the remaining selected species, either there were no observations made in this area, or only a small portion of these included colonies that were assessed, not enough to perform a confident analysis.

Except for *V. flagellum*, which was observed in the majority of the transects across the Gigante seamount complex, most of the other species were mostly recorded in only a few transects, mostly inside the Gigante seamount area (Tab. VI).

Table V. Total number of observations and number of colonies fully or partially assessed for each species recorded in the Gigante seamount complex and respective percentages of occurrences for which Physical Condition or Epibiosis Level were not assessed due to uncertainty issues. Species selected for overall condition assessment are indicated in bold.

Species	**Total Observations**	**N/A Phys. Cond. (%)**	**N/A Ep. Level (%)**	**No. colonies assessed**
***Acanthogorgia* sp.**	242	86,4	87,2	33
Antipathella subpinnata (Ellis & Solander, 1786)	0	0,0	0,0	0
Callogorgia verticillata (Pallas, 1766)	103	52,4	55,3	55
Candidella imbricata (Johnson, 1862)	300	77,7	77,7	82
Dentomuricea* aff. *meteor Grasshoff, 1977	277	80,5	82,7	61
Errina dabneyi (Pourtalès, 1871)	1	100,0	0,0	1
Leiopathes expansa Johnson, 1899	0	0,0	0,0	0
Leiopathes glaberrima (Esper, 1792)	12	75,0	58,3	5
Narella bellissima (Kükenthal, 1915)	28	60,7	60,7	12
Narella versluysi (Hickson, 1909)	0	0,0	0,0	0
Paracalyptrophora josephinae (Lindström, 1877)	7	28,6	28,6	5
Paragorgia johnsoni Gray, 1862	0	0,0	0,0	0
Viminella flagellum (Johnson, 1863)	10554	35,5	38,4	6812
TOTAL	11524	39,0	41,8	7066

Table VI. Total number of colonies fully or partially assessed for each species recorded across the different areas of the Gigante seamount complex. Species selected for overall condition assessment are indicated in bold.

Species	**Gigante Seamount**	**127 Seamount**	**Western Ridge**
***Acanthogorgia* sp.**	27	1	5
Antipathella subpinnata (Ellis & Solander, 1786)	0	0	0
Callogorgia verticillata (Pallas, 1766)	48	7	0
Candidella imbricata (Johnson, 1862)	82	0	0
Dentomuricea* aff. *meteor Grasshoff, 1977	59	1	1
Errina dabneyi (Pourtalès, 1871)	1	0	0
Leiopathes expansa Johnson, 1899	0	0	0
Leiopathes glaberrima (Esper, 1792)	5	0	0
Narella bellissima (Kükenthal, 1915)	12	0	0
Narella versluysi (Hickson, 1909)	0	0	0
Paracalyptrophora josephinae (Lindström, 1877)	2	3	0
Paragorgia johnsoni Gray, 1862	0	0	0
Viminella flagellum Johnson, 1863	2422	2699	1691
TOTAL	2658	2711	1697

There were statistically significant differences detected between species, both regarding physical condition (Kruskal-Wallis, p<0,001) and epibiosis level (Kruskal-Wallis, p<0,001). Regarding physical condition, *Acanthogorgia* sp. scored a root mean square (RMS) of 1,64 (n=33), *C. verticillata* 3,61 (n=49), *C. imbricata* 2,67 (n=67), *D. meteor* 2,80 (n=54) and *V. flagellum* 3,37 (n=6805) (Fig. 7). Statistically significant differences were detected between *Acanthogorgia* sp. and *C. verticillata (*Dunn's test; p<0,001), *Acanthogorgia* sp. and *C. imbricata* (Dunn's test; p<0,001), *C. verticillata* and *D. meteor* (Dunn test; p=0,011) and *Acanthogorgia* sp. and *V. flagellum* (Dunn's test; p<0,001) regarding this indicator. The remaining pairwise comparisons did not reveal statistically significant differences (p>0,05) (Tab. VII). As for epibiosis level, *Acanthogorgia* sp. scored an RMS of 1,27 (n=31), *C. verticillata* 3,39 (n=46), *C. imbricata* 3,24 (n=67), *D. meteor* 2,26 (n=48) and *V. flagellum* 3,21 (n=6497) (Fig. 8). There were statistically significant differences detected between *Acanthogorgia* sp. and *C. verticillata* (Dunn's test; p<0,001), *Acanthogorgia* sp. and *C. imbricata* (Dunn's test; p<0,001), *C. verticillata* and *D. meteor* (Dunn test; p<0,001), *Acanthogorgia* sp. and *V. flagellum* (Dunn's test; p<0,001), *C. verticillata* and *V. flagellum* (Dunn's test; p=0,018) and *D. meteor* and *V. flagellum* (Dunn's test; p=0,015) regarding this variable). The remaining combinations all represented no statistically significant differences (Dunn test; p>0,05) (Tab. VIII).

Table VII. Dunn's test results regarding statistical differences on physical condition between the species analysed. P values that indicate statistically significant differences (p<0.05) between the species compared are highlighted in red.

Pairwise comparisons physical condition/species	**Z.value**	**P value** (adjust. Holm)
Acanthogorgia sp - *Callogorgia verticillata*	-5,0561	4,28E-06
Acanthogorgia sp - *Candidella imbricata*	-4,0127	4,80E-04
Callogorgia verticillata - *Candidella imbricata*	1,5637	0,2358
Acanthogorgia sp - *Dentomuricea* aff *meteor*	-2,3030	0,1064
Callogorgia verticillata - *Dentomuricea* aff *meteor*	3,1683	0,0107
Candidella imbricata - *Dentomuricea* aff *meteor*	1,8489	0,1934
Acanthogorgia sp - *Viminella flagellum*	-4,7699	1,66E-05
Callogorgia verticillata - *Viminella flagellum*	2,1360	0,1307
Candidella imbricata - *Viminella flagellum*	0,1248	0,9007
Dentomuricea aff *meteor* - *Viminella flagellum*	-2,3327	0,1180

Table VIII. Dunn's test results regarding statistical differences on epibiosis level for the species analysed. P values that indicate statistically significant differences (p<0.05) between the species compared are highlighted in red.

Pairwise comparisons epibiosis level/species	**Z.value**	**P value** (adjust. Holm)
Acanthogorgia sp - *Callogorgia verticillata*	-5,6699	1,43E-07
Acanthogorgia sp - *Candidella imbricata*	-3,9744	4,94E-04
Callogorgia verticillata - *Candidella imbricata*	2,3575	0,0736
Acanthogorgia sp - *Dentomuricea* aff *meteor*	-1,9478	0,1029
Callogorgia verticillata - *Dentomuricea* aff *meteor*	4,2059	2,08E-04
Candidella imbricata - *Dentomuricea* aff *meteor*	2,1921	0,0851
Acanthogorgia sp - *Viminella flagellum*	-4,9203	7,78E-06
Callogorgia verticillata - *Viminella flagellum*	2,9104	0,0181
Candidella imbricata - *Viminella flagellum*	-0,1833	0,8546
Dentomuricea aff *meteor* - *Viminella flagellum*	-3,0166	0,0153

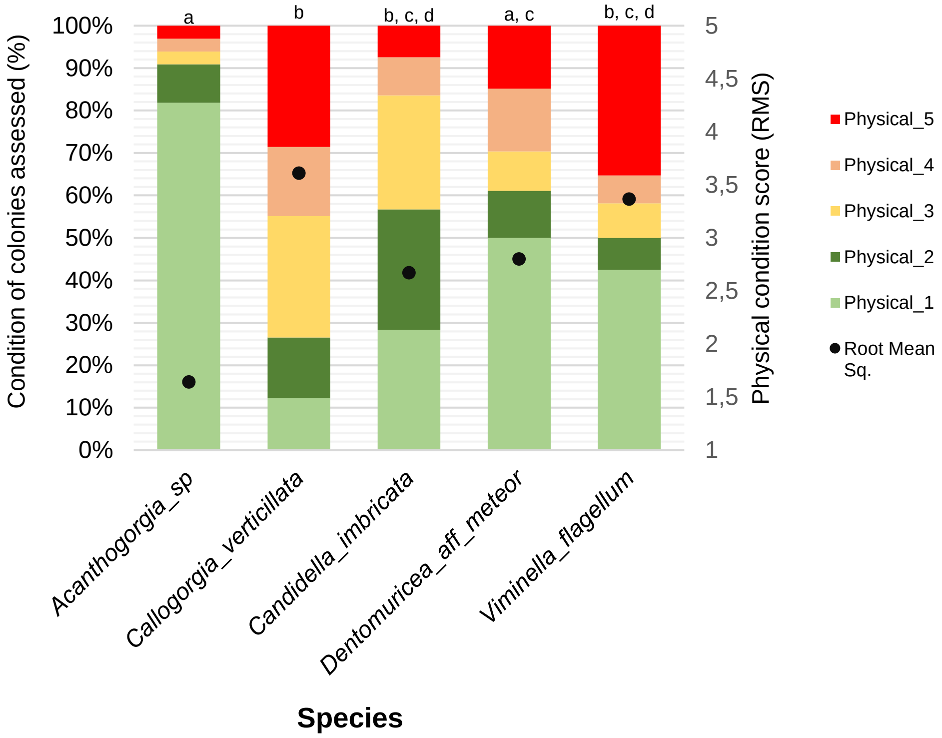


Figure 7. Representation of physical condition of the different species and their root mean squares. Different letters represent statistically significant differences (p<0,05).

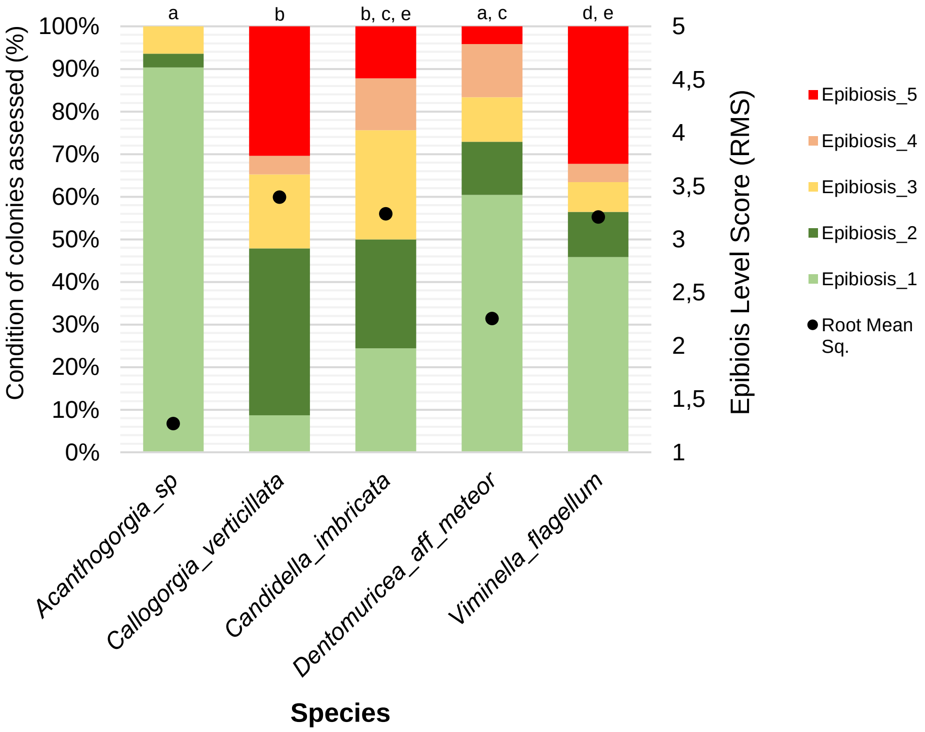


Figure 8. Representation of epibiosis level of the different species and their root mean squares. Different letters represent statistically significant differences (p<0,05).

Statistically significant differences between levels of structural complexity and physical condition were obtained (KW chi-squared = 6,70; p=0,035), with low structural complexity scoring an RMS of 3,37 (n=6805; *V. flagellum*), medium structural complexity 2,38 (n=100; *Acanthogorgia* sp. and *C. imbricata*) and high structural complexity 3,21 (n=103; *C. verticillata* and *D. meteor*) (Fig. 9). Statistically significant differences were detected between low and medium structural complexity regarding this indicator (Dunn's test; p=0,029). No statistically significant differences were detected between low and high structural complexity (Dunn's test; p=0,840) and medium and high structural complexity (Dunn's test; p=0,180) (Tab. IX). Regarding epibiosis level, statistically significant differences were detected between structural complexities (KW chi-squared = 8,44; p=0,015). Low and medium structural complexity showed significant differences between them (Dunn's test; p=0,011), with RMS a values of 3,21 and 2,77, respectively. No differences were detected between low and high (RMS=2,87) (Dunn's test; p=0,922) and medium and high structural complexities (Dunn's test; p=0,095) (Tab. X and Fig. 10)

Table IX. Dunn's test results regarding differences on physical condition between different structural complexities. P values that indicate statistically significant differences between the structural complexities compared are highlighted in red.

Pairwise comparisons physical condition	**Z.value**	**P.value** (Holm adjust.)
High - Low	-0 ,2007	0,840
High - Medium	1 ,6928	0,180
Low - Medium	2 ,5836	0,029

Table X. Dunn's test results regarding differences on epibiosis level between different structural complexities. P values that indicate statistically significant differences between the structural complexities compared are highlighted in red.

Pairwise comparisons epibiosis Level	**Z. value**	**P.value** (Holm adjust.)
High - Low	-0 ,0970	0,922
High - Medium	1 ,9834	0,095
Low - Medium	2 ,9044	0,011

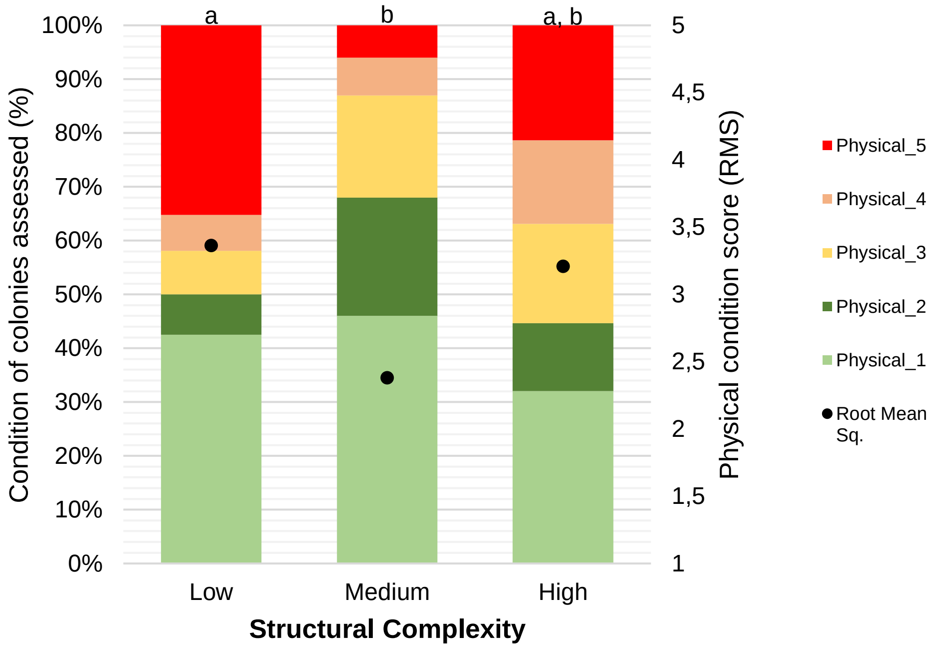


Figure 9. Representation of physical condition of the different species' structural complexities and their root mean squares. Different letters represent statistically significant differences (p<0,05).

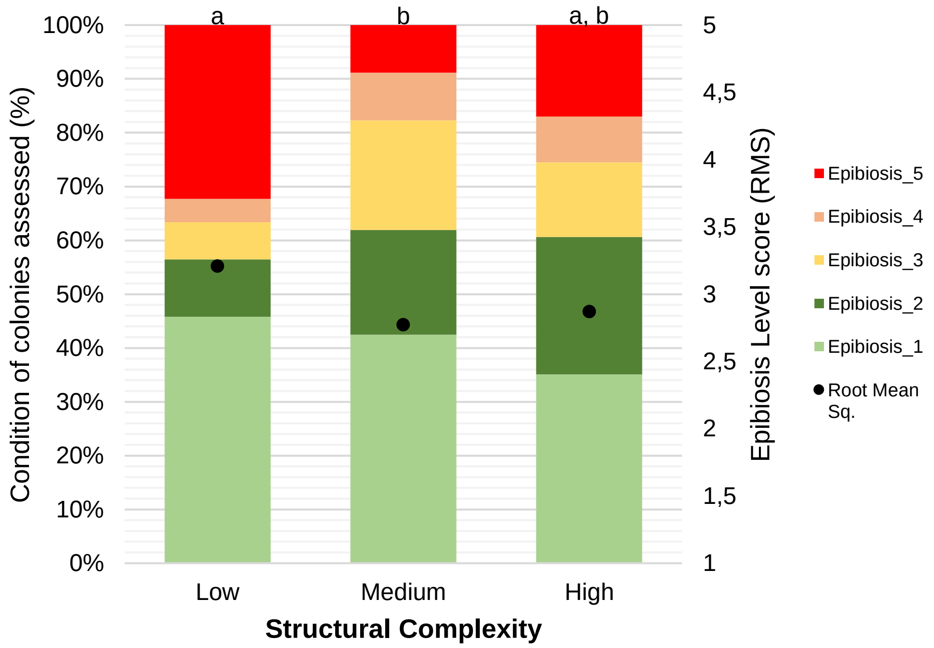


Figure 10. Representation of epibiosis level of the different species' structural complexities and their root mean squares. Different letters represent statistically significant differences (p<0,05).

Table XI. Total number of observations for each area of the Gigante Seamount complex, respective percentages of occurrences for which physical condition or epibiosis level were not assessed due to uncertainty issues and total number of 50m sections with at least one observation and with more than 10 observations, which were used for statistical analysis.

Areas	**Total Observations**	**N/A Phys. Cond. (%)**	**N/A Ep. Level (%)**	**No. 50m Sections (TOTAL/used)**
Gigante Seamount	4322	42,5	50,2	52/41
127 Seamount	3863	30,8	33,4	74/46
Western Ridge	3339	49,2	46,5	80/39
TOTAL	11524	39,0	41,8	206/126

There were statistically significant differences between the Gigante Seamount complex areas regarding physical condition (KW chi-squared = 110,97; p < 0,001) and epibiosis level (KW chi-squared = 90,754; p-value < 0,001). Regarding physical condition, Gigante seamount scored an RMS of 3,34 (n=2623), 127 Seamount 3,54 (n=2711) and Western Ridge 3,06 (n=1697) for this indicator (Fig. 11). All three areas registered statistically significant differences between them regarding this indicator (Dunn's test; p<0,001) (Tab. XII). As for epibiosis level, Gigante seamount scored an average of 2,56 (n=2439), 127 seamount 2,89 (n=2611) and Western Ridge 2,41 (n=1662) (Fig. 12), with all three areas registering differences between them (Tab. XIII).

***Table XII*.** Dunn's test results regarding differences on physical condition between different Gigante seamount complex areas. P values that indicate statistically significant differences between areas compared are highlighted in red.

Pairwise comparisons physical condition/areas	**Z. value**	**P value** (Holm adjust.)
127 Seamount - Gigante Seamount	4 ,2145	2,50E-05
127 Seamount - Western Ridge	10 ,5262	1,96E-25
Gigante Seamount - Western Ridge	6 ,7552	2,85E-11

***Table XIII*.** Dunn's test results regarding differences on epibiosis level between different Gigante seamount complex areas. P values that indicate statistically significant differences between areas compared are highlighted in red.

Pairwise comparisons physical condition/areas	**Z. value**	**P. value** (Holm adjust.)
127 Seamount - Gigante Seamount	6,023131	1,71E-09
127 Seamount - Western Ridge	9,263940	1,97E-20
Gigante Seamount - Western Ridge	3,809582	1,39E-04

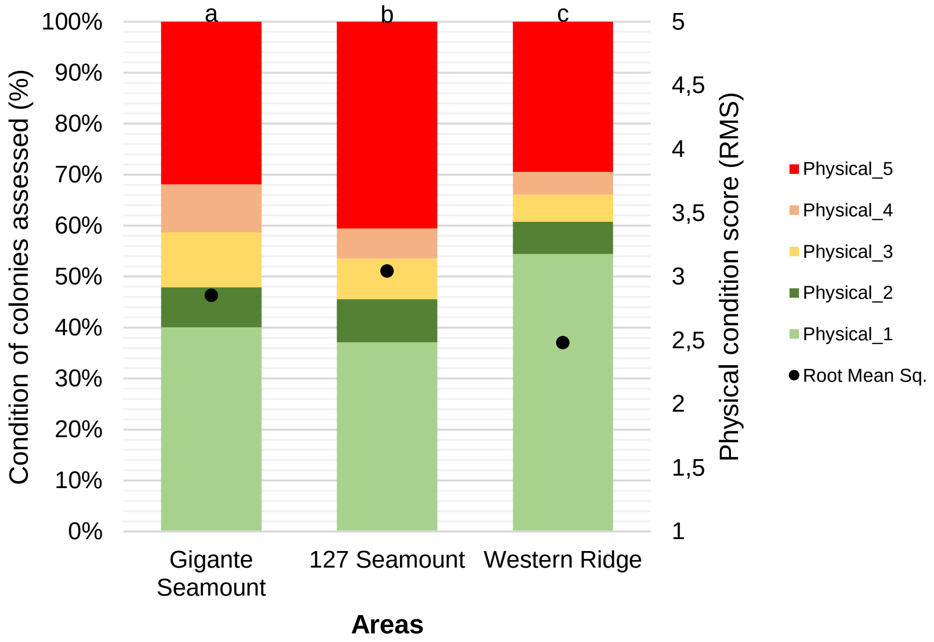


Figure 11. Representation of physical condition between the different areas of the Gigante seamount complex and their root mean squares. Different letters represent statistically significant differences (p<0,05).

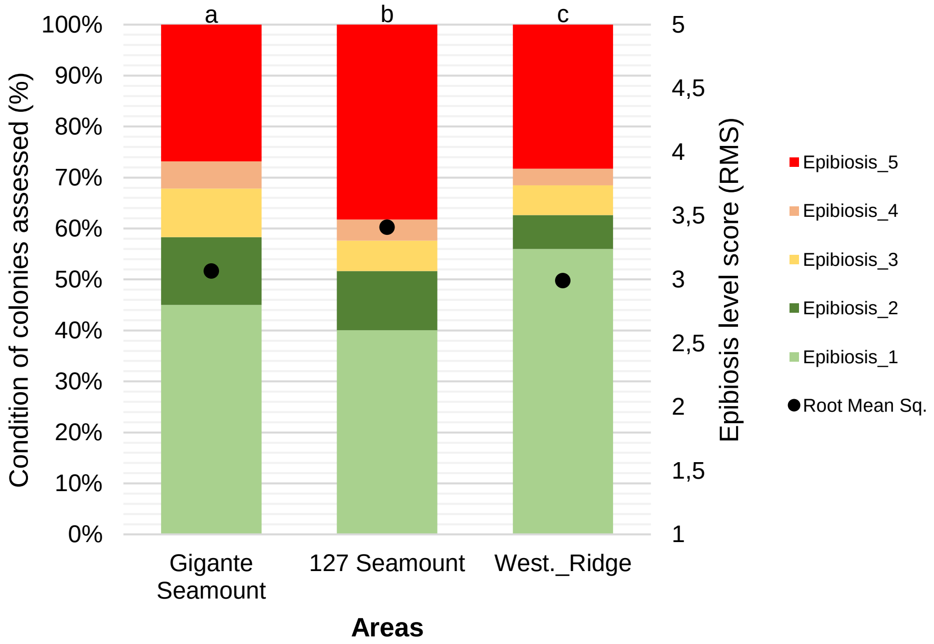


Figure 12. Representation of epibiosis level between the different areas of the Gigante seamount complex and their root mean squares. Different letters represent statistically significant differences (p<0,05).

The 127 Seamount registered the most fishing hours over 17 years (7723) and Gigante seamount showing the highest density of VMS pings/Km^2 (287). These two areas also comprehend the highest lost fishing annotated – 0,021 and 0,012 lines/m^2, respectively – with the Western Ridge area representing the lowest values regarding all three parameters (Tab. XIV). Figure 13 represents how fishing effort is distributed across the Gigante seamount complex, with a grid composed of 1km^2 cells, along with the video observations made.

Table XIV. Cumulative fishing hours (2002 to 2018), density of VMS pings/Km^2, and lost fishing lines annotated during video analysis for the different areas of Gigante Seamount complex.

Areas	**Cumulative fishing hours (2002-2018)**	**VMS pings/Km^2**	**Lines/m^2 annotated**
Gigante Seamount	6510	89	0,012
127 Seamount	8823	80	0,021
Western Ridge	1653	42	0,008

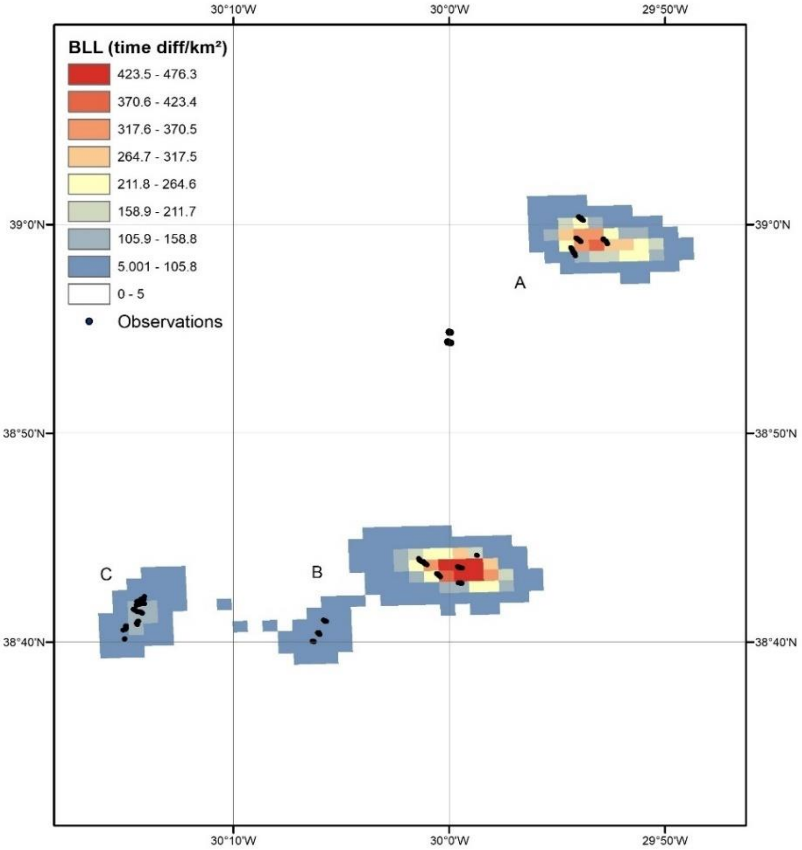


Figure 13. Bottom Longline (BLL) fishing effort (cumulative fishing hours 2002-2018/km^2) represented over a grid of 1km^2 cells, across the Gigante seamount complex and its different areas: A – Gigante seamount; B – 127 Seamount; C – Western Ridge; video observations are also displayed in black.

No statistically significant relationships were detected between physical condition and fishing effort (Spearman's rho = 0,013; p=0,882) and epibiosis level and fishing effort (Spearman's rho = 0,106; p=0,242) when all areas' 50m sections sample units were grouped (Fig. 14 & 15). When areas were analysed separately, epibiosis level and fishing effort showed a statistically significant relationship for Gigante seamount area (Spearman's rho = 0,505; p<0,001). No statistically significant relationships were detected regarding physical condition and fishing effort for Gigante Seamount (Spearman's rho = 0,296; p=0,061) physical condition and fishing effort for 127 Seamount (Spearman's rho = -0,182; p=0,226), epibiosis level and fishing effort for 127 Seamount (Spearman's rho = 0,248; p=0,101), physical condition and fishing effort for Western Ridge (Spearman's rho = 0,006; p=0,974) and epibiosis level and fishing effort for Western Ridge (Spearman's rho = -0,165; p=0,317) (Fig. 16 - 21)

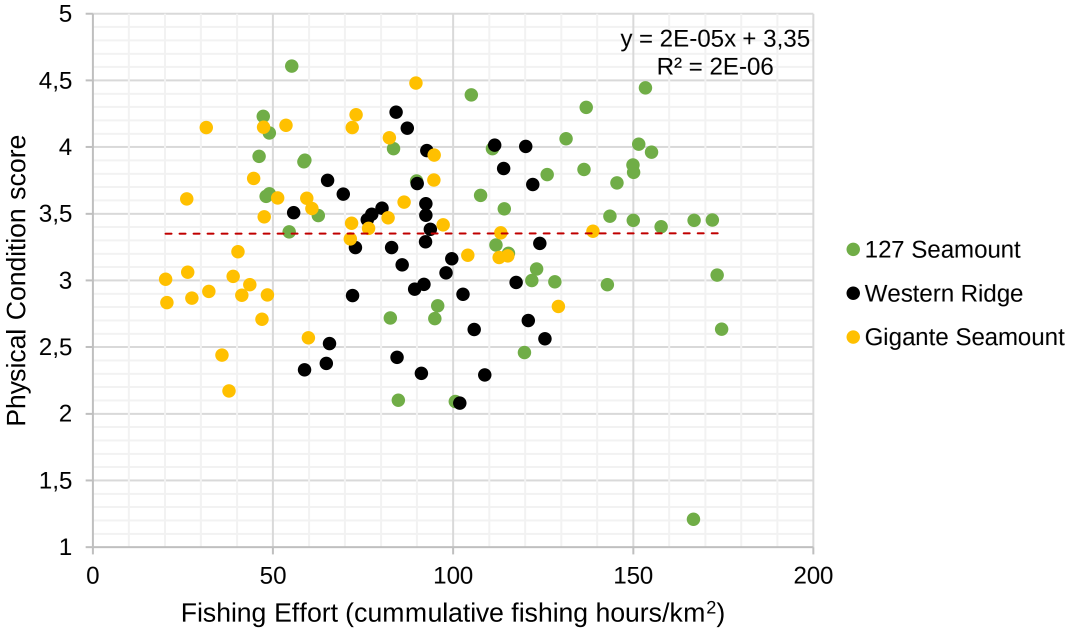


Figure 14. Representation of Spearman's correlation analysis between physical condition and fishing effort across the Gigante seamount complex. Values are root mean squares regarding 50m long transect sections. Trend line equation and R^2 are also displayed.

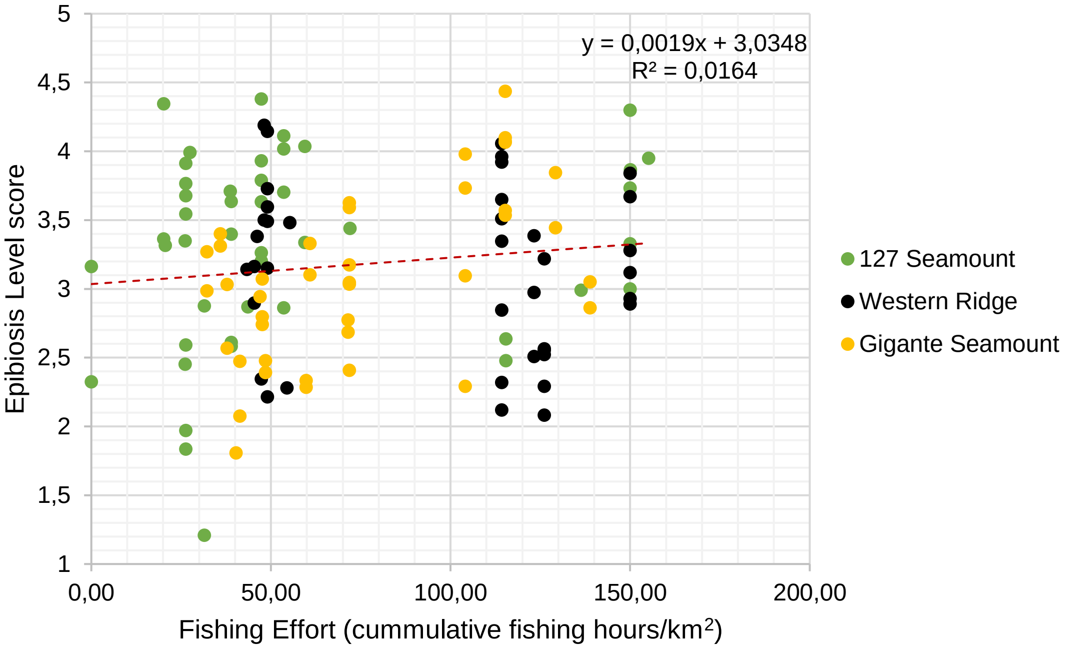


Figure 15. Representation of Spearman's correlation analysis between epibiosis level and fishing effort across the Gigante seamount complex. Values are root mean squares regarding 50m long transect sections. Trend line equation and R^2 are also displayed.

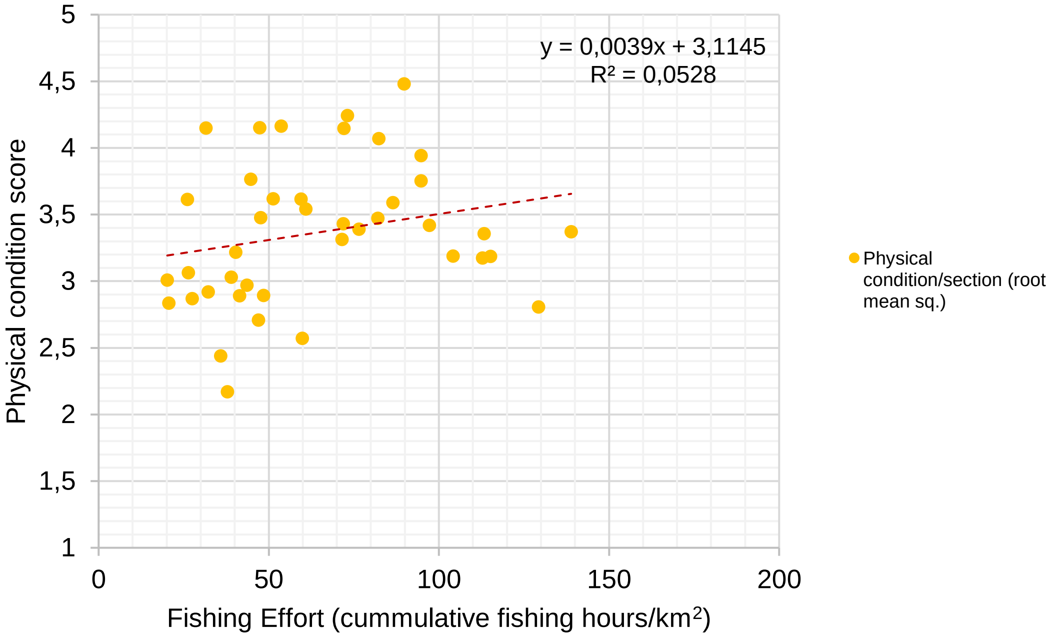


Figure 16. Representation of Spearman's correlation analysis between physical condition and fishing effort across the Gigante seamount area. Values are root mean squares regarding 50m long transect sections. Trend line equation and R^2 are also displayed.

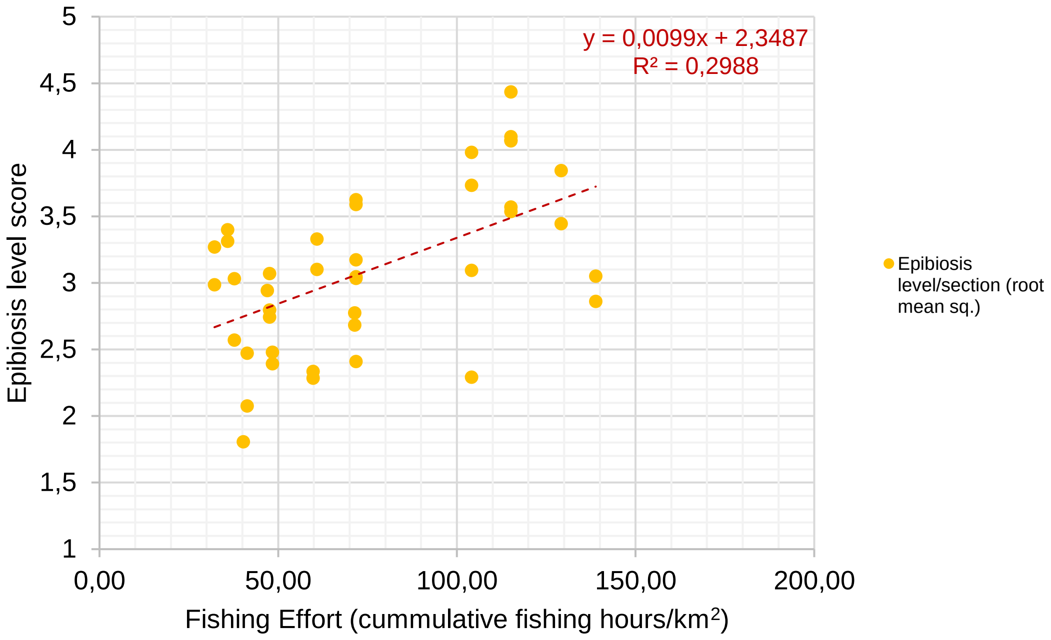


Figure 17. Representation of Spearman's correlation analysis between epibiosis level and fishing effort across the Gigante seamount area. Values are root mean squares regarding 50m long transect sections. Trend line equation and R^2 highlighted in red represent a statistically significant relationship between variables ($p<0,05$).

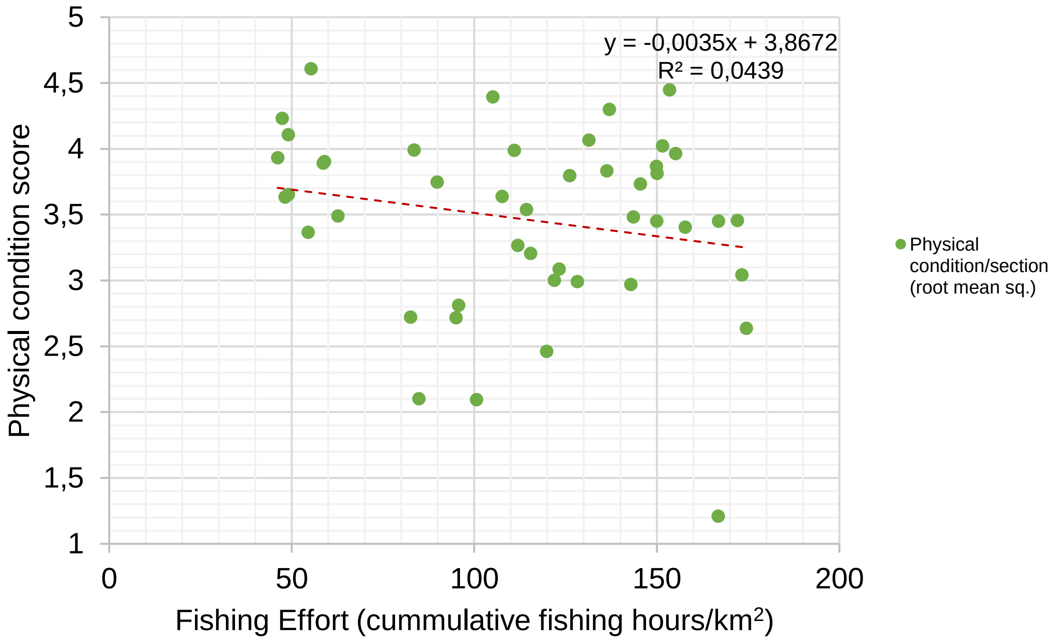


Figure 18. Representation of Spearman's correlation analysis between physical condition and fishing effort across the 127 seamount area. Values are root mean squares regarding 50m long transect sections. Trend line equation and R^2 are also displayed.

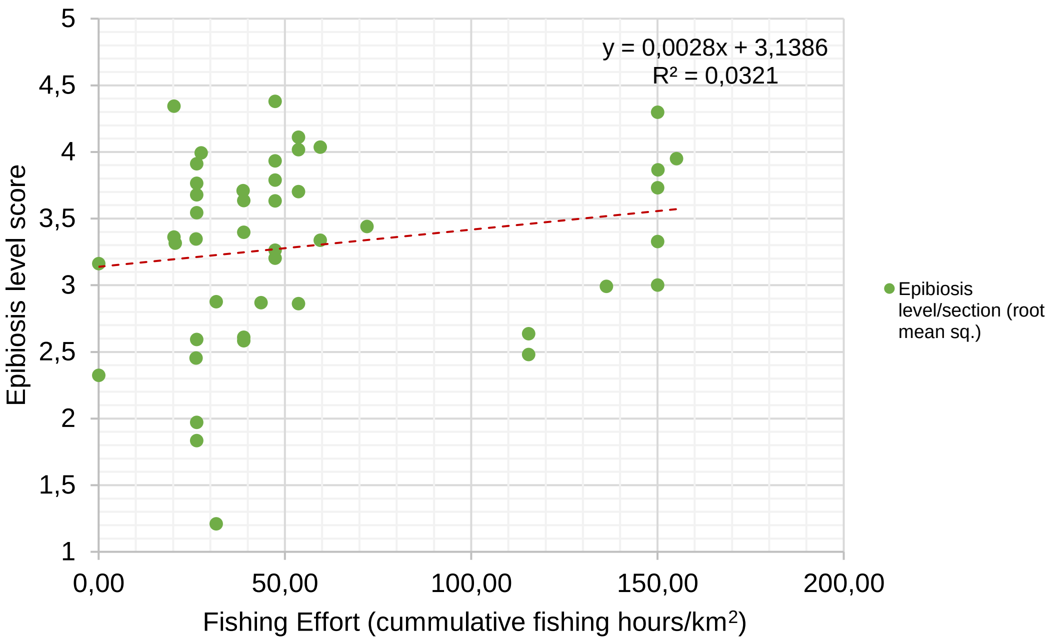


Figure 19. Representation of Spearman's correlation analysis between epibiosis level and fishing effort across the 127 seamount area. Values are root mean squares regarding 50m long transect sections. Trend line equation and R^2 are also displayed.

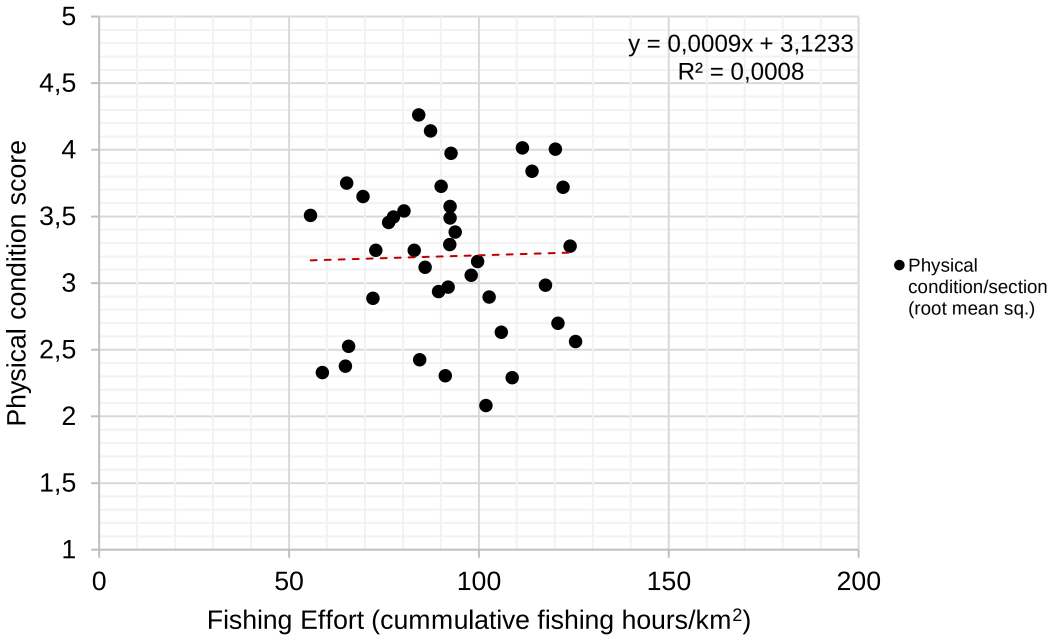


Figure 20. Representation of Spearman's correlation analysis between physical condition and fishing effort across the Western Ridge area. Values are root mean squares regarding 50m long transect sections. Trend line equation and R^2 are also displayed.

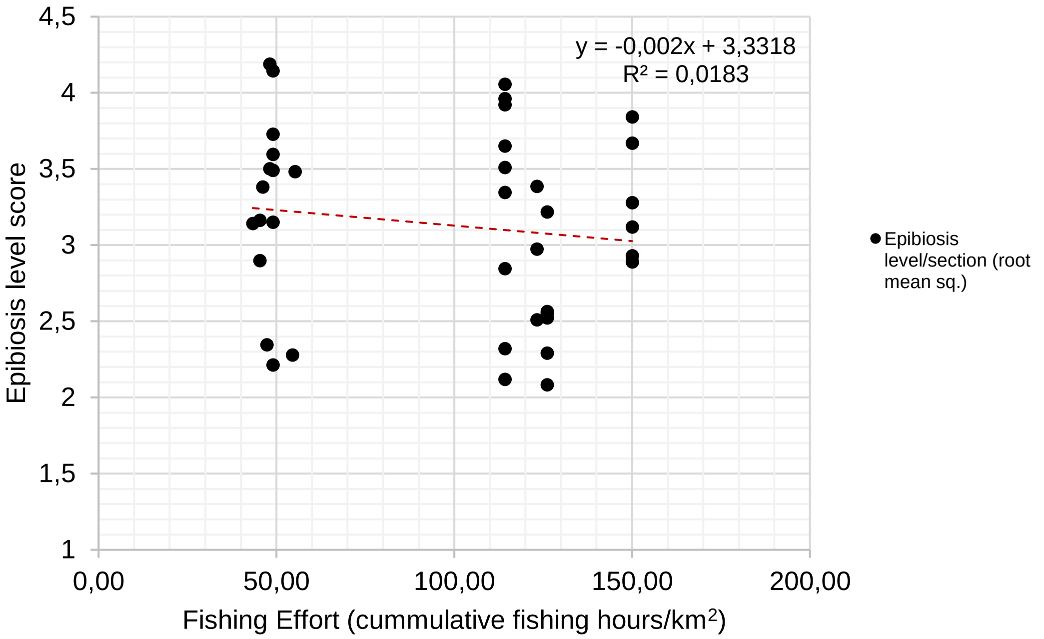


Figure 21. Representation of Spearman's correlation analysis between epibiosis level and fishing effort across the Western Ridge area. Values are root mean squares regarding 50m long transect sections. Trend line equation and R^2 are also displayed.

CHAPTER IV. DISCUSSION

In this study, two indicators – Physical condition and Epibiosis - and standardized methodologies were formulated and tested. This supported our objective of providing a contribution towards clearer and more objective Good Environmental Status assessments of D6 – seafloor integrity – within the MSFD framework, with a focus on criteria D6C3 regarding deep-sea ecosystems formed by cold-water corals, considered as VME indicators. Furthermore, we assessed whether 1) different CWC species show different susceptibility to impacts, 2) if these differences are correlated to their different structural complexities and 3) whether fishing intensity modulates the impacts (i.e., overall coral condition) observed across different areas. To test these hypotheses, comparisons across different CWC species, levels of structural complexity and study sites assessed -along with fishing effort data - were performed, regarding both indicators formulated.

Some conclusions can be drawn from our results, namely the fact that CWC species seem to be affected differently by disturbances, with some of these differences possibly being linked with species' structural complexity, despite some uncertainty associated. Moreover, it also appears that our study areas hold different overall condition levels, seemingly explained by different overall fishing intensities for each site. Nevertheless, most of our results seem to be uncertain, a conclusion that could have been driven by the low number of observations and assessments performed for most of the selected species, having observations of *V. flagellum* reached more than 10 times as much as the observations of the remaining species together. This led to a secondary selection of species considering the number of observations and colonies assessed for each. As a result, only five out of the initial thirteen species were selected for final analysis. The uneven distribution of number of assessments across each of these species probably limited the analyses performed as well, as overall condition almost solely reflected *V. flagellum* scores. Furthermore, the methodology used, the quality of the indicators applied, and observer-associated errors could also have caused some uncertainty to our results.

Regarding the majority of species, either there were not enough observations, or these were mostly comprised of annotations with some degree of uncertainty (N/A) (Tab. V & VI). Most of the times, this was either due to the small size of the colonies or the actual video quality/clarity, both reasons rendering the annotation process much more difficult and uncertain. In fact, out of the five selected species for analysis, *Acanthogorgia* sp. was the one which represented the higher percentage of "N/A's" regarding the assessment of both indicators. Despite being considered a species of medium structural complexity, size of most of the colonies observed was too small to successfully perform a certain and full assessment of their condition. This also occurred even for species with high structural complexity (*D. meteor*, for instance), where a considerable number of observations comprehended smaller colonies. Even when the video footage was clear enough for an assessment, the annotation process usually adopted a precautionary approach, as it was considered difficult to tell from physical or epibiosis damage and natural-considered growth, since little structure was present in order to clearly distinguish these. On the other hand, higher scores in the species with higher structural complexity (*C. verticillata*, *D. meteor* and even *Acanthogorgia* sp.) were usually attributed to taller, more complex colonies, where damage was more frequent and easily observed and recognized. Nevertheless, in these and most cases, we found epibiosis cover as a suitable indicator which facilitated the annotation process, since its assessment seems to be less susceptible to observer subjectivity than physical condition assessments, where damage assignments are usually based on the idea we have of a “normal” colony structure and its natural vertical stance position. Furthermore, literature seems to support our suggestion that this indicator is a suitable correlating variable against fishing effort in assessing its impacts to benthic communities (Bo et al., 2014a, b; Angiolillo et al., 2015; Ferrigno et al., 2018). Both physical damage and the easily recognizable impacts of parasitic colonization seem to be adequate ways to measure the adverse effects of these anthropogenic pressures on CWC-formed habitats, which could help providing GES assessments regarding criteria D6C3 and, ultimately, D6 and its other constituent criteria.

4.1. CONDITION OF COLD-WATER CORALS: DIFFERENCES AT SPECIES LEVEL

Some differences between species regarding both indicators were detected, however, caution in withdrawing conclusions in this matter is important, due to the low number of occurrences and assessments performed for the five species selected, except for *V. flagellum*, as already mentioned. Physical condition and epibiosis level scores distribution across species is markedly distinct in some cases, as Figures 7 and 8 represent, especially when addressing *Acanthogorgia* sp. and most of the remaining species. Not only statistically significant differences were found between this species and the remaining (except for *D. meteor*) but also a clearly different pattern of scores is visible. *C. verticillata,* in regard to both indicators, shows a much more even distribution of each score than *Acanthogorgia* sp. for instance, as well as considerably higher root mean square values (Physical condition RMS=3,61; Epibiosis level RMS=3,39) than the latter (Physical condition RMS=1,64; Epibiosis level RMS=1,27). However, given that only 33 colonies of *Acanthogorgia* sp. were partially or fully assessed, the results from such analysis should thus be treated with caution. Regarding *V. flagellum*, score distribution for both indicators shows a distinct pattern, where scores of 1 and 5 are much more frequent than scores of 2, 3 or 4. A possible reason for this could be visibility constraints of the video itself, which in many cases led to inevitably assessing more colonies fully affected by epibiosis (score of 5) more easily than colonies partially colonized (scores of 2-4), regardless of how precautionary our annotation approach was. This could have biased the results, possibly unrealistically risen the proportion of scores of 5 for *V. flagellum*.

When these species were grouped into classes of structural complexity, some differences remained. However, the premise that species with higher structural complexity are more susceptible and vulnerable to disturbances than species with low structural complexity was not confirmed and thus the correlation previously reported for deep-water CWC species in the Azores (Sampaio et al., 2012; Pham et al., 2014), cannot be corroborated. Despite statistical differences detected between low and medium complexities for both indicators, their RMS refute our hypothesis (Fig. 9 & 10). However, it is worth mentioning that every assessment contributing to the RMS value of low structural complexity species come from *V. flagellum*, which is likely to, once again, have biased the results. Hence this conclusion might be unreliable. Although no statistically significant differences were found between low and high structural complexity and medium and high structural complexity, especially regarding physical damage, a somewhat distinct pattern appears to be showing for species with medium structural complexity and species with high structural complexity, with the latter showing a higher mean square value, mainly as a result of a higher proportion of scores of 5, visible in Figure 9. However, a cautious interpretation of these results must be made, due to the low number of colonies assessed for medium and high structural complexities.

Despite some of the limitations mentioned, these results seem to suggest that our VME indicator taxa – CWCs – along with our developed indicators could be used in GES assessments regarding D6 and benthic ecosystems formed by these organisms.

4.2. DIFFERENCES ACROSS SITES

The different areas of the Gigante Seamount complex were also compared against each other by grouping the assessments performed to their respective site, thereby generating a global RMS value for each area and indicator used, which could potentially be used to generate GES assessments for single geomorphological units. All three areas registered statistical differences between them regarding both indicators (Fig 11 & 12), with the 127 seamount registering the highest RMS value for physical condition (RMS=3,54) and epibiosis level (RMS=2,89), much due to the higher proportion of scores of 5 when compared with the other two areas. On the other hand, the Western Ridge area recorded the lowest RMS values for both indicators (Physical condition RMS=3,06; Epibiosis level RMS=2,41). These differences are almost exclusively driven by the records of *V. flagellum*, as previously pointed out. However, it might be worth mentioning that when comparing Gigante Seamount and 127 Seamount areas, this species' dominant proportion of assessments is slightly different: whereas 127 Seamount assessments of V. flagellum represent 99,5% of all assessments in the area (similarly to the Western Ridge area), in Gigante Seamount, these rank a little lower: 91,1%. This could have lessened the possible bias already mentioned regarding assessments of *V. flagellum*, thereby scoring less scores of 5 and overall lower RMS values than 127 Seamount. These differences recorded seem to support the idea that our indicators can be used to effectively generate GES assessments regarding D6 and its criteria across different sites.

4.3. DIFFERENCES EXPLAINED BY FISHING EFFORT

The 127 seamount represented the higher amount of cumulative fishing hours over a period of 17 years per km^2 (8823h), followed by Gigante seamount (6510h) and with the Western Ridge area having the lowest amount of cumulative fishing hours (1653h) (Tab. XIV). When comparing all three areas, their RMS values seem to be in line with their overall fishing effort values: the 127 Seamount area scored the highest RMS, Gigante seamount the second highest RMS and Western Ridge the lowest, seemingly showing a correlation between CWC's condition and fishing effort, which suggests that fishing effort might explain the differences across sites regarding their overall different conditions measured by our indicators. This further supports the use of physical damage and epibiosis level as suitable indicators to assess GES across geomorphological units that are differently impacted by anthropogenic pressures.

Correlations between indicators and fishing effort were also performed, both using the Gigante Seamount complex as a single unit and across the different areas assessed. The fact that no statistically significant relationship was detected between both indicators and fishing effort when considering the Gigante Seamount complex contradicts the previous assumptions. A few reasons could have motivated this outcome, one being the fact that there is usually some error associated with fishing effort data, particularly regarding smaller vessels, where some gaps still exist regarding information provided via VMS. Therefore, since the Azores fleet is predominantly artisanal, the fishing effort maps generated may not fully represent the fishing activity patterns in the region (Morato et al., 2020d). The selection of a finer grid used for analysis could also have aggravated this issue. However, this selection was built upon the scale of our sampling design, having considered that a grid with 100x100m size cells would be suitable for the 50m sections from each transect that comprehended our sampling units. Furthermore, more sampling units ranging a broader fishing effort gradient are possibly required for more consensual results. In fact, from analysing the scatterplots generated and isolating higher fishing effort values, it seems that sampling units tend to congregate towards higher physical condition scores (Fig 14 & 15). This could raise the question of a possible fishing effort tipping point, that when reached, could lead to a correlation that meets our hypotheses, although only speculatively. It is also interesting to notice how the different areas' sampling units are distinctly distributed across the fishing effort gradient, regarding both indicators. Regarding physical condition, it seems that Western Ridge sampling units tend to congregate around fishing effort values of 90, whereas at Gigante Seamount, these seem to be grouped around slightly lower fishing effort values. Concerning epibiosis level, a clearly different overall pattern is visible, which is also noteworthy. Nevertheless, lost fishing lines/m^2 seem to be in accordance with the fishing effort data for each area, which might indicate that this could act as a reliable proxy for future assessments. However, literature appears to reference this indicator as prone to bias, since the presence of more fishing lines lost also correlates strongly with regional scale differences regarding terrain topography – where more structurally complex areas tend to accumulate more fishing gear - and not exclusively to fishing intensity (Williamson et al., 2014).

When individual areas are analysed, it is interesting to notice the correlation established between epibiosis level and fishing effort in Gigante Seamount, with no other area or indicator resulting in a correlation with fishing effort. In fact, even considering the same Gigante Seamount area, a correlation between physical condition and fishing effort did not appear. This upholds the idea of having used epibiosis level as an indicator, since it might have shown a different sensibility towards impacts modulated by fishing effort in this area, which validates the thought that this indicator might act as a reliable tool to perform assessments of GES regarding D6. This appears to be supported by literature, as previously mentioned. Bo et al. (2014b), for instance, documented that most of *C. verticillata* colonies observed were found to be affected by some epibenthic organism, a result obtained despite having analysed a far lesser extent of seafloor area than this study comprehended (1.500m^2 instead of the total 29.454 m^2 herein examined), an issue present in other studies regarding similar assessments (e.g. Bo et al., 2014a; Enrichetti et al., 2019b). In our case, it must be mentioned that the amount of video footage recorded and analysed would likely not be possible without the low-cost camera system Azor drift-cam used to gather video footage of the deep seabed of the Azores over the past two years, by immensely increasing the potential of seafloor surveys with only a fraction of the operation costs of other, much more complex video assessments.

Our results appear to show some uncertainty and inconsistencies; the most likely explanation in most cases is probably related to insufficient data gathered, leading to overall limited assessments. Some methodological adaptations might also be required to limit possible observer-associated errors, such as defining a size limit for colonies to be assessed, even in situations of a close, clear view of the colony, since, as mentioned above, small structures might often lead to an incorrect appraisal of its condition. Another relevant issue to consider is the annotation of already dead colonies, where a particularly sensible approach in these cases might be important. Regarding *V. flagellum,* for instance, annotations of dead colonies lying upturned on the seafloor were usually subject to a high degree of uncertainty, where the distinction between a dead specimen and fragments of other colonies was often unclear. Nevertheless, it seems our indicators work as objective tools to assess impact status on these benthic communities, thereby capable of generating GES assessments, providing clearer methodologies to evaluate D6C3 and D6 itself and therefore contributing towards the maintenance of seafloor integrity.

FINAL REMARKS

With this work, we have contributed towards the development of suitable indicators of GES, along with an objective methodology with which cold-water coral deep-sea ecosystems, specifically, might be assessed more easily, within the MSFD framework and regarding Descriptor 6. Further methodological developments and adaptations will probably still be required for these impact scales formulated, such as the previously mentioned minimum size limit for colony assessment and perhaps reviewing the approach to be had in cases of uncertainty in the annotation process. Furthermore, their application should be tested at a broader spatial scale and gathering more data with which to perform better assessments and therefore generate more holistic conclusions regarding CWC deep-sea ecosystems and GES assessments of D6. Continuous future efforts are then crucial to constantly provide accurate descriptions of the impacts that fishing activities trigger in this extensive biome. Moreover, we have improved the knowledge and understanding regarding these habitat-forming organisms and their susceptibility to human-generated impacts.

In conclusion, a clear contribution to posterior GES assessments of Descriptor 6 was made, endorsing the future protection and maintenance of natural spatial connectivity of seafloor habitats and its functional ecosystem processes, as both comprehend the concept of seafloor integrity.

CHAPTER V. REFERENCES

Althaus, F., Williams, A., Schlacher, T. A., Kloser, R. J., Green, M. A., Barker, B. A., ... & Schlacher-Hoenlinger, M. A. (2009). Impacts of bottom trawling on deep-coral ecosystems of seamounts are long-lasting. *Marine Ecology Progress Series*, *397*, 279-294.

Angiolillo, M., di Lorenzo, B., Farcomeni, A., Bo, M., Bavestrello, G., Santangelo, G., ... & Canese, S. (2015). Distribution and assessment of marine debris in the deep Tyrrhenian Sea (NW Mediterranean Sea, Italy). Marine pollution bulletin, 92(1-2), 149-159.

Ashford, O. S., Kenny, A. J., Barrio Froján, C. R., Downie, A., Horton, T., & Rogers, A. D. (2019). On the influence of Vulnerable Marine Ecosystem habitats on peracarid crustacean assemblages in the Northwest Atlantic Fisheries Organisation Regulatory Area. *Frontiers in Marine Science*, *6*, 401.

Bashmachnikov, I. L., Lafon, V. M., & Martins, A. M. (2004, November). SST stationary anomalies in the Azores region. In *Remote Sensing of the Ocean and Sea Ice 2004* (Vol. 5569, pp. 148-155). International Society for Optics and Photonics.

Beazley, L. I., Kenchington, E. L., Murillo, F. J., & Sacau, M. D. M. (2013). Deep-sea sponge grounds enhance diversity and abundance of epibenthic megafauna in the Northwest Atlantic. *ICES Journal of Marine Science*, *70*(7), 1471-1490.

Benn, A. R., Weaver, P. P., Billet, D. S., Van Den Hove, S., Murdock, A. P., Doneghan, G. B., & Le Bas, T. (2010). Human activities on the deep seafloor in the North East Atlantic: an assessment of spatial extent. PloS one, 5(9), e12730.

Bo, M., Bava, S., Canese, S., Angiolillo, M., Cattaneo-Vietti, R., & Bavestrello, G. (2014a). Fishing impact on deep Mediterranean rocky habitats as revealed by ROV investigation. *Biological Conservation*, *171*, 167-176.

Bo, M., Bavestrello, G., Angiolillo, M., Calcagnile, L., Canese, S., Cannas, R., ... & Cau, A. (2015). Persistence of pristine deep-sea coral gardens in the Mediterranean Sea (SW Sardinia). PLoS One, 10(3), e0119393.

Bo, M., Cerrano, C., Canese, S., Salvati, E., Angiolillo, M., Santangelo, G., & Bavestrello, G. (2014b). The coral assemblages of an off-shore deep Mediterranean rocky bank (NW S icily, I taly). Marine Ecology, 35(3), 332-342.

Braga-Henriques, A., Carreiro-Silva, M., Porteiro, F. M., de Matos, V., Sampaio, Í., Ocana, O., & Avila, S. P. (2011). The association between a deep-sea gastropod Pedicularia sicula (Caenogastropoda: Pediculariidae) and its coral host Errina dabneyi (Hydrozoa: Stylasteridae) in the Azores. *ICES Journal of Marine Science*, *68*(2), 399-407.

Braga-Henriques, A., Porteiro, F. M., Ribeiro, P. A., Matos, V. D., Sampaio, Í., Ocaña, O., & Santos, R. S. (2013). Diversity, distribution and spatial structure of the cold-water coral fauna of the Azores (NE Atlantic). *Biogeosciences*, *10*(6), 4009-4036.

Braga-Henriques, A., Porteiro, F., Sampaio, Í., Matos, V., Carreiro-Silva, M., Ocaña, O., ... & Santos, R. S. (2008). Cold-water corals of the Azores: preliminary assessment of distribution, diversity and associated fauna. In Proceedings of the 4th International Deep-Sea Coral Symposium, Wellington, New Zealand, Poster (Vol. 10, No. 2, p. 142).

Brooke, S., & Young, C. M. (2009). In situ measurement of survival and growth of Lophelia pertusa in the northern Gulf of Mexico. Marine Ecology Progress Series, 397, 153-161. Buhl-Mortensen, L., Vanreusel, A., Gooday, A. J., Levin, L. A., Priede, I. G., Buhl-Mortensen, P., ... & Raes, M. (2010). Biological structures as a source of habitat heterogeneity and biodiversity on the deep ocean margins. Marine Ecology, 31(1), 21-50.

Buhl-Mortensen, L., Vanreusel, A., Gooday, A. J., Levin, L. A., Priede, I. G., Buhl-Mortensen, P., ... & Raes, M. (2010). Biological structures as a source of habitat heterogeneity and biodiversity on the deep ocean margins. Marine Ecology, 31(1), 21-50.

Carreiro-Silva, M., Andrews, A. H., Braga-Henriques, A., De Matos, V., Porteiro, F. M., & Santos, R. S. (2013). Variability in growth rates of long-lived black coral Leiopathes sp. from the Azores. Marine Ecology Progress Series, 473, 189-199.

Carreiro-Silva, M., Braga-Henriques, A., Sampaio, I., de Matos, V., Porteiro, F. M., & Ocaña, O. (2011). Isozoanthus primnoidus, a new species of zoanthid (Cnidaria: Zoantharia) associated with the gorgonian Callogorgia verticillata (Cnidaria: Alcyonacea). *ICES Journal of Marine Science*, *68*(2), 408-415.

Carreiro-Silva, M., Ocana, O., Stanković, D., Sampaio, I., Porteiro, F. M., Fabri, M. C., & Stefanni, S. (2017). Zoantharians (Hexacorallia: Zoantharia) associated with cold-water corals in the Azores region: new species and associations in the deep sea. *Frontiers in Marine Science*, *4*, 88.

Cartes, J. E., LoIacono, C., Mamouridis, V., López-Pérez, C., & Rodríguez, P. (2013). Geomorphological, trophic and human influences on the bamboo coral Isidella elongata assemblages in the deep Mediterranean: To what extent does Isidella form habitat for fish and invertebrates?. Deep Sea Research Part I: Oceanographic Research Papers, 76, 52-65.

Carvalho, N., Edwards-Jones, G., & Isidro, E. (2011). Defining scale in fisheries: Small versus large-scale fishing operations in the Azores. *Fisheries Research*, *109*(2-3), 360-369.

Cau, A., Follesa, M. C., Moccia, D., Alvito, A., Bo, M., Angiolillo, M., ... & Cannas, R. (2015). Deepwater corals biodiversity along roche du large ecosystems with different habitat complexity along the south Sardinia continental margin (CW Mediterranean Sea). Marine biology, 162(9), 1865-1878.

Clark, M. R., & Koslow, J. A. (2007). Impacts of fisheries on seamounts. *Seamounts: ecology, fisheries, and conservation*, *12*, 413-441.

Clark, M. R., & Rowden, A. A. (2009). Effect of deepwater trawling on the macro-invertebrate assemblages of seamounts on the Chatham Rise, New Zealand. *Deep Sea Research Part I: Oceanographic Research Papers*, *56*(9), 1540-1554.

Clark, M. R., Althaus, F., Schlacher, T. A., Williams, A., Bowden, D. A., & Rowden, A. A. (2016). The impacts of deep-sea fisheries on benthic communities: a review. *ICES Journal of Marine Science*, *73*(suppl_1), i51i69.

Clark, M. R., Bowden, D. A., Rowden, A. A., & Stewart, R. (2019). Little evidence of benthic community resilience to bottom trawling on seamounts after 15 years. *Frontiers in Marine Science*, *6*, 63.

Collie, J. S., Escanero, G. A., & Valentine, P. C. (2000). Photographic evaluation of the impacts of bottom fishing on benthic epifauna. *ICES Journal of Marine Science*, *57*(4), 987-1001.

Danovaro, R., Snelgrove, P. V., & Tyler, P. (2014). Challenging the paradigms of deep-sea ecology. *Trends in ecology & evolution*, *29*(8), 465-475.

Dayton, P. K. (1972). Toward an understanding of community resilience and the potential effects of enrichments to the benthos at McMurdo Sound, Antarctica. In Proceedings of the colloquium on conservation problems in Antarctica (pp. 81-96). Lawrence, KS: Allen Press.

de Matos, V., Gomes-Pereira, J. N., Tempera, F., Ribeiro, P. A., Braga-Henriques, A., & Porteiro, F. (2014). First record of Antipathella subpinnata (Anthozoa, Antipatharia) in the Azores

(NE Atlantic), with description of the first monotypic garden for this species. *Deep Sea Research Part II: Topical Studies in Oceanography*, *99*, 113-121.

Diogo, H., Pereira, J. G., Higgins, R. M., Canha, Â., & Reis, D. (2015). History, effort distribution and landings in an artisanal bottom longline fishery: An empirical study from the North Atlantic Ocean. Marine Policy, 51, 75-85.

Dominguez-Carrió, C., Carreiro-Silva, M., Blasco-Ferre, J., Ramos, M., Taranto, G., Rodrigues, L., GutiérrezZárate, C., Morato, T., (2020). Vulnerable Marine Ecosystems identified in the Azores by means of towed camera systems and recommendations for the protection of these ecosystems: executive summary Feb 2020. Okeanos Centre of the University of the Azores, Horta, Portugal, pp.62

Dominguez-Carrió, C., Fontes, J., & Morato, T. (2021). A cost-effective video system for a rapid appraisal of deep-sea benthic habitats: The Azor drift-cam. *Methods in Ecology and Evolution*.

D'Onghia, G., Maiorano, P., Carlucci, R., Capezzuto, F., Carluccio, A., Tursi, A., & Sion, L. (2012). Comparing deep-sea fish fauna between coral and non-coral “megahabitats” in the Santa Maria di Leuca cold-water coral province (Mediterranean Sea).

Enrichetti, F., Bava, S., Bavestrello, G., Betti, F., Lanteri, L., & Bo, M. (2019b). Artisanal fishing impact on deep coralligenous animal forests: a Mediterranean case study of marine vulnerability. Ocean & Coastal Management, 177, 112-126.

Enrichetti, F., Bo, M., Morri, C., Montefalcone, M., Toma, M., Bavestrello, G., ... & Bianchi, C. N. (2019a). Assessing the environmental status of temperate mesophotic reefs: A new, integrated methodological approach. Ecological Indicators, 102, 218-229.

Enrichetti, F., Dominguez-Carrió, C., Toma, M., Bavestrello, G., Betti, F., Canese, S., & Bo, M. (2019c). Megabenthic communities of the Ligurian deep continental shelf and shelf break (NW Mediterranean Sea). PloS one, 14(10), e0223949.

European Commission, 2010. Commission Decision of 1 September 2010 on criteria and methodological standards on good environmental status of marine waters (notified under document C (2010) 5956)(2010/477/EU). *Official Journal of the European Union*, *232*, 12-24.

European Commission, 2012. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Blue Growth opportunities for marine and maritime sustainable growth. COM(2012) 494 final.

European Commission., 2008. Directive 2008/56/EC of the European Parliament and the Council establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). *Official Journal of the European Union*, *164*, 19-40.

European Commission., 2017. Commission decision (EU) 2017/848 of 17 May 2017 laying down criteria and methodological standards on good environmental status of marine waters and specifications and standardised methods for monitoring and assessment, and repealing Decision 2010/477/EU. *Official Journal of the European Union L*, *125*, 43-74.

European Commission., 2020a. Report from the commission to the European parliament and the council on the implementation on the marine Strategy Framework Directive (Directive 2008/56/EC). COM(2020) 259 final.

European Commission., 2020b. Commission Staff Working Document. Background document for the Marine Strategy Framework Directive on the determination of good environmental status and its links to assessments and the setting of environmental targets. SWD(2020) 61 final.

FAO, (2009). Report of the Technical Consultation on International Guidelines for the Management of Deep-sea Fisheries in the High Seas, Rome. 4–8 February and 25–29 August 2008, FAO Fisheries and Aquaculture Report, 881. 86 pp.

FAO. (2016). Vulnerable marine ecosystems. Processes and practices in the high seas. Food and Agriculture Organization of the United Nations Fisheries and aquaculture Technical Paper 595, 185 pp.

Fauconnet, L., Pham, C. K., Canha, A., Afonso, P., Diogo, H., Machete, M., ... & Morato, T. (2019). An overview of fisheries discards in the Azores. *Fisheries Research*, *209*, 230-241.

Ferrigno, F., Appolloni, L., Russo, G. F., & Sandulli, R. (2018). Impact of fishing activities on different coralligenous assemblages of Gulf of Naples (Italy). Journal of the Marine Biological Association of the United Kingdom, 98(1), 41-50.

Gage, J. D., & Tyler, P. A. (1991). *Deep-sea biology: a natural history of organisms at the deep-sea floor*. Cambridge University Press.

Glover, A. G., Gooday, A. J., Bailey, D. M., Billett, D. S. M., Chevaldonné, P., Colaço, A., ... & Vanreusel, A. (2010). Temporal change in deep-sea benthic ecosystems: a review of the evidence from recent time-series studies. Advances in marine biology, 58, 1-95.

Gomes-Pereira, J. N., Carmo, V., Catarino, D., Jakobsen, J., Alvarez, H., Aguilar, R., ... & Colaço, A. (2017). Cold-water corals and large hydrozoans provide essential fish habitat for Lappanella fasciata and Benthocometes robustus. *Deep Sea Research Part II: Topical Studies in Oceanography*, *145*, 33-48.

Gori, A., Bavestrello, G., Grinyó, J., Dominguez-Carrió, C., Ambroso, S., & Bo, M. (2017). Animal forests in deep coastal bottoms and continental shelf of the Mediterranean Sea. Marine Animal Forests: the ecology of benthic biodiversity hotspots, 207-233.

Grinyó, J., Gori, A., Ambroso, S., Purroy, A., Calatayud, C., Dominguez-Carrió, C., ... & Gili, J. M. (2016). Diversity, distribution and population size structure of deep Mediterranean gorgonian assemblages (Menorca Channel, Western Mediterranean Sea). Progress in Oceanography, 145, 42-56.

Hall–Spencer, J., Allain, V., & Fosså, J. H. (2002). Trawling damage to Northeast Atlantic ancient coral reefs. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *269*(1490), 507-511.

He, P., Chopin, F., Suuronen, P., Ferro, R.S.T and Lansley, J. 2021. Classification and illustrated definition of fishing gears. FAO Fisheries and Aquaculture Technical Paper No. 672. Rome, FAO.

Heifetz, J., Stone, R. P., & Shotwell, S. K. (2009). Damage and disturbance to coral and sponge habitat of the Aleutian Archipelago. *Marine Ecology Progress Series*, *397*, 295-303.

Henry, L. A., Navas, J. M., Hennige, S. J., Wicks, L. C., Vad, J., & Roberts, J. M. (2013). Cold-water coral reef habitats benefit recreationally valuable sharks. *Biological conservation*, *161*, 67-70.

Jennings, S., & Kaiser, M. J. (1998). The effects of fishing on marine ecosystems. In *Advances in marine biology* (Vol. 34, pp. 201-352). Academic Press.

Kazanidis, G., Orejas, C., Borja, A., Kenchington, E., Henry, L.-A., Callery, O., Carreiro-Silva, M., Egilsdottir, H., Giacomello, E., Grehan, A., Menot, L., Morato, T., Ragnarsson, S. A., Rueda, J. L., Stirling, D. E., Stratmann, T., van Oevelen, D., Palialexis, A., Johnson, D., & Roberts, J. M.. (2020). Assessing the environmental status of selected North Atlantic deep-sea ecosystems. Ecological Indicators, 119, 106624.

Kelleher, K. (2005). Discards in the world's marine fisheries: an update (Vol. 470). Food & Agriculture Org..

Koslow, J., Boehlert, G. W., Gordon, J. D. M., Haedrich, R. L., Lorance, P., & Parin, N. (2000). Continental slope and deep-sea fisheries: implications for a fragile ecosystem. *ICES Journal of marine Science*, *57*(3), 548557.

Lacharité, M., & Metaxas, A. (2013). Early life history of deep-water gorgonian corals may limit their abundance. *PLoS One*, *8*(6), e65394.

Levin, L. A., & Sibuet, M. (2012). Understanding continental margin biodiversity: a new imperative. *Annual Review of Marine Science*, *4*, 79-112.

Maynou, F., & Cartes, J. E. (2012). Effects of trawling on fish and invertebrates from deep-sea coral facies of Isidella elongata in the western Mediterranean. Journal of the Marine Biological Association of the United Kingdom, 92(7), 1501-1507.

Morato, T., Afonso, P., Menezes, G. M., Santos, R. S., & Silva, M. A. (2020b). The Azores Marine Ecosystem: An Open Window Into North Atlantic Open Ocean and Deep-Sea Environments. *Frontiers in Marine Science*, *7*, 930.

Morato, T., Bulman, C., & Pitcher, T. J. (2009). Modelled effects of primary and secondary production enhancement by seamounts on local fish stocks. *Deep Sea Research Part II: Topical Studies in Oceanography*, *56*(25), 2713-2719.

Morato, T., Combes, M., Brito, J., Rodrigues, L., Dominguez-Carrió, C., Taranto, G.H., Fauconnet, L., Ramos, M., Blasco-Ferre, J., Gutiérrez-Zárate, C., Pham, C.K., Colaço, A., Gonzalez-Irusta, J.M., Giacomello, E., & Carreiro-Silva, M. (2020d) Systematic conservation planning scenarios for the Azores deep-sea: draft v.11 Feb 2020. Okeanos Centre of the University of the Azores, Horta, Portugal.

Morato, T., et al. (2020a). Deep-sea scientific research in the Azores. Ocean Governance in Archipelagic Regions. International Conference 2019. Arquipelago. Life and Marine Sciences. Supplement 11. https://doi.org/10.25752/arq.21174.

Morato, T., Machete, M., Kitchingman, A., Tempera, F., Lai, S., Menezes, G., ... & Santos, R. S. (2008). Abundance and distribution of seamounts in the Azores. *Marine Ecology Progress Series*, *357*, 17-21.

Morato, T., Watson, R., Pitcher, T. J., & Pauly, D. (2006). Fishing down the deep. *Fish and fisheries*, *7*(1), 24-34.

Mortensen, P. B., Buhl-Mortensen, L. E. N. E., Gordon, D. C., Fader, G. B., McKeown, D. L., & Fenton, D. G. (2005). Effects of fisheries on deepwater gorgonian corals in the Northeast Channel, Nova Scotia. In American Fisheries Society Symposium (Vol. 41, p. 369). American Fisheries Society.

Muñoz, P. D., Murillo, F. J., Sayago-Gil, M., Serrano, A., Laporta, M., Otero, I., & Gómez, C. (2011). Effects of deep-sea bottom longlining on the Hatton Bank fish communities and benthic ecosystem, north-east Atlantic. Journal of the Marine Biological Association of the United Kingdom, 91(4), 939-952.

Murillo, F. J., Durán Muñoz, P., Altuna, A., & Serrano, A. (2011). Distribution of deep-water corals of the Flemish Cap, Flemish Pass, and the Grand Banks of Newfoundland (Northwest Atlantic Ocean): interaction with fishing activities. *ICES Journal of Marine Science*, *68*(2), 319-332.

Mytilineou, C., Smith, C. J., Anastasopoulou, A., Papadopoulou, K. N., Christidis, G., Bekas, P., ... & Dokos, J. (2014). New cold-water coral occurrences in the Eastern Ionian Sea: Results from experimental long line fishing. Deep Sea Research Part II: Topical Studies in Oceanography, 99, 146-157.

OSPAR 2010. Background document for coral gardens. Biodiversity Series, Publication Number: 486/2010 Available at: https://www.ospar.org/work-areas/bdc/species-habitats/list-of-threatened-declining-specieshabitats.

Peran, A. D., Pham, C. K., Amorim, P., Cardigos, F., Tempera, F., & Morato, T. (2016). Seafloor characteristics in the Azores region (North Atlantic). *Frontiers in Marine Science*, *3*, 204.

Pham, C. K., Canha, A., Diogo, H., Pereira, J. G., Prieto, R., & Morato, T. (2013). Total marine fishery catch for the Azores (1950–2010). ICES Journal of Marine Science, 70(3), 564-577.

Pham, C. K., Diogo, H., Menezes, G., Porteiro, F., Braga-Henriques, A., Vandeperre, F., & Morato, T. (2014). Deep-water longline fishing has reduced impact on Vulnerable Marine Ecosystems. *Scientific reports*, *4*, 4837.

Pham, C. K., Vandeperre, F., Menezes, G., Porteiro, F., Isidro, E., & Morato, T. (2015). The importance of deepsea vulnerable marine ecosystems for demersal fish in the Azores. *Deep Sea Research Part I: Oceanographic Research Papers*, *96*, 80-88.

Pinho, M. R., & Menezes, G. (2009). Pescaria de demersais dos Açores. Boletim do Núcleo Cultural da Horta, 18, 85-102.

Ragnarsson, S. Á., Burgos, J. M., Kutti, T., van den Beld, I., Egilsdóttir, H., Arnaud-Haond, S., & Grehan, A. (2017). The impact of anthropogenic activity on cold-water corals. *Marine Animal Forests*, 1-35.

Ramirez-Llodra, E., Brandt, A., Danovaro, R., De Mol, B., Escobar, E., German, C. R., ... & Narayanaswamy, B. E. (2010). Deep, diverse and definitely different: unique attributes of the world's largest ecosystem. *Biogeosciences*, *7*(9), 2851-2899.

Ramirez-Llodra, E., Tyler, P. A., Baker, M. C., Bergstad, O. A., Clark, M. R., Escobar, E., ... & Van Dover, C. L. (2011). Man and the last great wilderness: human impact on the deep sea. *PLoS one*, *6*(8), e22588.

Rice, J., Arvanitidis, C., Borja, A., Frid, C., Hiddink, J., Krause, J., ... & Trabucco, B. (2010). Marine Strategy Framework Directive–task group 6 report seafloor integrity. *EUR 24334 EN*, 73.

Roark, E. B., Guilderson, T. P., Dunbar, R. B., Fallon, S. J., & Mucciarone, D. A. (2009). Extreme longevity in proteinaceous deep-sea corals. Proceedings of the National Academy of Sciences, 106(13), 5204-5208.

Sabatier, P., Reyss, J. L., Hall-Spencer, J. M., Colin, C., Frank, N., Tisnerat-Laborde, N., ... & Douville, E. (2012). 210Pb-226Ra chronology reveals rapid growth rate of Madrepora oculata and Lophelia pertusa on world's largest cold-water coral reef. Biogeosciences (BG), 9(3), 1253-1265.

Sampaio, Ã., Braga-Henriques, A., Pham, C., Ocaña, O., De Matos, V., Morato, T., & Porteiro, F. M. (2012). Cold-water corals landed by bottom longline fisheries in the Azores (north-eastern Atlantic). *Marine Biological Association of the United Kingdom. Journal of the Marine Biological Association of the United Kingdom*, *92*(7), 1547.

Snelgrove, P. V., Soetaert, K., Solan, M., Thrush, S., Wei, C. L., Danovaro, R., ... & Parkes, R. J. (2018). Global carbon cycling on a heterogeneous seafloor. Trends in ecology & evolution, 33(2), 96-105.

SRRN (2014). Estratégia Marinha para a subdivisão dos Açores. Diretiva Quadro Estratégia Marinha. Secretaria Regional dos Recursos Naturais. Junho de 2014.

Stuart, C. T., Rex, M. A., & Etter, R. J. (2003). Large-scale spatial and temporal patterns of deep-sea benthic species diversity. *Ecosystems of the World*, 295-312.

Sumaila, U. R., Khan, A., Teh, L., Watson, R., Tyedmers, P., & Pauly, D. (2010). Subsidies to high seas bottom trawl fleets and the sustainability of deep-sea demersal fish stocks. *Marine Policy*, *34*(3), 495-497.

Suuronen, P., Chopin, F., Glass, C., Løkkeborg, S., Matsushita, Y., Queirolo, D., & Rihan, D. (2012). Low impact and fuel efficient fishing—Looking beyond the horizon. *Fisheries research*, *119*, 135-146.

Tempera, F., Atchoi, E., Amorim, P., Gomes-Pereira, J., & Gonçalves, J. M. S. (2013). Atlantic Area Marine Habitats: Adding new Macaronesian habitat types from the Azores to the EUNIS Habitat Classification.

Wareham, V. E., & Edinger, E. N. (2007). Distribution of deep-sea corals in the Newfoundland and Labrador region, Northwest Atlantic Ocean. *Bulletin of Marine Science*, *81*(3), 289-313.

Watling, L., & Norse, E. A. (1998). Disturbance of the seabed by mobile fishing gear: a comparison to forest clearcutting. *Conservation Biology*, *12*(6), 1180-1197.

Watson, R. A., & Morato, T. (2013). Fishing down the deep: Accounting for within-species changes in depth of fishing. *Fisheries Research*, *140*, 63-65.

Watson, R., & Morato, T. (2004). Exploitation patterns in seamount fisheries: a preliminary analysis. *Fisheries Centre Research Reports*, 61.

Wheeler, A. J., Bett, B. J., Billett, D. S. M., Masson, D. G., & Mayor, D. J. (2005). The impact of demersal trawling on northeast Atlantic deepwater coral habitats: the case of the Darwin Mounds, United Kingdom. In American Fisheries Society Symposium (Vol. 41, pp. 807-818). American Fisheries Society.

Williamson, D. H., Ceccarelli, D. M., Evans, R. D., Hill, J. K., & Russ, G. R. (2014). Derelict fishing line provides a useful proxy for estimating levels of non-compliance with no-take marine reserves. PLoS One, 9(12), e114395.

Xavier, J. R., Rees, D. J., Pereira, R., Colaço, A., Pham, C. K., & Carvalho, F. C. (2021). Diversity, Distribution and Phylogenetic Relationships of Deep-Sea Lithistids (Porifera, Heteroscleromorpha) of the Azores Archipelago. Frontiers in Marine Science, 8, 479.

Zeller, D., Cashion, T., Palomares, M., & Pauly, D. (2018). Global marine fisheries discards: A synthesis of reconstructed data. Fish and Fisheries, 19(1), 30-39.

APPENDIX I

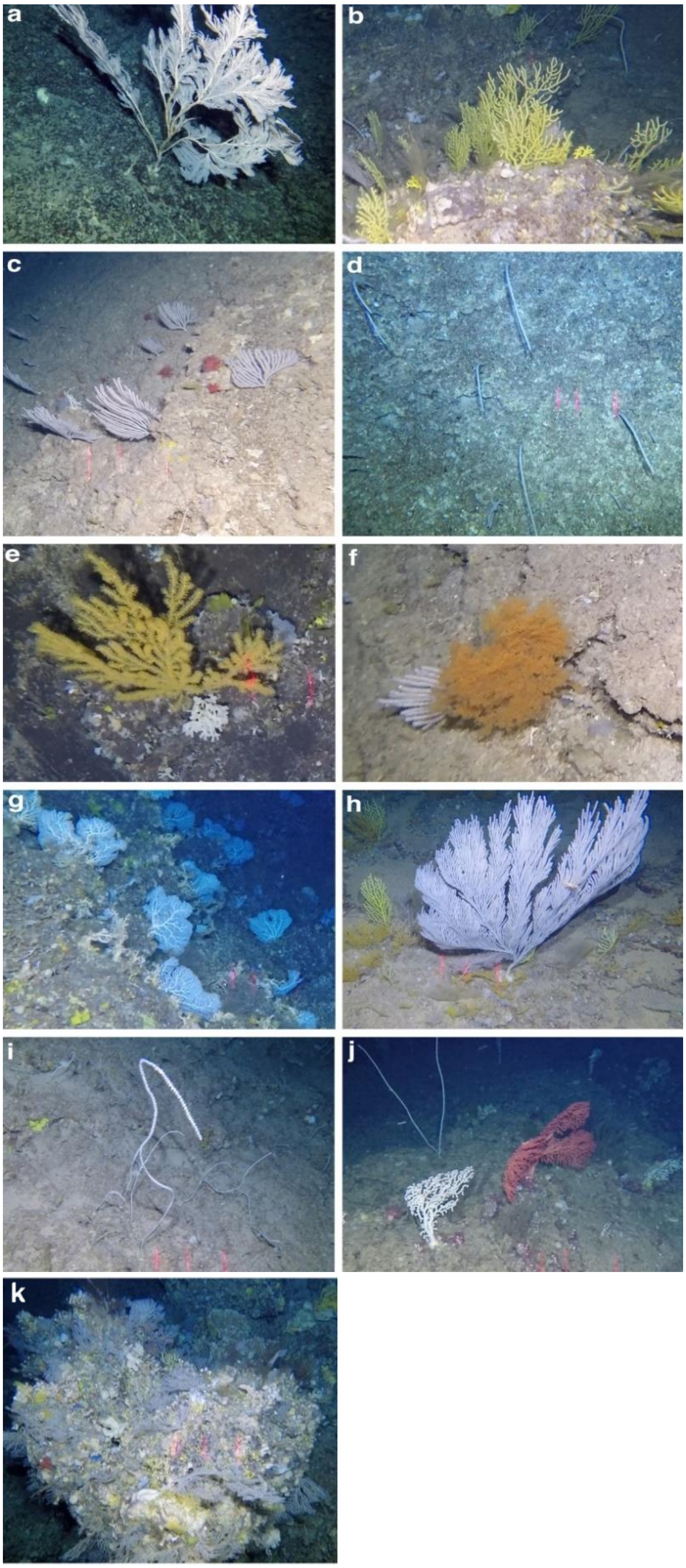


Figure 1. Selected CWC species. (a) *Callogorgia verticillata; (b) Dentomuricea* aff *meteor;* (c) *Narella bellissima;* (d) *Narella versluysi;* (e) *Acanthogorgia* sp.; (f) *Leiopathes* spp.; (g) *Errina dabneyi;* (h*) Paracalyptrophora josephinae*; (i) *Viminella flagellum*; (j) *Paragorgia johnsoni*; (k) *Candidella imbricata. Image credits: IMAR/Okeano-UAç, Azor drift-cam*

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