Ecosystem goods and services valuation and environmental risk assessment

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Author:	**Lead Authors:** Anthony Grehan, Stephen Hynes, Oisin Callery, Daniel Norton (NUIG), Joana Gafeira (BGS) **Contributing Authors:** Kyle Burnett, Naomi Foley (NUIG), David Stirling (MSS), José-Manuel González-Irusta, Telmo Morato (IMAR/DOP), Sandy Henderson (BGS)

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Abstract

The **Convention on Biological Diversity** in 2004 set out 12 principles to underpin implementation of the ecosystem approach that can be broadly grouped into four categories:

People

The care of nature is a shared responsibility for all of society; we most value all knowledge and perspectives; we most involve more of society in decisions.

Scale and Dynamics

Work at the right geographic scale and timescale; look well ahead into the future; work with inevitable environmental change.

Functions and services

Maintain the flow of ecosystem services; work within the capacity of natural systems; balance the demand for use and conservation of the environment.

Management

Allow decisions to be led locally, as far as practicable; assess the effects of decisions on others; consider economic factors.

Fifteen years later the integration of ecosystem services and natural capital into environmental assessment is still very much in its infancy. Despite their seemingly remote nature, deep sea benthic habitats generate ecosystem services which provide benefits to society. Examples of these ecosystem services include provisioning ecosystem services such as fisheries, regulating ecosystem services such as nutrient cycling and maintenance of biodiversity and cultural ecosystems such as existence value. This report examines the assessment, mapping and valuation of ecosystem services in the marine and specifically for deep sea benthic habitats in the ATLAS case studies. For the provisioning ecosystem service of fisheries, a comparison is made between qualitative and quantitative approaches in methods of measuring and mapping ecosystem services generated from benthic habitats.

In addition, this report has collated maps assessing the risk of fisheries impact - the most widespread and impacting human activity in the North Atlantic – in areas where vulnerable marine ecosystems and fish habitat are likely to occur in each ATLAS case study. This work presented as an atlas will provide a foundation to underpin subsequent testing of blue growth scenarios in each of the case studies.

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Partner 1 University of Edinburgh (UEDIN)

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Partner 9 MARUM, University of Bremen (UniHB)

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Partner 13 University of Oxford (UOX)

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Partner 22 Instituto Espanol de Oceanografia (IEO)

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Partner 24 AquaTT

Partner 25 Iodine

List of acronyms

ABNJ - Areas Beyond National Jurisdiction

AMOC - Atlantic Meridional Overturning Circulation BBNJ - Biodiversity Beyond National Jurisdiction

CEM - Conservation and Enforcement Measures EA - Enterprise Allocation

EAF - Ecosystem Approach Framework

EBSA - Ecologically or Biologically Significant Area

ECS - Extended Continental Shelf

EEZ - Exclusive Economic Zone

ENACW - Eastern North Atlantic Central Water

ICES - International Council for the Exploration of the Sea

IFMPs - Integrated Fisheries Management Plans

MAPAMA - Spanish Ministry for Agriculture, Fisheries, Food and Environment

MESMA - Monitoring and Evaluation of Spatially Managed Areas project

MOW - Mediterranean Outflow Water

MPA - Marine Protected Area

MSFD – Marine Strategy Framework Directive

MSP - Maritime Spatial Planning

NAFO - Northwest Atlantic Fisheries Organization

NEAFC - North East Atlantic Fisheries Commission

RFMOs – Regional Fisheries Management Organisations

SAC – Special Area of Conservation

SEA - Strategic Environment Assessment

SFAs -Shrimp Fishing Areas

TAC - Total Allowable Catch

UNGA - United Nations General Assembly

VME - Vulnerable Marine Ecosystem

VMS - Vessel Monitoring Scheme

1. Mapping Ecosystem Goods and Services

1.1. Introduction

This report analyses and adapts existing economic valuation approaches to deliver a framework suitable for the unique challenges encountered by the ATLAS case study areas and the valuation of the ocean services which they supply to humanity. Economic valuation of the deep sea is limited. Existing information is usually tied to the provisioning services of the ocean such as fisheries and fish habitat; with little information on regulating and cultural services, or future potential services from Blue Growth. Provisioning services such as fisheries are quantifiable, but regulating or cultural services are not well known to the public. This makes total valuation a demanding exercise, but one that has been attempted for a few deep sea ecosystems, such as cold water corals. Applied valuation studies of the deep sea and associated ecosystems include discrete choice experiments (Glenn et al., 2010; Wattage, et al., 2011; Jobstvogt et al., 2014; Aanesen et al., 2015), contingent valuation surveys (Ressurreição, et al., 2011; Ressurreição et al., 2012) and benefit transfer (Beaumont et al, 2008; Norton et al., 2018; Hynes et al. 2018).

There are number of different definitions of **'ecosystem services'** (Nahlik et al., 2012), ranging from the succinct **'The benefits people obtain from ecosystems'** (MEA, 2005) to the one used here and defined by Norton et al. (2018) and again by Austen et al., (2019); **'Marine ecosystem services are provided by the processes, functions and structure of the marine environment that directly or indirectly contribute to societal welfare, health and economic activities'**. Figure 1 demonstrates the path from the bio-chemical or bio-physical process and ecosystem structure through to ecosystem function which when utilised by society creates an ecosystem service. This service can (sometimes) be valued using a variety of different methods. ***However it should be noted that if a potential ecosystem service (or ecosystem function) is not used or interacted (even cognitively for non-use values) with by a person or society then no ecosystem service is generated.***

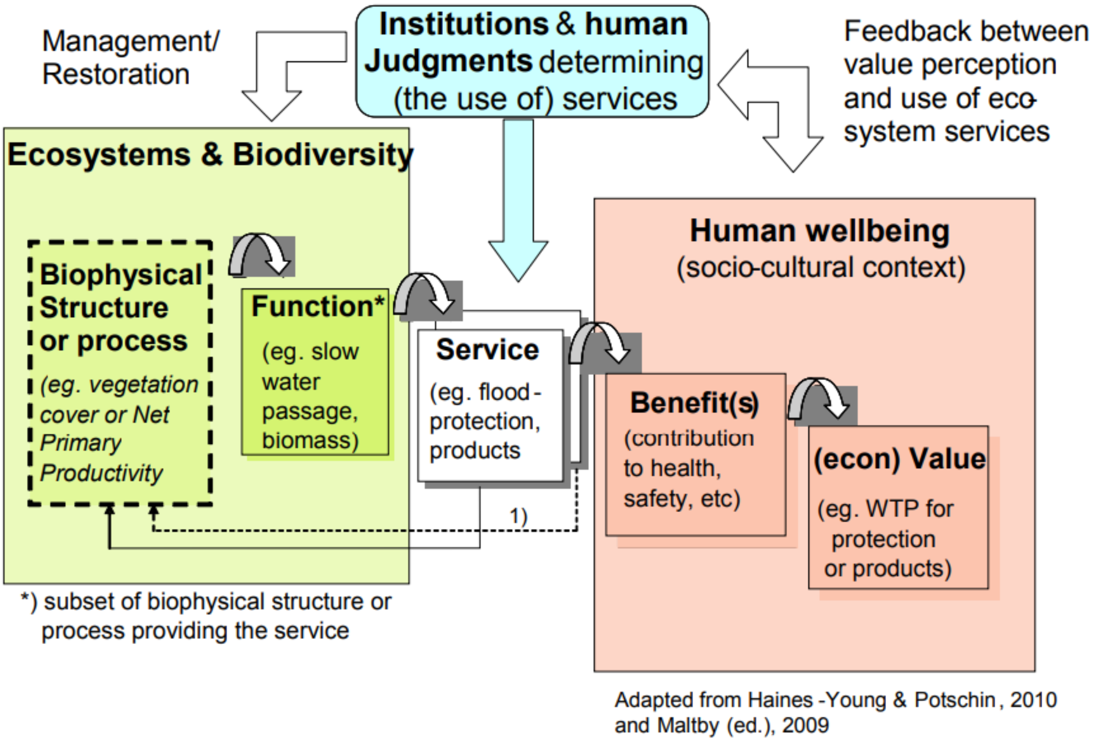


Figure 1. The path from ecosystem structure to ecosystem service to economic benefit

The ATLAS Deliverable 5.1 report identified the ecosystem services associated with each of the case study areas. The report used both the Millennium Ecosystem Assessment (MA) and the CICES framework in the identification process. The MA was used so that supporting services from the deep sea could be included. From an economic perspective, the way to value services is to estimate the flow of values emanating from natural sources (Armstrong et al, 2014). However, the danger of double counting these values, first as supporting service values, and then as values inherent in provisioning, regulating or cultural values, was pointed to as a serious problem early on in the development of ecosystem service valuation, and has underlined the need to keep these values separate (Beaumont et al., 2008). While it remains important to take account of supporting services in particular for the deep sea it is necessary to avoid double counting. The information gathered using the MA framework was then converted to the CICES framework as a stepping stone for the monetary evaluation. Therefore, for the valuation of ecosystem services in ATLAS D6.2 we will use the CICES framework. The CICES framework also includes a more layered presentation of ecosystem services (ESs); in that, it divides the services into several types (see Division, Group and Class in Table 1). This allows for a more systematic presentation, and also opens the possibility for identification of services that might otherwise go un-noticed.

Table 1 presents case study ESs using the CICES framework. This sets the scene for further ecosystem services work, translating the ecosystem services identified using the MA framework to the CICES framework. In this instance supporting services are omitted with the exception of habitat and nurseries. As noted with the outcome of the MA matrix, a significant number of ecosystem services have been identified for the case studies whose environments are mainly in the deep sea. Abiotic resources are presented in Table 2. For abiotic resources, the table remains incomplete particularly with regard to cultural ESs. Examples of these abiotic cultural ESs in the deep sea could include shipwrecks. It is something to be explored further with individual case studies.

Table 1. CICES Framework Ecosystem Services for ATLAS Case Studies

Section	Division	Group	Armstrong et al (2010, 2012); THURBER (2014)	LoVe	Mingulay	Azores	Flemish Cap	West of Shetland and W of Scotland Slope	Rockall Bank	Porcupine Seabight	Bay of Biscay	Gulf of Cadiz/Strait of Gibraltar/Alboran Sea	Reykjanes Ridge	S Davis Strait/Western Greenland/Labrador Sea	SE USA (Bermuda Transect)
Provisioning	Nutrition	Biomass	*Finfish, shellfish, marine mammals*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			Aquaculture (not in Armstrong et al)									✓			
	Materials	Biomass	*Raw materials*	✓	✓					✓	✓	✓			✓
			Chemical compounds for industrial or pharmaceutical use		✓	✓	✓	✓	✓	✓		✓	✓		✓
Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota	*Waste absorption and detoxification*	✓	✓	✓	✓	✓		✓	✓	✓			✓
			Carbon sequestration / absorption	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
		Mediation by ecosystems	*Carbon sequestration / absorption*	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
			Waste absorption and detoxification	✓	✓	✓	✓	✓		✓	✓	✓			✓
	Mediation of flows	Mass flows	*Waste absorption and detoxification*	✓	✓	✓	✓	✓		✓	✓	✓			✓
	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	*Habitat & nursery (supporting)*	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
		Pest and disease control	*Biological regulation*		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
			Biological regulation		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
		Water conditions	?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Atmospheric composition and climate regulation	*Gas and climate regulation*	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Cultural	Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Physical and experiential interactions	*Tourism*	✓	✓	✓		✓				✓			✓
			Recreation	✓	✓	✓					✓	✓			✓
		Intellectual and representative interactions	*Scientific research*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			Educational	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓
			Cultural heritage	✓	✓		✓	✓	✓	✓		✓		✓	✓
			Indigenous heritage		✓			✓				✓		✓	✓
			Entertainment (documentaries)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			Aesthetic	✓	✓	✓	✓		✓			✓	✓	✓	✓
		Other cultural outputs	*Existence*	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
			Bequest	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓

Table 2. CICES Identification of Abiotic Resources

Section	Division	Group	Armstrong et al (2010, 2012); MA Adapted Framework	LoVe	Mingulay	Azores	Flemish Cap	West of Shetland and W of Scotland Slope	Rockall Bank	Porcupine Seabight	Bay of Biscay	Gulf of Cadiz/Strait of Gibraltar/Alboran Sea	Reykjanes Ridge	S Davis Strait/Western Greenland/Labrador Sea	SE USA (Bermuda Transect)
Abiotic Provisioning	Nutritional abiotic substances	Mineral	Minerals (provisioning)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Abiotic materials	Non-metallic	Minerals (provisioning)			✓	✓	✓		✓		✓	✓		✓
	Energy	Renewable abiotic energy sources	Energy (provisioning)	✓	✓	✓			✓			✓			
		Non-renewable energy sources	Oil and Gas (provisioning)	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓
Regulation & Maintenance by natural physical structures and processes	Mediation of waste, toxics and other nuisances	By natural chemical and physical processes	Waste disposal sites (provisioning)	✓		✓	✓ (fishing and shipping)	✓			✓	✓			✓
Cultural settings dependent on abiotic structures	Physical and intellectual interactions with land-/seascapes [physical settings]	By physical and experiential interactions or intellectual and representational interactions	Research of the deep sea	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Spiritual, symbolic and other interactions with land-/seascapes [physical settings]	By type	Shipwrecks?												

The Economics of Ecosystems and Biodiversity (TEEB) presents an approach to monetary valuation of ecosystem services. This is shown in Figure 2. The first part of this approach for ATLAS was undertaken in D5.1, namely the full range of ecosystem services from case studies and a qualitative review of goods and services. This report will cover to some extent the final three steps: pre-valuation review, qualitative and where possible quantitative review of goods and services and monetary valuation of ecosystem services.

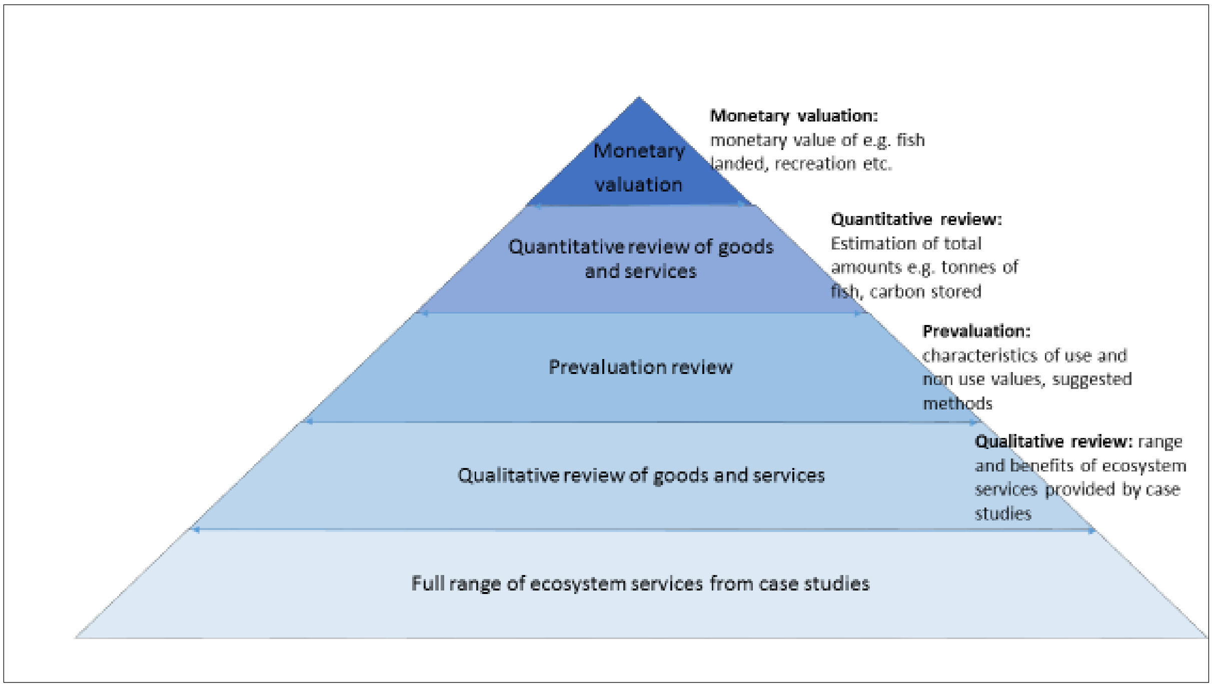


Figure 2. Adapted TEEB pyramid. Source: Armstrong et al., (2010).

The remainder of the report will discuss deep-sea marine ecosystem service benefit valuation using the Total Economic Value (TEV) framework, along with a qualitative valuation of ecosystem services where data is available for each case study area. A quantitative estimation of the volume of landings and value of landings for the provisioning ecosystem service of fisheries is also presented for case studies where sufficient data was available.

1.2. Valuing Ecosystem Services

Ecosystem goods and services contribute to human wellbeing in several ways and individuals have several motivations for placing a value on these resources. These motivations can be teased out using the total economic value (TEV) framework as shown in Figure 2 (Pearce and Turner, 1990). Ecosystem services frameworks such as CICES blend well with the TEV framework of environmental economics. TEV shows how ecosystem goods and services that provide several sources of value to humans can be represented in economic terms. Figure 3 presents the TEV framework and how the values are connected with services identified in the CICES framework.

Figure 3 illustrates how values in TEV are divided into use and non-use values, and these are further subdivided. Use value involves some interaction with the resource either directly or indirectly:

- *Direct use values* imply use of the resource in a consumptive manner, such as fisheries, or a non-consumptive manner, such as recreational activities.
- *Indirect use values* are the role of the aquatic environment (marine, ponds or lakes) in providing key ecosystem services such as nutrient cycling, habitat provision or climate regulation.
- *Option values* are the benefit of keeping open the option to make use of the resource in the future even though such use is not currently planned or conceived.

Non-use values are associated with benefits derived simply from the knowledge that the natural resource and aspects of the natural environment is maintained. Non-use values can be split into:

- *Existence values* which are derived simply from knowing that the aquatic environment or certain aspects of it continue to exist regardless of the uses of the resource.
- *Bequest values* which are the value of the knowledge that the resource will be passed on to future generations.

Table 3. Overview of different revealed preference and stated preference approaches to ecosystem service valuation

Type and methods	Description
Revealed preference methods	**Methods based on values for ecosystem services that are 'revealed' by behaviour in associated markets.**
Market prices	Market prices are rarely equal to values. Prices do not generally reveal the 'consumer surplus' (the value to the consumer over and above the price paid). They can also be distorted by taxes and subsidies.
Production functions	Production functions are statistical models which relate how changes in some ecosystem function affect production of a marketed good or service.
Avoided costs/ Replacement costs	Avoided or replacement costs are a measure of the value of a service based on the cost to replace the ecosystem function or service.
Non-market revealed preference techniques	**Methods based on values for ecosystem services that are revealed by behaviour in associated markets.**
Travel cost	The travel cost method is used to estimate the value of sites which people travel to (i.e. for recreation) based on the theory that the time taken and travel costs represents the value of access to the site.
Hedonic pricing	Hedonic pricing is a statistical modelling technique which estimates the implicit price paid for environmental characteristics of the area or for a pleasing sea view through the variation in the property prices in different areas.
Stated preference methods	**Methods based on surveys in which respondents give valuation responses in hypothetical situations**
Contingent valuation	Contingent valuation is a method of valuing a single change to an environmental good or service where the change is described and the respondent is asked their Willingness to pay(WTP)/ Willingness to accept (WTA).
Choice experiments	Choice experiments estimate values from the choices respondents make between options with different specified attributes of an environmental good.
Value transfer (VT)	**A secondary valuation methodology that uses existing value evidence to be applied to new cases without the need for primary valuation studies.**
Point, function and meta-analysis transfer methods	Point VT transfers a single value or mean of value which may or may not be adjusted. Function transfer is a function which has be estimated using a primary valuation method. Meta-analysis pools similar primary studies together to generate statistically robust functions for use in VT.

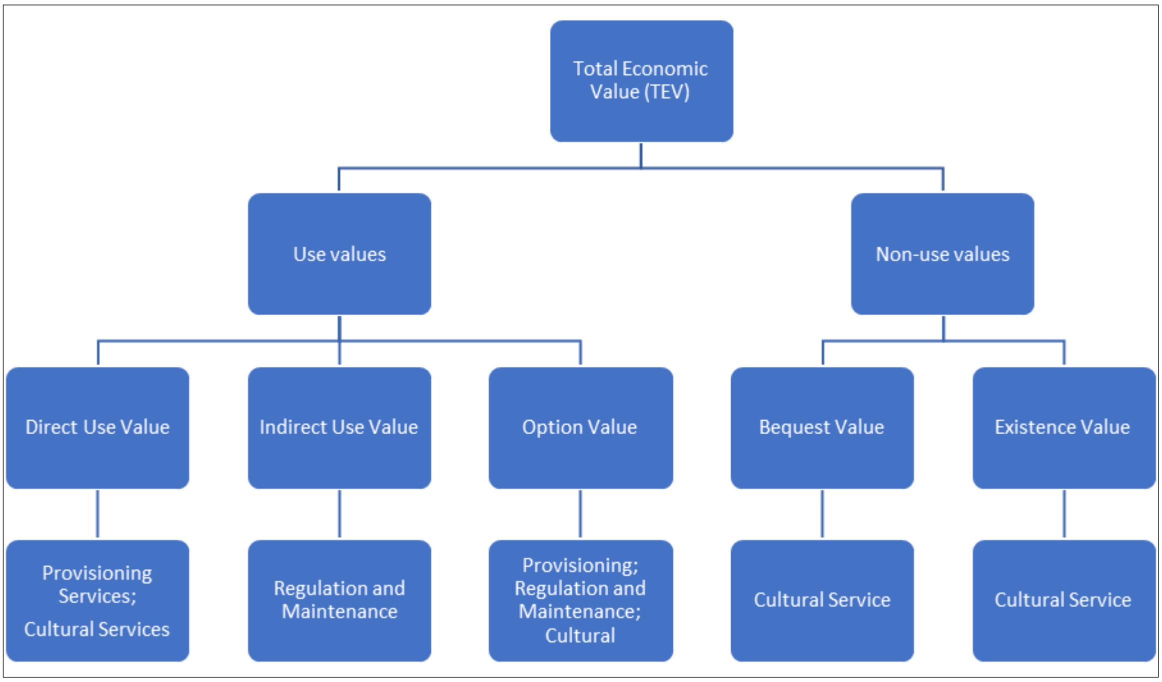


Figure 3. Total Economic Value framework and the link with CICES categories.

The valuation methods used to value ecosystem services can be divided into two main types: Revealed preference (RP) and Stated Preference (SP) methods, as shown in Table 3 and 4.

Table 4. The different services found in case study areas, and the valuation methods that could be applied to determine their worth.

	Ecosystem Services	Valuation methods
Provisioning	Fish/Shellfish Feed Raw Materials Renewable Energy	Market values
Regulation and Maintenance	Climate Regulation Carbon Sequestration / Absorption Biological Regulation Food Web Dynamics Habitat	Replacement Costs, Mitigation Costs, Averting behaviour or Market Values Production function approach
Cultural	Recreation Tourism Cultural Heritage Biodiversity Education	Market or Implicit values, Travel Cost, Hedonic pricing, *Discrete Choice Experiments*, Contingent Valuation

While most marine related valuation studies focus on coastal environments, there have been some studies carried out on the deep sea and in ATLAS case study countries including Ireland, UK and Azores. Applied valuation studies of the deep sea and associated ecosystems include discrete choice experiments (Glenn et al., 2010; Wattage et al., 2011; Jobstvogt et al., 2014; Aanesen et al., 2015), contingent valuation surveys (Ressurreição et al., 2011; Ressurreição et al., 2012; Ressurreição et al., 2012) and benefit transfer (Beaumont et al, 2008).

Glenn et al.,(2010) and Wattage et al.,(2011) carried out a discrete choice experiment (DCE) to estimate the values the general public held for the protection of cold-water corals (CWC) in Ireland. Due to a statistically insignificant cost parameter the authors refrained from estimating the willingness to pay (WTP) for the attributes. However, from the follow up questions in the survey it was found that a large percentage of those surveyed valued CWC and would like to see them protected for future generations, for their role as essential fish habitats, for their pure existence value and for the option to use or see them in the future.

Jobsvogt et al.,(2014) conducted a DCE for the deep sea area of the north and northwest UK EEZ (12-200nm off the coast). A list of deep-sea ecosystem services from existing literature, specifically Armstrong et al., (2010; 2012), and van den Hove and Moreau (2007), served as the source for potential attributes. The list included supporting services, provisioning services, regulating services and cultural services. The potential attributes list was further refined with the use of focus groups and interviews (Jobstvogt et al., 2014). From the list of identified ES, two were chosen for the final experimental design to value both use and non-use values attached to deep-sea environments around the Scottish coast. They found a high WTP for deep sea protection ranging from £70 - £77 despite the remoteness of and lack of familiarity with these areas.

Aanesen et al.,(2015) designed a discrete choice experiment to derive willingness to pay for increasing the protection of cold water corals in Norway. Choice attributes results were selected using existing literature and expert interviews. The possibility that CWC play an important role as a fish habitat was the most important variable to explain people's WTP for the protection of CWC. The study found a high WTP for the protection of CWC in the range of €274 - €287. Though not directly related to the deep sea, Norton and Hynes (2014) carried out a DCE to estimate the values of non-market benefits associated with achieving good (marine) environmental status (GES) under the Marine Strategy Framework Directive (MSFD). Related descriptors of the MSFD were combined into six attributes including the price attribute. The results of the study demonstrated that the Irish public were willing to pay to avoid deterioration in the state of the marine environment. The estimated welfare impact per person ranged between €99.31 to avoid the low degradation scenario and €217.77 per person to avoid the high level of degradation scenario (Norton and Hynes, 2014).

Ressurreição et al., (2011) use a contingent valuation method to estimate the public's WTP to avoid loss in the number of species in the marine waters around the Azores. The aim of the study was to estimate the marginal value associated with increased levels of species loss and also to estimate the WTP to avoid loss of species in different marine taxa. The paper is of particular relevance to ATLAS research for a number of reasons: (1) the CVM is carried out in the Azores, one of the ATLAS case study areas, (2) it aims to value biodiversity (rather than one charismatic species) in response to European legislation requirements including the MSFD and (3) differences are tested between the WTP of residents versus visitors to the Azores. The results suggested a greater WTP to preserve all marine taxa as a whole than for a series of individual marine taxa.

More recently Norton and Hynes (2018) used a combination of the contingent valuation method (CVM) and value transfer (VT) to estimate the value of non-market benefits associated with the achievement of GES as specified in the MSFD for Atlantic member states. The study estimated that the overall value of achieving GES for five Atlantic member states varied between €2.37 billion and €3.64 billion. Elsewhere, Norton et al., (2018) provide an overview of marine ecosystem services from Irish marine waters which includes the ATLAS Porcupine Bank case study area.

While the previous research on ecosystem service benefit valuation in the deep sea is limited there has been a number of interesting qualitative assessments carried out. In that regard, Galparsoro et al., (2014), and Salomidi, et al., (2012) are reviewed and synthesized for this report. Salomidi et al. developed a sea-floor habitat ecosystem service scoring system. Their research created a framework to address ecosystem based marine-spatial planning requirements, not only with detailed information on the sea-floor, but also a standardized system of classifying ecosystems through EUNIS Codes. Salomidi et al., compiled the goods, services, sensitivity, and conservation status of 56 European sea beds as a crucial first step to establish guidelines towards effective conservation and sustainable practices in European waters.

Galparsoro et al. (2014) expanded on Salomidi et al. (2012)'s work by assessing 62 sea-floor habitats, and valuing ESs therein. Galparsoro et al. (2014) state that of the world's surface, only 8% is coastal, yet 43% of the estimated total value of global ES originate there. Their report showed that biodiversity provides a large percentage of the benefits gained from ES, with 41% of their total study area providing high ES benefit, and 58% providing low benefits (99% of all areas providing some ES/biodiversity benefits).

With growing anthropogenic pressures in the marine environment, the value provided through habitat-based ES of the sea-floor will aid further policy action, development of Marine Protected Areas, conservation, and resource use (Global Ocean Commission, 2014). Climate change will inevitably alter the deep-sea benthos because deep-sea communities are tightly linked to primary production processes at or near the surface (Smith, 2008).

1.3. Case Studies

The 12 case studies from the EU-ATLAS Project were selected for this report to understand their specific ES. The EU-ATLAS Project selected these regions due to their importance to deep-sea ecology, and their location on the Atlantic meridional overturning circulation (AMOC).

The case studies used are (Figure 4, below):

- LoVe Observatory, Lofosten-Vesterålen, NORWAY (CS1)
- Faroe-Shetland Channel, UNITED KINGDOM (CS2)
- Rockall Bank, Northeast Atlantic Ocean (CS3)
- Mingulay Reef Complex, Western Scotland, UNITED KINGDOM (CS4)
- Porcupine Seabight, IRELAND (CS5)
- Bay of Biscay, FRANCE/SPAIN (CS6)
- Gulf of Cadiz – Strait of Gibraltar - Alborán Sea, SPAIN/MOROCCO/PORTUGAL (CS7)
- The Azores, Autonomous Region of The Azores, Portuguese Republic (CS8)
- Reykjanes Ridge, ICELAND (CS9)

Unfortunately, there were three EU-ATLAS Project case-studies which did not apply the European Nature Identification System (EUNIS) Codes used by Galparsoro et al., (2014) and Salomidi et al., (2012) to provide ecosystem service scores, thus they were excluded from the synthesis report. These case studies are:

- Davis Strait/Baffin Bay, North Atlantic, Greenland and Canada
- Flemish Cap, ABNJ – North American Regional Fisheries Management Organizations
- Mid-Atlantic Canyons, Cape Hatteras, Virginia, United States

Five ATLAS case studies: Faroe Shetland Channel, Rockall Bank, Porcupine Seabight, Bay of Biscay and the Azores, had EU STECF demersal fisheries data at sufficient scale and detail to assess deep sea fishing landings and value of those landings. However, not all ATLAS case-studies had EU STECF fishing data that covered the area completely or at a suitable scale, leaving gaps in landings totals. The proximity to territorial waters for some of the smaller case studies where smaller fishing vessels dominate catches also contributed to lack of data. Future studies may make it possible to distill data taken in proximity to coastal fleets to fill the lacuna of data in Lofosten-Vesterålen, and Mingulay Reef, or incomplete coverage of EU STECF data in the Azores, Gulf of Cadiz – Gibraltar – Alborán Sea, and Reykjanes Ridge. Figure 4 shows the locations of all EU-Atlas Project case studies in the North Atlantic.

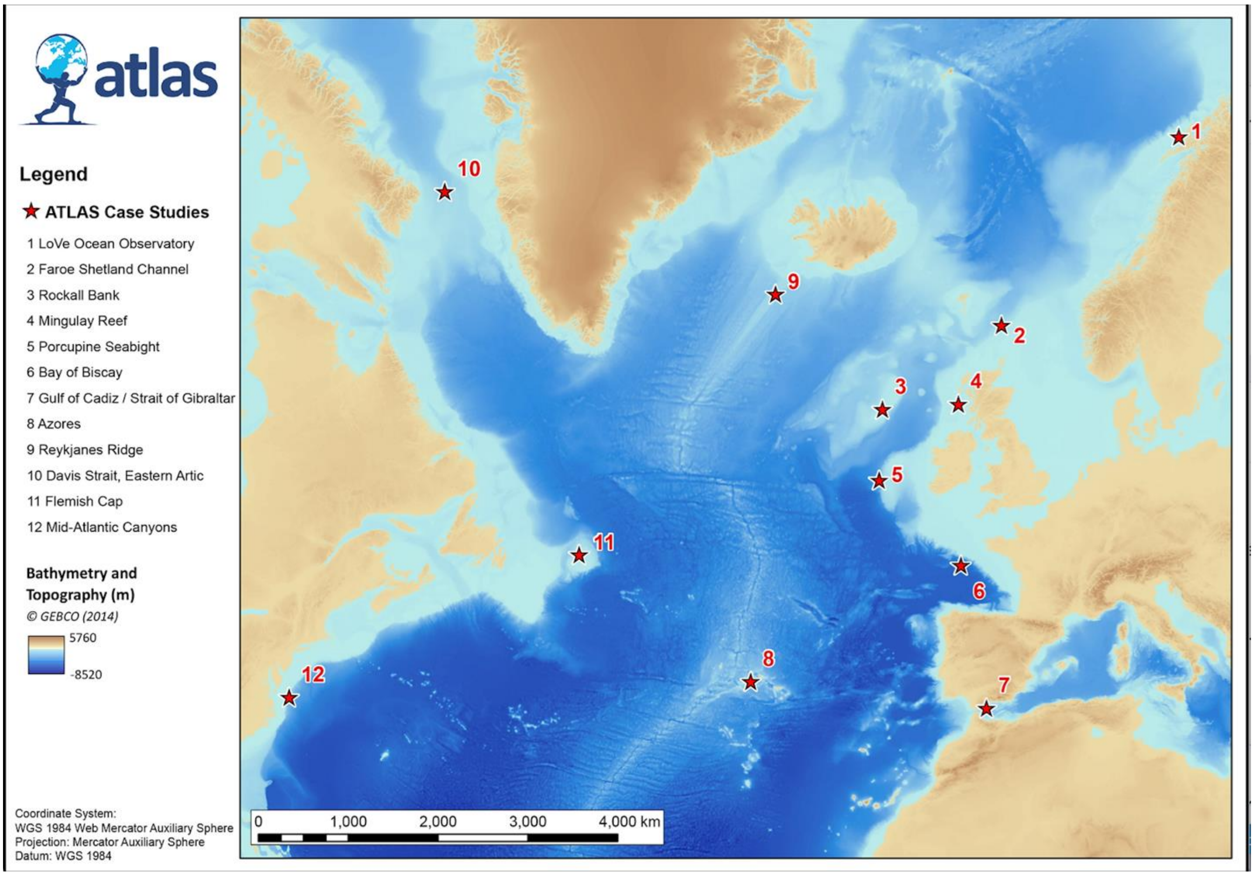


Figure 4. EU Atlas case studies with EU-SeaMap sea-floor habitats

EMODnet sea-floor habitats mapped within ATLAS case-studies provides information on which habitats are in these ecologically important regions and combining this data with Galparsoro's study provides an expert-opinion indicator of ES potential for the ATLAS case study benthic habitats.

1.4. Data and methodology

As previously stated, there is a lower level of information available for deep sea benthic ecosystems relative to terrestrial or even near shore benthic ecosystems. This relative lack of data impacts the possible assessment of ecosystem services. This report therefore uses a mixed methods approach using a qualitative approach to map the expected or potential ecosystem service delivery levels initially for 12 ecosystem service types as described by Galparsoro et al., (2014) and a quantitative approach for estimating the ecosystem service of food provision through generated estimates of landings volume and value for case studies where data was available. Table 5 below shows the ecosystem services framework described by Galparsoro et al., (2014) and its connection to the CICES ecosystem services framework (Version 4.3.)

Table 5. Galparsoro et al., (2014) ES Framework compared to CICES ES Framework

Galparsoro et al., (2014) Ecosystem Services Framework	CICES V4.3. Ecosystem Services Framework
Provisioning Services	**Provisioning Services**
Food provision	Nutrition
Raw materials	Materials
Regulating Services	**Regulation & Maintenance**
Water quality regulation/bioremediation of waste	Mediation of waste, toxics and other nuisances
Disturbance and natural hazard prevention	Mediation of flows
Photosynthesis / chemosynthesis / primary production[1]	
Nutrient cycling[1]	
Reproduction and nursery areas	Lifecycle maintenance, habitat and gene pool protection
Air quality and climate regulation	Atmospheric composition and climate regulation
Maintenance of biodiversity	Lifecycle maintenance, habitat and gene pool protection
Cultural Services	**Cultural Services**
Cognitive benefits	Intellectual and representative interactions
Leisure / recreation / cultural inspiration	Physical and experiential interactions
Feel good / warm glow	Spiritual, symbolic and other interactions with biota, ecosystems and seascapes

1.4.1. Qualitative mapping approach

Habitats with EUNIS Codes assessed by Salomidi et al., (2012) and Galparsoro et al., (2014) used High, Low, or Negligible for scoring the level of ESs provided in each case. EUNIS seafloor habitat polygons in each case study were scored as H, L, or N.

Occasionally EMODnet data points contained multiple habitats with similar seabed substrata, for example: A6.3 or A6.4 (Deep-sea sand, or deep-sea muddy sand). Each habitat's scores were averaged from Table 1 to accurately reflect values. The most common example of this occurred with areas labelled as "A4.12 or A4.27 or A4.33" (Sponge communities on deep circalittoral rock, faunal

[1] Under the CICES framework these are classed as ecosystem functions rather than ecosystem services as they support the generation of other ecosystem services. Under MEA they were known as supporting services but are no longer counted in more recent ES classification systems as to do so would lead to double counting

communities on deep moderate energy circalittoral rock, or faunal communities on deep low energy circalittoral rock). As Galparsoro et al., (2014) scored each of these habitats separately, all three scores from Table 1 were averaged and re-applied to the case-study polygons where it was possible for three habitats to exist. Although imperfect, this provides a rudimentary framework for scoring of ES if sea-floor habitat data is available with corresponding EUNIS Codes. However, more detailed data on the sea-floor is necessary to more accurately value the habitats which are found there.

Table 6. Ecosystem Services Scores per Galparsoro et al.(2014) (High (H), Low (L), Negligible (N))

Habitat name	EUNIS code	Food	Raw material	Air quality	Disturbance	Photosynthesis	Nutrient	Reproduction	Biodiversity	Wate	Cognitive	Leisure	Feelgood
Infralittoral rock and other hard substrata	A3*	H	H	H	H	H	L	H	H	H	H	H	H
Atlantic and Mediterranean high energy infralittoral rock	A3.1*	H	H	H	H	H	L	H	H	H	H	H	H
High energy infralittoral seabed		H	H	H	H	H	L	H	H	H	H	H	H
High energy infralittoral mixed hard sediments		H	H	H	H	H	L	H	H	H	H	H	H
Atlantic and Mediterranean moderate energy infralittoral rock	A3.2*	H	H	H	L	H	H	H	H	H	H	H	L
Moderate energy infralittoral seabed		H	H	H	L	H	H	H	H	H	H	H	L
Moderate energy infralittoral mixed hard sediments		H	H	H	L	H	H	H	H	H	H	H	L
Atlantic and Mediterranean low energy infralittoral rock	A3.3*	H	H	H	L	H	H	H	H	H	H	H	L
Low energy infralittoral seabed		H	H	H	N	H	H	H	H	H	H	H	L
Low energy infralittoral mixed hard sediments		H	H	H	N	H	H	H	H	H	H	H	L
Silted kelp on low energy infralittoral rock with full salinity	A3.31	H	H	H	N	H	H	H	H	H	H	H	L
Circalittoral rock and other hard substrata	A4*	H	H	L	H	N	H	H	H	H	H	L	L
Atlantic and Mediterranean high energy circalittoral rock	A4.1*	H	H	L	H	N	H	H	H	H	H	L	L
High energy circalittoral seabed		H	H	L	H	N	H	H	H	H	H	L	L
High energy circalittoral mixed hard sediments		H	H	L	H	N	H	H	H	H	H	L	L
Very tide-swept faunal communities on circalittoral rock or mixed faunal turf communities on circalittoral rock	A4.11 or A4.13*	H	H	N	H	N	H	H	H	H	L	L	L
Sponge communities on deep circalittoral rock	A4.12	H	H	N	H	N	H	H	H	H	H	L	L
Atlantic and Mediterranean moderate energy circalittoral rock	A4.2*	L	L	L	N	N	H	H	H	H	H	L	L
Moderate energy circalittoral seabed		L	N	L	N	N	H	H	H	H	H	L	L
Moderate energy circalittoral mixed hard sediments		L	N	L	N	N	H	H	H	H	H	L	L
Faunal communities on deep moderate energy circalittoral rock	A4.27	L	L	L	N	L	H	H	H	H	H	L	L
Atlantic and Mediterranean low energy circalittoral rock	A4.3*	H	L	H	N	L	H	H	H	H	H	H	L
Low energy circalittoral seabed		H	L	L	N	N	H	H	H	H	H	H	L
Low energy circalittoral mixed hard sediments		H	L	L	N	N	H	H	H	H	H	H	L
Brachiopod and ascidian communities on circalittoral rock	A4.31	L	L	L	L	L	L	L	H	L	H	H	L
Faunal communities on deep low energy circalittoral rock	A4.33	H	L	H	N	L	H	H	H	H	H	H	H
Infralittoral coarse sediment	A5.13*	H	H	N	N	N	L	H	N	N	N	L	L
Circalittoral coarse sediment	A5.14*	H	H	N	N	N	L	L	L	N	N	N	N
Deep circalittoral coarse sediment	A5.15*	H	L	N	N	N	L	N	L	N	N	N	N
Deep circalittoral seabed		H	L	N	N	N	L	N	L	N	N	N	N
Infralittoral fine sand or infralittoral muddy sand	A5.23* or A5.24*	H	L	N	N	N	L	H	L	N	N	L	L
Infralittoral fine sand	A5.23*	H	L	N	N	N	L	H	L	N	N	L	L
Infralittoral muddy sand	A5.24*	H	L	N	N	N	L	H	L	N	N	L	L
Circalittoral fine sand or circalittoral muddy sand	A5.25* or A5.26*	H	L	N	N	N	L	H	L	N	N	N	N
Circalittoral fine sand	A5.25*	H	L	N	N	N	L	H	L	N	N	N	N
Circalittoral muddy sand	A5.26*	H	L	N	N	N	L	L	L	L	N	N	N
Deep circalittoral sand	A5.27	H	L	N	L	N	L	L	L	L	N	N	N
Infralittoral sandy mud or infralittoral fine mud	A5.33* or A5.34*	H	N	N	N	N	L	L	L	L	N	N	N
Infralittoral sandy mud	A5.33*	H	N	N	N	N	L	L	L	L	N	N	N
Infralittoral fine mud	A5.34*	L	N	N	N	N	L	N	L	L	N	N	N
Circalittoral sandy mud or circalittoral fine mud	A5.35* or A5.36*	H	N	N	N	N	L	L	L	L	N	N	N
Circalittoral sandy mud	A5.35*	H	N	N	N	N	L	L	L	L	N	N	N
Circalittoral fine mud	A5.36*	H	N	N	N	N	L	L	L	L	N	N	N
Deep circalittoral mud	A5.37*	H	N	N	N	N	L	L	L	L	N	N	N
Infralittoral mixed sediments	A5.43*	H	L	N	N	N	L	L	H	L	N	N	N
Circalittoral mixed sediments	A5.44*	H	L	N	N	N	L	L	H	L	N	N	N
Deep circalittoral mixed sediments	A5.45*	H	L	N	N	N	L	L	H	L	N	N	N
Deep circalittoral mixed hard sediments		H	N	N	N	N	N	H	H	N	N	N	N
Upper slope seabed		H	N	N	N	N	N	L	H	N	N	N	N
Upper slope mixed hard sediments		H	N	N	N	N	N	L	H	N	N	N	N
Deep-sea rock and artificial hard substrata	A6.1*	L	N	N	N	N	N	N	H	N	N	N	N
Deep-sea bedrock	A6.11	N	N	N	N	N	N	N	H	N	N	N	N
Deep-sea mixed substrata	A6.2	L	N	N	N	N	N	N	H	N	N	N	N
Deep-sea sand or deep-sea muddy sand	A6.3* or A6.4	L	N	N	N	N	N	N	H	N	N	N	N
Deep sea coarse sediment		L	N	N	N	N	N	N	H	N	N	N	N
Deep-sea sand	A6.3*	L	N	N	N	N	N	N	H	N	N	N	N
Deep-sea muddy sand	A6.4	L	N	N	N	N	N	N	H	N	N	N	N
Deep-sea mud	A6.5	L	N	N	N	N	N	N	H	N	N	N	N
Abyssal seabed		N	N	N	N	N	N	N	L	N	H	N	N
Upper bathyal seabed		N	N	N	N	N	N	N	L	N	L	N	N
Mid bathyal seabed		N	N	N	N	N	N	N	L	N	L	N	N
Lower bathyal seabed		N	N	N	N	N	N	N	L	N	L	N	N

*EUNIS habitat code is given for those habitats included in the classification; * indicates that the assessment was based upon Salomidi et al. (2012).*

To synthesize the information between Galparsoro et al., (2014), Salomidi et al., (2012), and the EMODnet dataset, corresponding EUNIS Codes were employed. This made it possible to assign ES scores to the habitats found in ATLAS case study areas using GIS.

1.4.2. EUNIS

EUNIS Codes (http://unis.eea.europa.eu) provide standards for habitat classification with scientific description on each habitat from natural to artificial, terrestrial to freshwater and marine, and from coastal to deep waters (Davies and Moss, 2002). The European Nature Information System (EUNIS) brings together European data from several institutions and is comprised of three interlinked modules on sites, species and habitat types. The EUNIS information system was developed by the European Biodiversity Data Centre (BDC) and is hosted by European Environment Agency (Rodwell et al., 2018). The dataset supports implementation of EU and global biodiversity strategies and the 7th Environmental Action Programme (EEA, 2018).

EUNIS Codes for the marine realm specifically focus on the substrata of the sea-floor, with subdivisions based on species occurrence on certain substrates (EUNIS, 2018). The EUNIS information system provides access to the publicly available data in the EUNIS database. The information includes:

data on species, habitat types and designated sites compiled in the framework of Natura 2000 (EU Habitats and Birds Directives); the EUNIS habitat classification; data from material compiled by the European Topic Centre of Biological Diversity; information on species, habitat types and designated sites mentioned in relevant international conventions and in the IUCN Red Lists; specific data collected in the framework of the EEA's reporting activities, which also constitute a core set of data to be updated periodically, e.g. Eionet priority areas such as nationally designated areas (CDDA) (EUNIS, 2018).

Sea-floor habitat designations do not include pelagic zones or the water column above the sea-floor.

Salomidi et al., (2012) and Galparsoro et al., (2014) assessed EUNIS marine level-4 habitats and scored them as High, Low, or Negligible based on research and expert opinion. Each habitat assessed was given scores for each of 12 ES categories.

They are organized as follows:

Provisioning Services, which consists of (1) *food provision* and *(2) raw materials*;

Regulating Services, which consists of (3) *air quality and climate regulation*, (4) *disturbance and natural hazard prevention*, (5) *photosynthesis / chemosynthesis / primary production*, (6) *nutrient cycling*, (7) *reproduction and nursery areas*, (8) *maintenance of biodiversity,* and *(9) water quality regulation/bioremediation of waste*, and

Cultural Services, consists of (10) *cognitive benefits*, (11) *leisure / recreation / cultural inspiration*, and (12) *feel good / warm glow*

1.4.3. Mapping Seafloor Habitats

The following sources were used to provide seafloor habitat distributions in the case studies:

EMODnet —European Marine Observation and Data Network [http://www.emodnet-hydrography.eu/; European Commission; Directorate-General for Maritime Affairs and Fisheries (DG MARE)].

EUSeaMap —Mapping European seabed habitats (http://jncc.defra.gov.uk/page-6266). EUSeaMap is a broad-scale modeled habitat map built in the framework of MESH (Mapping European Seabed Habitats) and BALANCE (Baltic Sea Management—Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning) INTERREG IIIB-funded projects (Cameron and Askew, 2011).

The data from these sources covers 4.2 million km2 and yet does not fully cover the EU seas providing only 47% coverage according to Tempera (2015). The same report attempts to address this shortfall by using data from the UNEP's Global Seafloor Geomorphic Features Map (GSGFM) to extend EUNIS coverage to 74% (Tempera, 2015). The data used in the analysis here was the EU-SeaMap 2016 but note that just prior to publication of this report this dataset has been updated (July 2019) and is available via the EMODnet website.

Figure 5 shows the extent of EU-SeaMap sea-floor habitat mapping for the main deep sea benthic EUNIS habitats found in the case study sites. The complete list of EUNIS codes and ES scores used for this report are in Table 6.

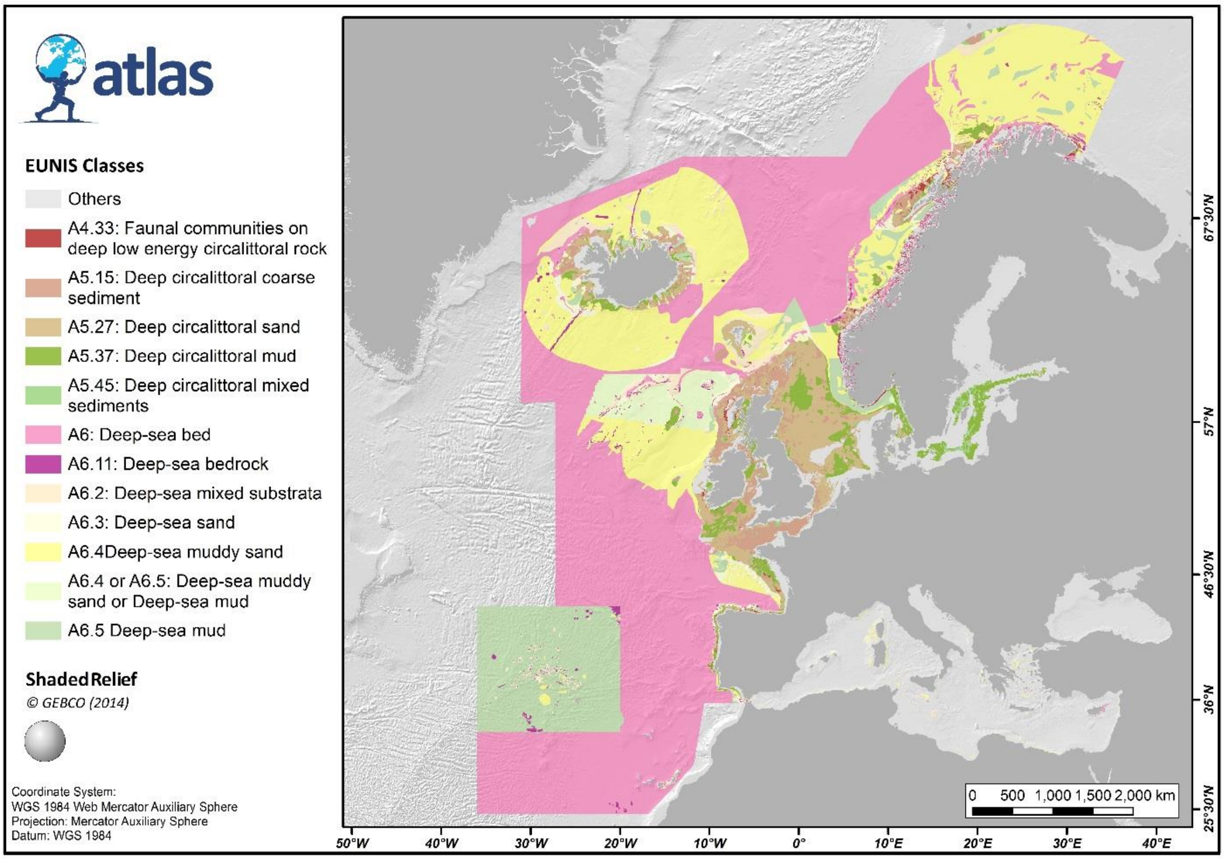


Figure 5. EU-SEA Map 2016 with EUNIS Codes for sea-floor habitats relevant to the ATLAS Cases Studies.

1.4.4. Measuring fisheries: a quantitative approach to ecosystem service assessment

In order to measure the food ecosystem service for deep sea benthic habitat, fisheries landings data was used based on the 2016 EU landings as reported in the EU STECF Deep Sea Species dataset (DG Maritime Affairs and Fisheries and Joint Research Centre, 2018).

The landings data is only for EU ships and is drawn from the STECF dataset contained in the Deep Sea Annex (https://stecf.jrc.ec.europa.eu/dd/effort). The Deep Sea Annex dataset was checked against the Western Waters Annex data where a limited number of double counting of observations was observed. These duplicates were removed before further analysis. The analysis is based on the fish species listed under the 2016 EU Deep-Sea Access Regime (EU 2016/2336 of 14 December 2016) establishing the specific conditions for fishing for deep-sea stocks in the north-east Atlantic and provisions for fishing in international waters of the north-east Atlantic and repealing Council Regulation (EC) No 2347/2002. A search of species in the ASFIS 'List of Species for Fishery Statistics Purposes' (http://www.fao.org/fishery/collection/asfis/en) that matched those described in the Regulation 2016/2336 generated 193 species. To these were added Anglerfishes (*Lophiidae*) and European Hake (*Merluccius merluccius*) because while they are not listed as deep-sea species in the Deep-Sea Access Regime they nevertheless are found at depths between 200-1000m often in areas where vulnerable marine ecosystems occur. This list of 195 species was then matched to the STECF database generating landing records for 41 species in 2016 (see Appendix 1). The landings values for each species per ICES rectangles (0.5° latitude by 1.0° longitude) and total landings for all 41 species were then extracted from the dataset.

To get a more accurate measurement of where fishing activity was being undertaken, fishing effort data obtained from Global Fishing Watch (GFW; https://globalfishingwatch.org) were used to apportion the landings data at a resolution of 0.01° latitude by 0.01° longitude proportional to the fishing effort (measured in hours) within each ICES rectangle. The estimates of fishing effort produced by GFW are largely based on vessel location data gathered from automatic identification systems (AIS) transmissions. While not all vessels are equipped with AIS transponders, it is estimated that the ones which do use AIS (usually larger vessels) are responsible for more than 50% of fishing effort beyond a distance of 100 nautical miles from shore, and more than 80% of fishing effort in the high seas, meaning that these data are highly representative of fishing activity in deeper waters. GFW uses two neural networks to process AIS data and identify, based on vessel behaviour, when vessels are fishing and what methods they are using, however, these neural networks cannot differentiate between boats fishing for pelagic species and boats fishing for demersal species, and therefore demersal fisheries may be even further concentrated than shown in the maps generated using this approach. Figure 6 outlines this method graphically.

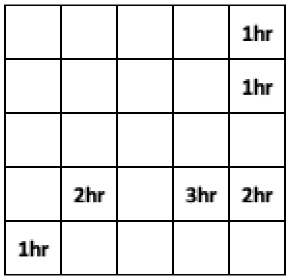
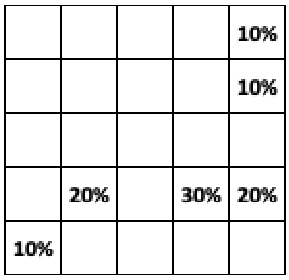
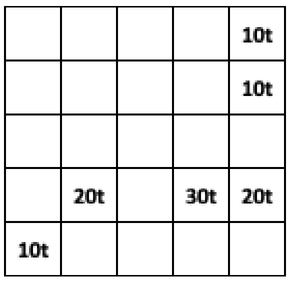
<table>
<tr><td>(a)</td><td>
</td><td>The total fishing effort within a given ICES rectangle can be calculated by finding the sum of the fishing hours recorded in all 0.01x0.01° cells within that ICES rectangle. This figure shows an example a 0.05x0.05° box in which there is a total fishing effort of 10 hours.</td></tr>
<tr><td>(b)</td><td>
</td><td>Knowing the total fishing effort in a given ICES rectangle, the fishing effort per 0.01x0.01° cell can be expressed as a percentage of the total activity within that rectangle. This figure shows how this would be done for the same 0.05x0.05° box shown above.</td></tr>
<tr><td>(c)</td><td>
</td><td>These percentages can then be used to distribute the total landings in a given ICES rectangle proportionally to the fishing effort occurring in each 0.01x0.01° cell within that rectangle. This example shows how a total fish catch of 100t would be distributed within the 0.05x0.05° box referenced in the two figures above.</td></tr>
</table>

Figure 6. Allocation of landings from STECF data based on AIS data.

1.4.5. Fisheries valuation

Fisheries has a direct use value – therefore market prices should be available for this service. For most case studies the main activity is commercial fisheries. To value the fisheries, landings prices were used from the Irish Marine Institute (MI) Stock Book (Marine Institute, 2017). If no value was in the Stock Book, prices from 2012 were taken from the Atlas of Commercial Fisheries (Marine Institute, 2016). As shown in Table 7, the correlation of prices for 20 species covered in the Stock Book compared to

2012 prices was shown to be high (greater than .95). This is the justification of using 2012 values when no present values were available. The estimated prices per species are given in Appendix 1.Correlation of fisheries data 2012-2016.

Table 7. Price Correlation of fisheries data (MI Stock Book, 2012-2016)

	2012Price	*2014Price*	*2015Price*	*2016Price*
2012 Prices	1			
2014 Prices	0.98	1		
2015 Prices	0.98	0.99	1	
2016 Prices	0.96	0.96	0.97	1

1.4.6. Qualitative mapping approach for estimating ecosystem services

Nine case studies were used for their importance to deep-sea ecology, and diverse sea-floor habitats. These case studies include a range of locations in the northern hemisphere with different marine conditions, species, and placement within EEZs or in ABNJ.

These nine regions were assessed with STECF and AIS demersal fisheries landings estimates (Section 1.4.4.) , to compare with the ES of Food provisioning scored by Galparsoro et al., (2014) and Salomidi et al., (2012). There was data at a sufficient level and scale to estimate the value of fisheries for five of the regions (Table 16).

1.4.6.1. LoVe Observatory, Lofosten-Vesterålen, Norway

The Lofosten-Versterålen case study of the LoVe Observatory in Norway consists of 21 habitats, off the northern coast of the Andoya province (Figure 7). The marine ecosystem is highly valuable because of its productivity for coastal fisheries and spawning ground for several species, and habitat for coral including *Lopheia pertusa*, the only species in the genus *Lophelia*, a cold-water coral found in the deep waters of the North Atlantic (ATLAS, 2018; Armstrong et al., 2010). The area is also important for the tourism industry, and oil-and-gas developments are being considered. Thus, the region is important for provisioning, regulating, and cultural ES (ATLAS 2018).

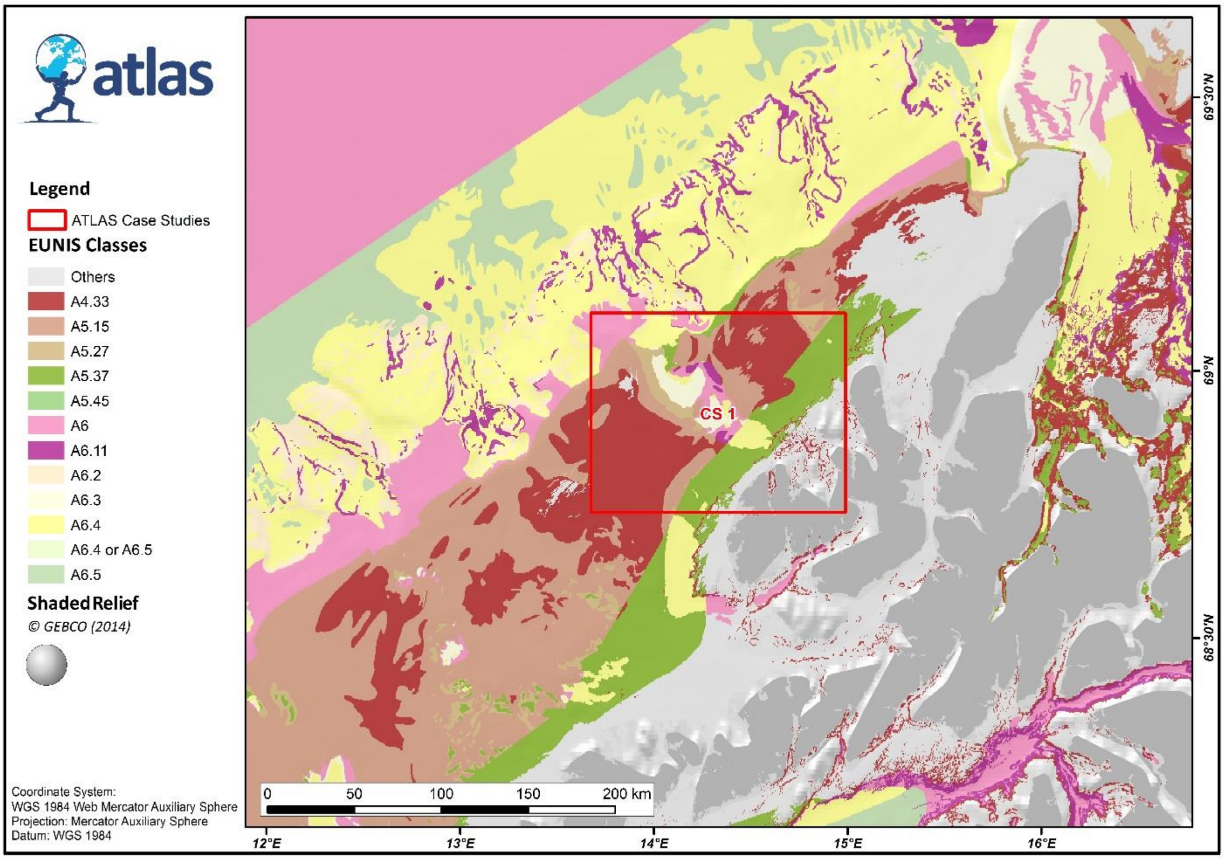


Figure 7. Lofosten-Versteralen EUNIS sea-floor habitats

The case study area is dominated by circalittoral deep low energy benthic habitats of rock (A4.33) with smaller areas of deep mud (A5.37) and coarser sediments (A5.15). The former rock areas provide high scores for most ecosystem services while the latter are especially important for food provisioning (Table 8).

Habitat	% of total area	Food	Raw Material	Air Quality	Disturbance	Photosynthesis	Nutrient	Reproduction	Biodiversity	Waste	Cognitive	Leisure	Feelgood
A3	0.05%	H	H	H	H	H	L	H	H	H	H	H	H
A3.1	0.02%	H	H	H	H	H	L	H	H	H	H	H	H
A3.2	0.15%	H	H	H	L	H	H	H	H	H	H	H	L
A3.3	0.13%	H	H	H	L	H	H	H	H	H	H	H	L
A4.12 or A4.27 or A4.33	0.15%	H	H	H	H	L	H	H	H	H	H	L	L
A4.2	0.03%	L	L	L	N	N	H	H	H	H	H	L	L
A4.3	0.71%	H	L	H	N	L	H	H	H	H	H	H	L
A4.33	35.47%	H	L	H	N	L	H	H	H	H	H	H	H
A5.14	0.05%	H	H	N	N	N	L	L	L	N	N	N	N
A5.15	15.24%	H	L	N	N	N	L	N	L	N	N	N	N
A5.27	3.68%	H	L	N	L	N	L	L	L	L	N	N	N
A5.33	0.28%	H	N	N	N	N	L	L	L	L	N	N	N
A5.35	0.96%	H	N	N	N	N	L	L	L	L	N	N	N
A5.37	18.04%	H	N	N	N	N	L	L	L	L	N	N	N
A6	6.83%	L	N	N	N	N	N	N	H	N	N	N	N
A6.11	1.11%	N	N	N	N	N	N	N	H	N	N	N	N
A6.2	0.37%	L	N	N	N	N	N	N	H	N	N	N	N
A6.3	4.06%	L	N	N	N	N	N	N	H	N	N	N	N
A6.4	6.64%	L	N	N	N	N	N	N	H	N	N	N	N
Na (Mixed seabed)	6.01%												
Total	100%												

Table 8. Lofosten-Versteralen, Norway. Habitats by percentage of area, Ecosystem Service Scores.

The following maps (Figures 8, 9) of the LoVe study area indicates a high score for food provisioning near the coast. These regions are important not only for their provisioning scores, but also regulating and cultural ES scores as well (Galparsoro et al., 2014).

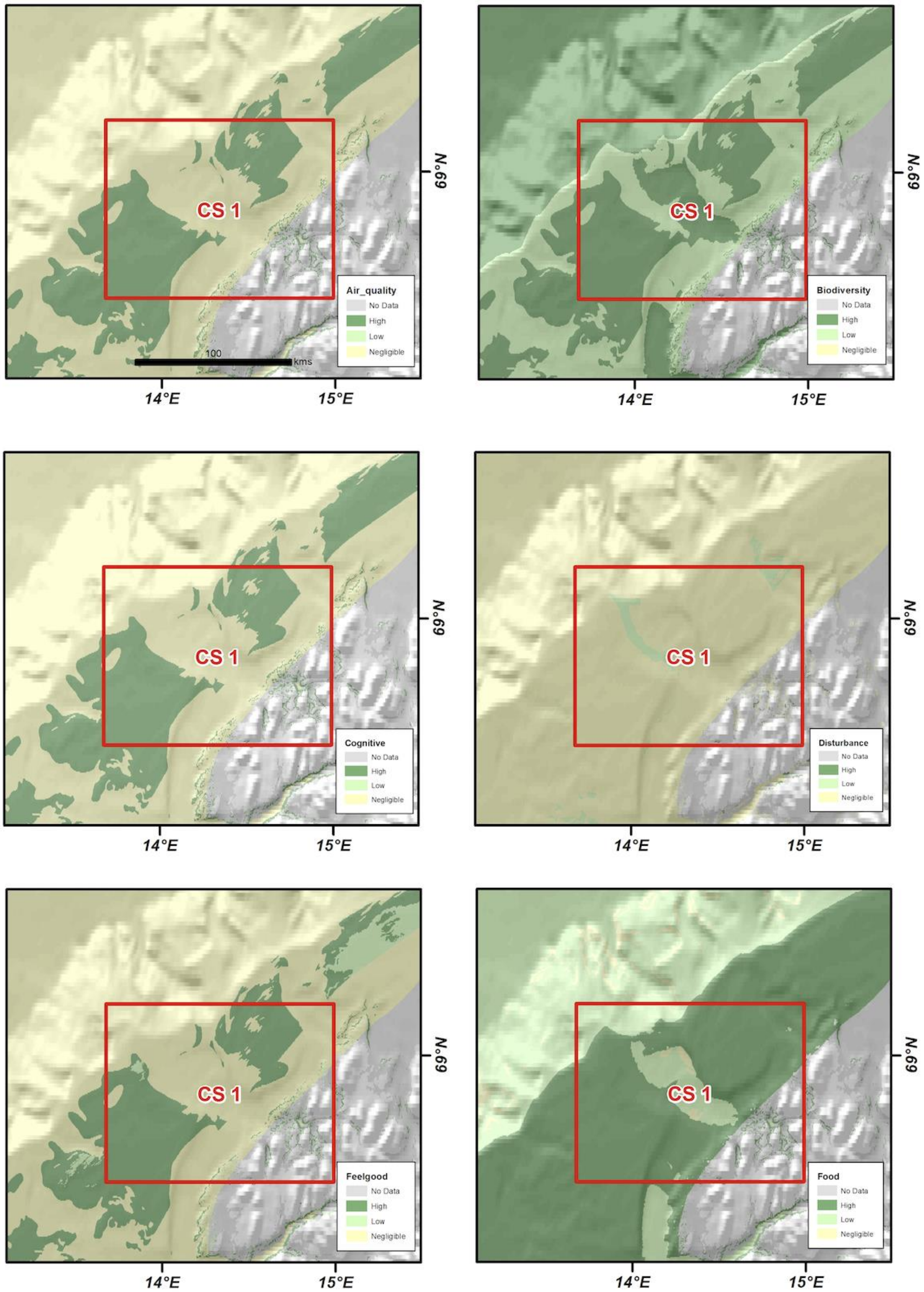


Figure 8. Ecosystem Service Scores for LoVe Observatory, Lofosten-Vesterålen, Norway (Air quality, Biodiversity, Cognitive, Disturbance, Feelgood, Food)

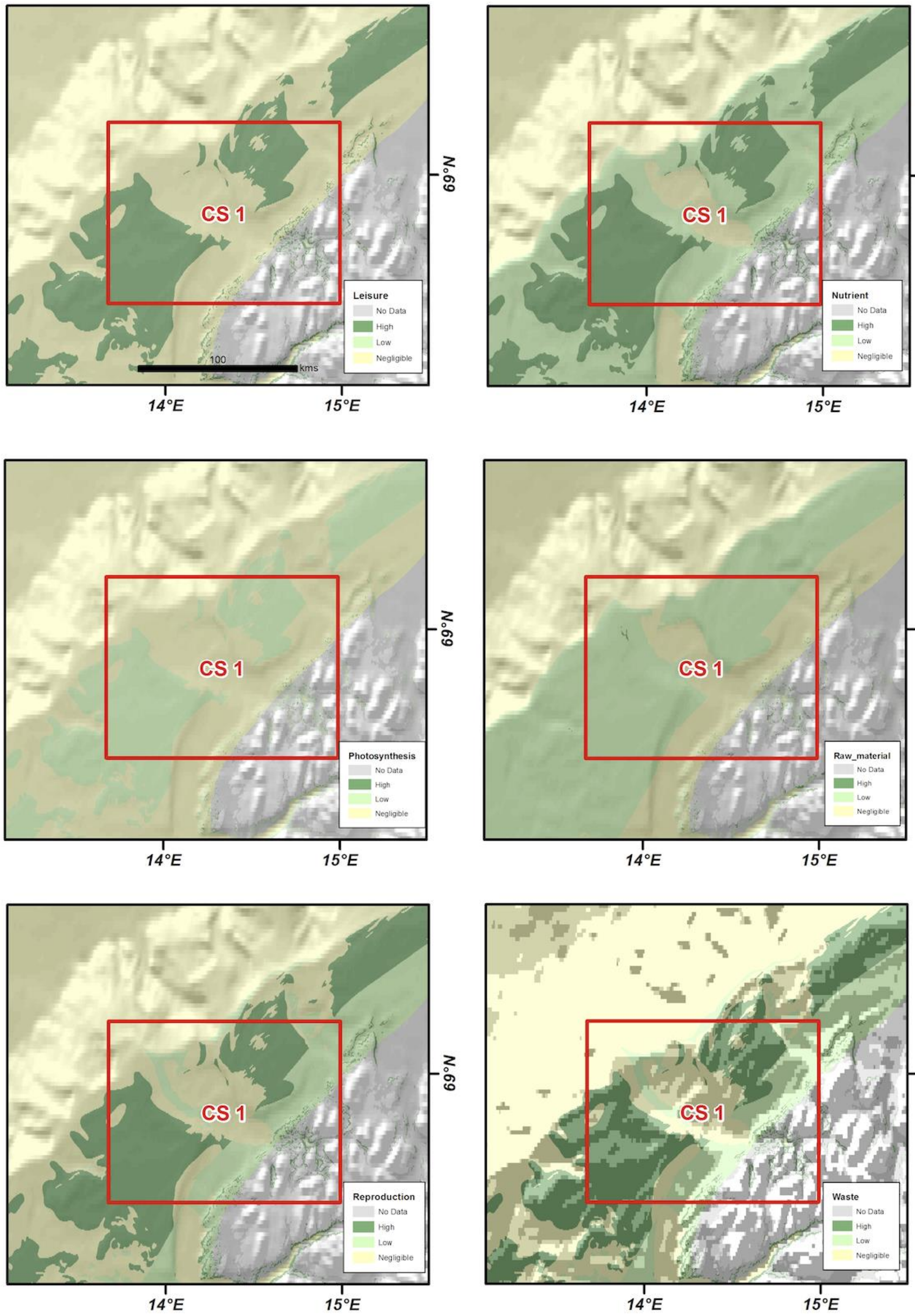


Figure 9. Ecosystem Service Scores for LoVe Observatory, Lofosten-Vesterålen, Norway (Leisure, Nutrient, Photosynthesis, Raw material, Reproduction, Waste)

1.4.6.2. Faroe Shetland Channel, United Kingdom

The Faroe Shetland Channel case study is located to the north of Scotland, and off the west coast of Norway. It is located in a region of the deep sea between northern Scotland, the Faroe Islands, and the Shetland Islands. The region has a diverse range of benthic species, sponge communities, with a very productive region between 400 – 600m between the junction of the Faroe Bank Channel to the northeastern reaches of the West Shetland Channel (ATLAS, 2018).

There are 6 habitats within the study area (Figure 10), but all are classified as A6, which is the deep-sea bed. ES scores from Galparsoro were *low* for food provisioning and *high* for biodiversity for all A6 substrata with all other ES factors scored as "negligible" (Table 9). Thus, this region indicates an importance for biodiversity, with a low level of benthic fisheries potential rather than most regulating or cultural ES factors according to expert opinion (Galparsoro et al., 2014). Figures 11 and 12 show the spatial distribution of the predicted supply of ES.

Table 9. Faroe-Shetland, UK Habitats by percentage of area, Ecosystem Service Scores.

Habitat	Percentage of total Area	Food	Raw Material	Air Quality	Disturbance	Photosynthesis	Nutrient	Reproduction	Biodiversity	Water	Cognitive	Leisure	Feelgood
A6	2.82%	L	N	N	N	N	N	N	H	N	N	N	N
A6.11	0.07%	N	N	N	N	N	N	N	H	N	N	N	N
A6.2	78.5%	L	N	N	N	N	N	N	H	N	N	N	N
A6.3	7.76%	L	N	N	N	N	N	N	H	N	N	N	N
A6.4	10.2%	L	N	N	N	N	N	N	H	N	N	N	N
A6.5	0.59%	L	N	N	N	N	N	N	H	N	N	N	N
Total	100%												

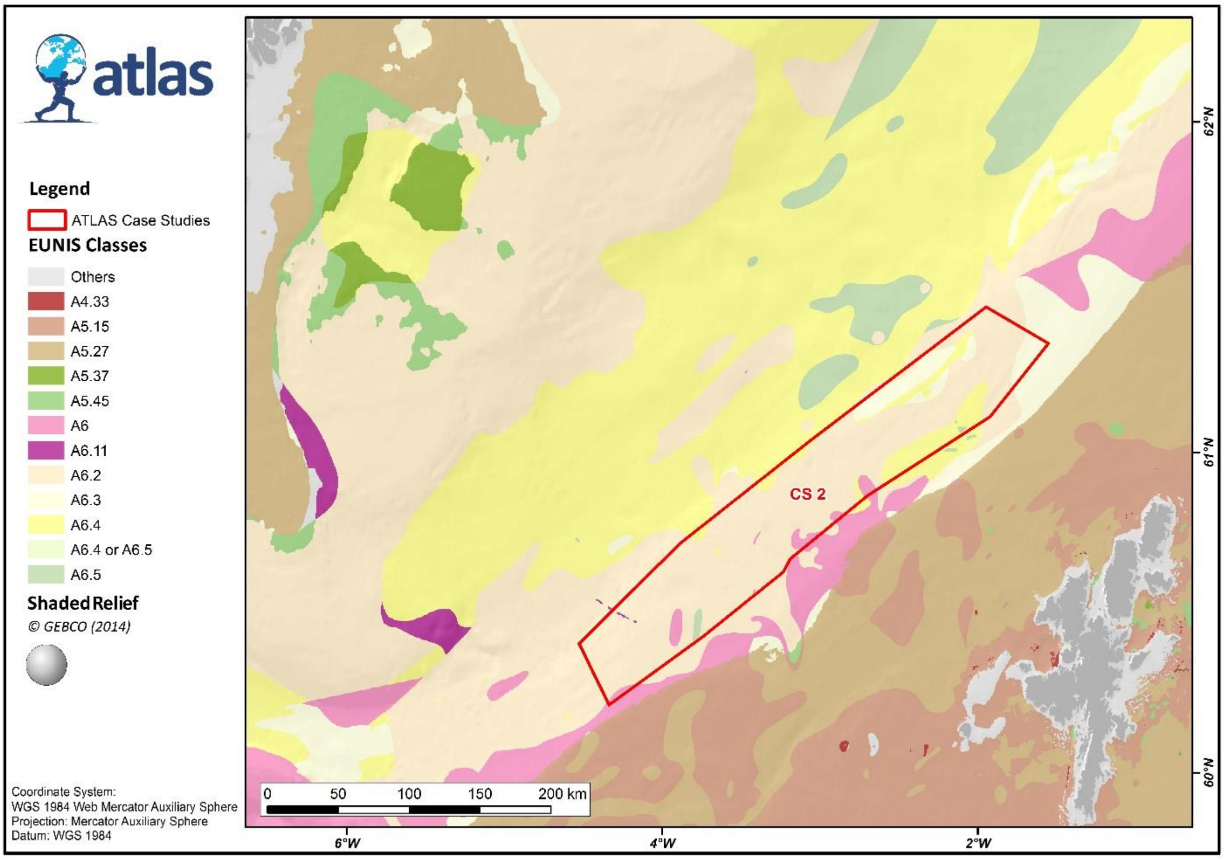


Figure 10. Faroe-Shetland EUNIS sea-floor habitats

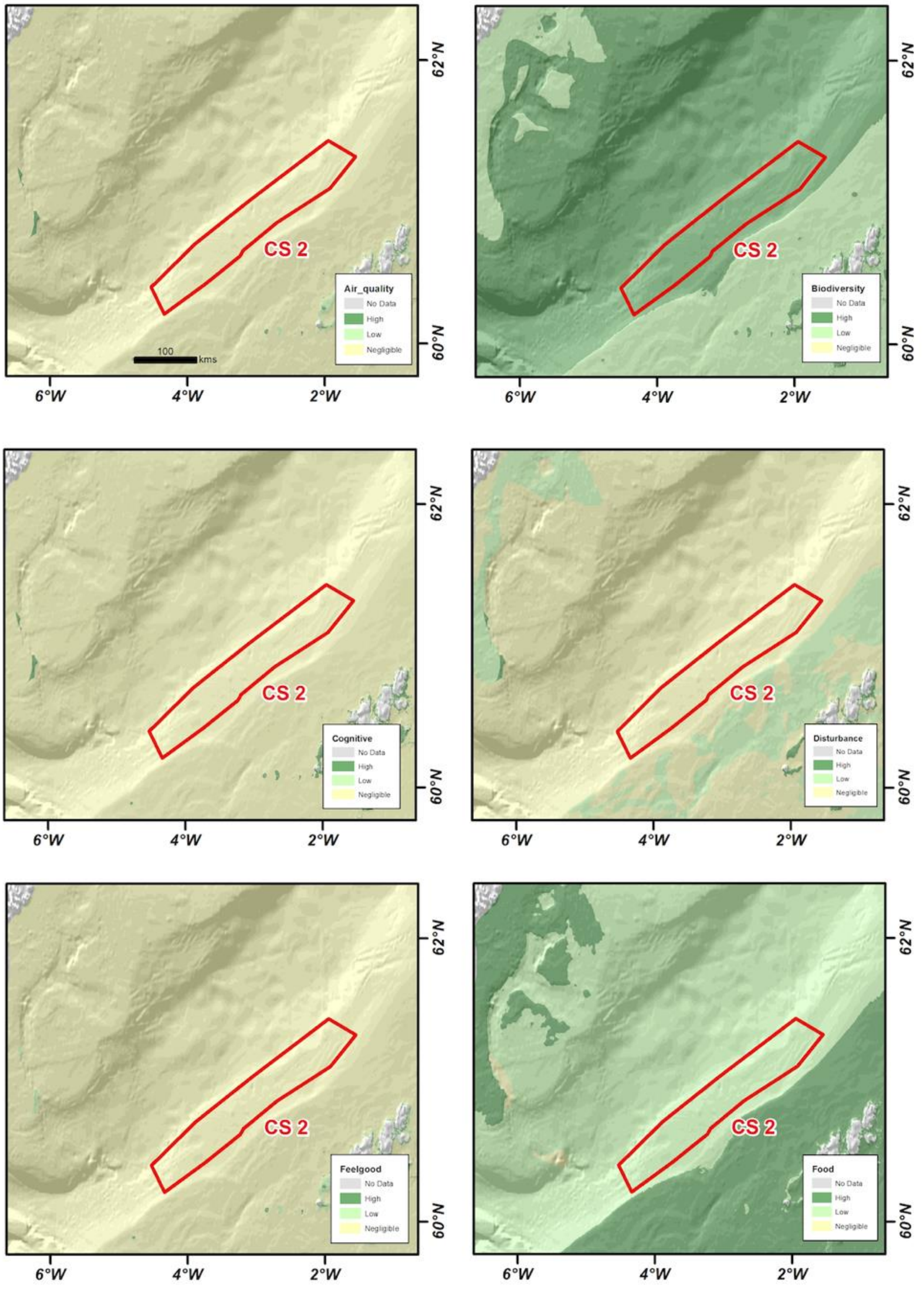


Figure 11. Ecosystem Service Scores for Faroe Shetland Channel, United Kingdom (Air quality, Biodiversity, Cognitive, Disturbance, Feelgood, Food)

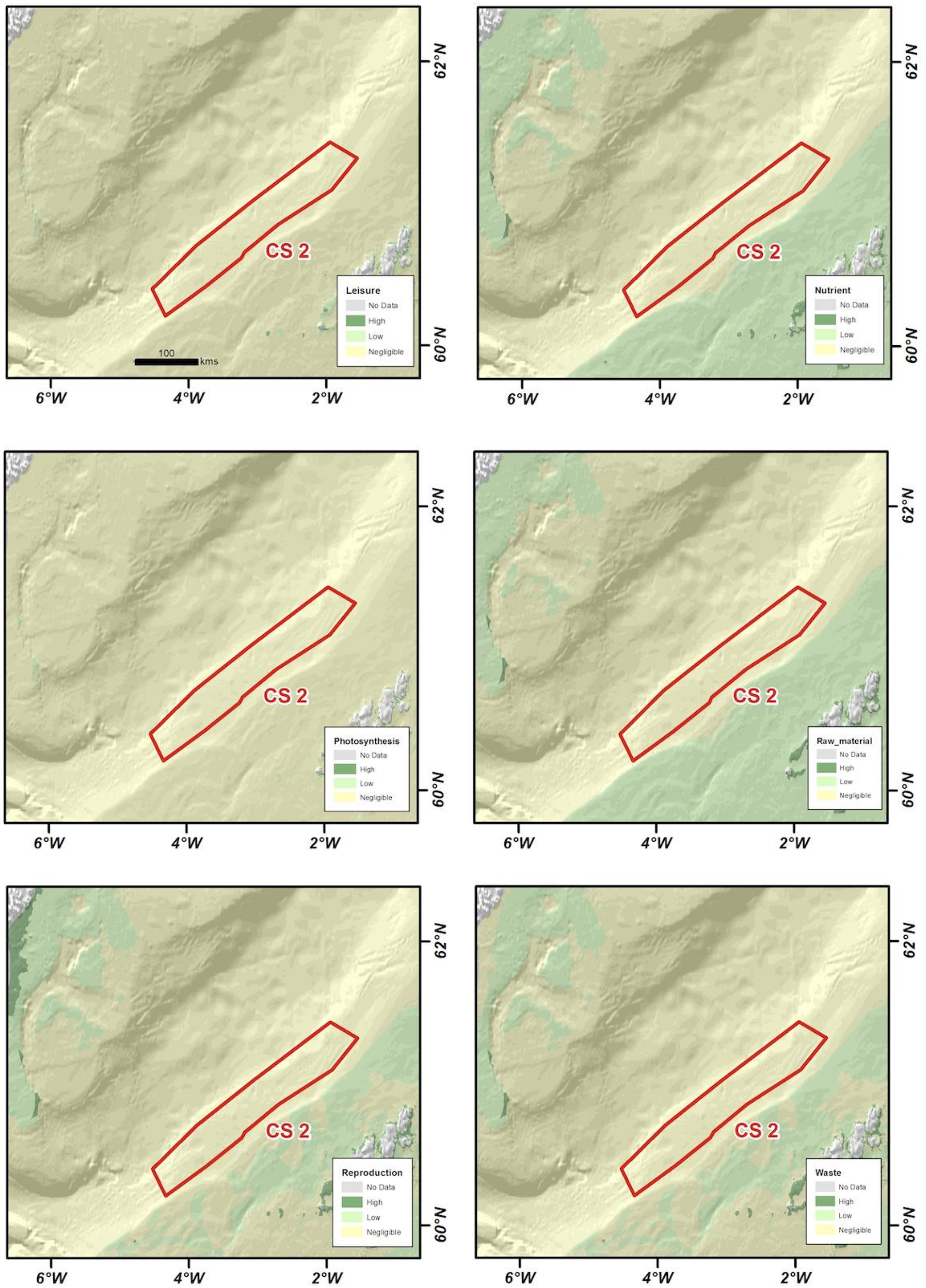


Figure 12. Ecosystem Service Scores for Faroe Shetland Channel, United Kingdom (Leisure, Nutrient, Photosynthesis, Raw material, Reproduction, Waste)

1.4.6.3. Rockall Bank, Northeast Atlantic Ocean

The Rockall Bank in the Northeast Atlantic Ocean is generally deeper than 200m and contains the continental slope into the deep-sea bed further than 500m down. The region is primary known for its fish production due to upwelling near Rockall in conjunction with migration paths for various species crossing through the area, and demersal fisheries are very productive here (Neat & Campbell, 2011). Due to this level of productivity, bottom trawling is present here, but with it comes concerns for damage to cold-water coral communities (such as *L. pertusa*) on the sea-floor, some of which are over 4,000 years old and grow very slowly (Hall-Spencer et al., 2002).

Table 10. Rockall Bank Habitats by percentage of area, Ecosystem Service Scores

Habitat	% of total Area	Food	Raw Material	Air Quality	Disturbance	Photosynthesis	Nutrient	Reproduction	Biodiversity	Water	Cognitive	Leisure	Feelgood
A4.27	0.20%	L	L	L	N	L	H	H	H	H	H	L	L
A4.33	0.49%	H	L	H	N	L	H	H	H	H	H	H	H
A5.15	2.12%	H	L	N	N	N	L	N	L	N	N	N	N
A5.27	0.87%	H	L	N	L	N	L	L	L	L	N	N	N
A5.37	18.4%	H	N	N	N	N	L	L	L	L	N	N	N
A6.11	1.13%	N	N	N	N	N	N	N	H	N	N	N	N
A6.2	3.92%	L	N	N	N	N	N	N	H	N	N	N	N
A6.3	1.74%	L	N	N	N	N	N	N	H	N	N	N	N
A6.4	34.04%	L	N	N	N	N	N	N	H	N	N	N	N
A6.4 or A6.5	38.08%	L	N	N	N	N	N	N	H	N	N	N	N
Total	100%												

Out of the 10 habitats present, five are part of the deep-sea (Table 10). The small areas of A4.27 (faunal communities on deep moderate energy circalittoral rock) and A4.33 (faunal communities on deep low energy circalittoral rock), plus the surrounding area of A5.15 (deep circalittoral mixed sediments) represent an area that is higher in elevation from the abyssal plain, and contribute to productive demersal fisheries (ICES 2016, 2017).

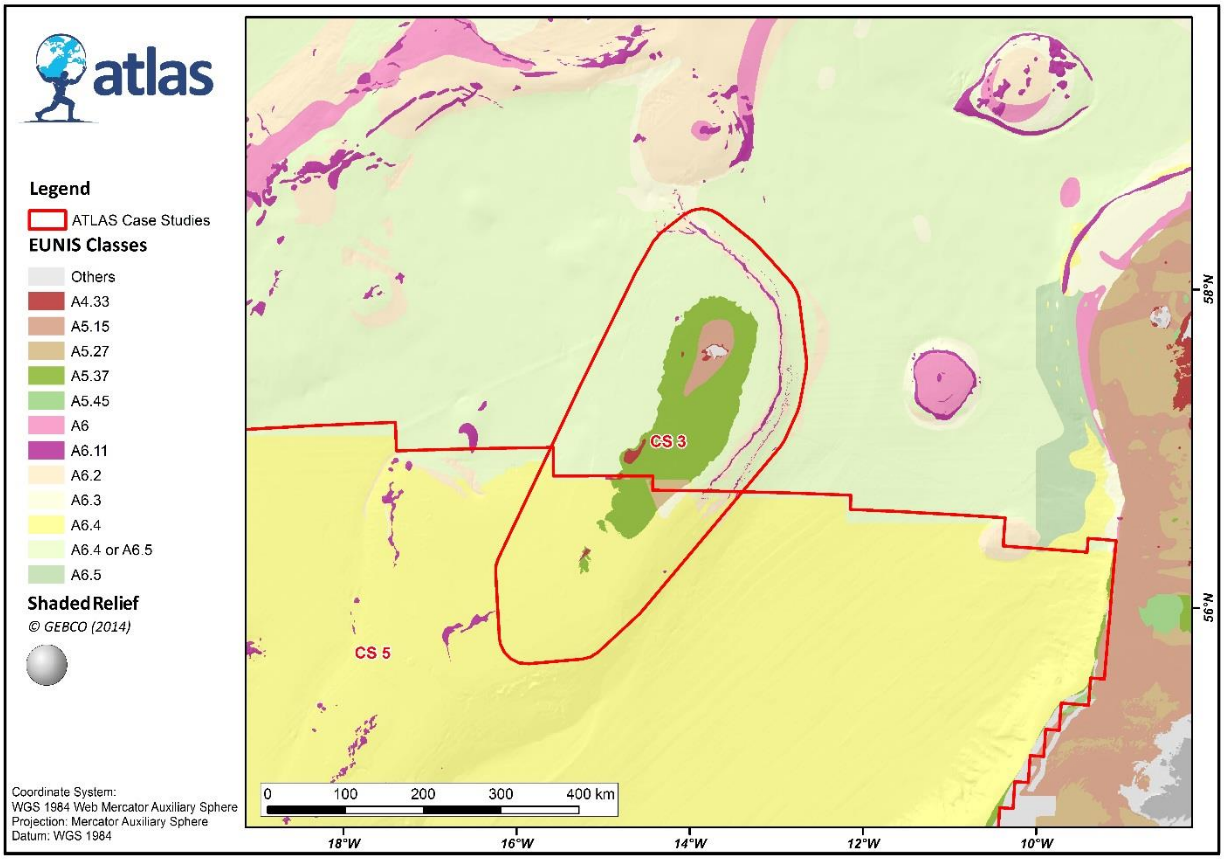


Figure 13. Rockall Bank EUNIS sea-floor habitats

The Rockall Bank sea-floor map, (Figure 13 above), has a horizontal line which separates the northern and southern half, approximately. Upon closer inspection, it is an artefact of the survey from the EMODnet dataset. On the northern half, it is definitively labelled as A6.5, or deep-sea mud. Whereas the southern half is labeled as A6.5 or A6.4, which is deep-sea mud, or deep-sea muddy sand. The two habitats, when assessed by Galparsoro et al., (2014), have the same ES scores, and ecologically, they are very similar (Figures 14 and 15), even if on the map the shading is slightly different.

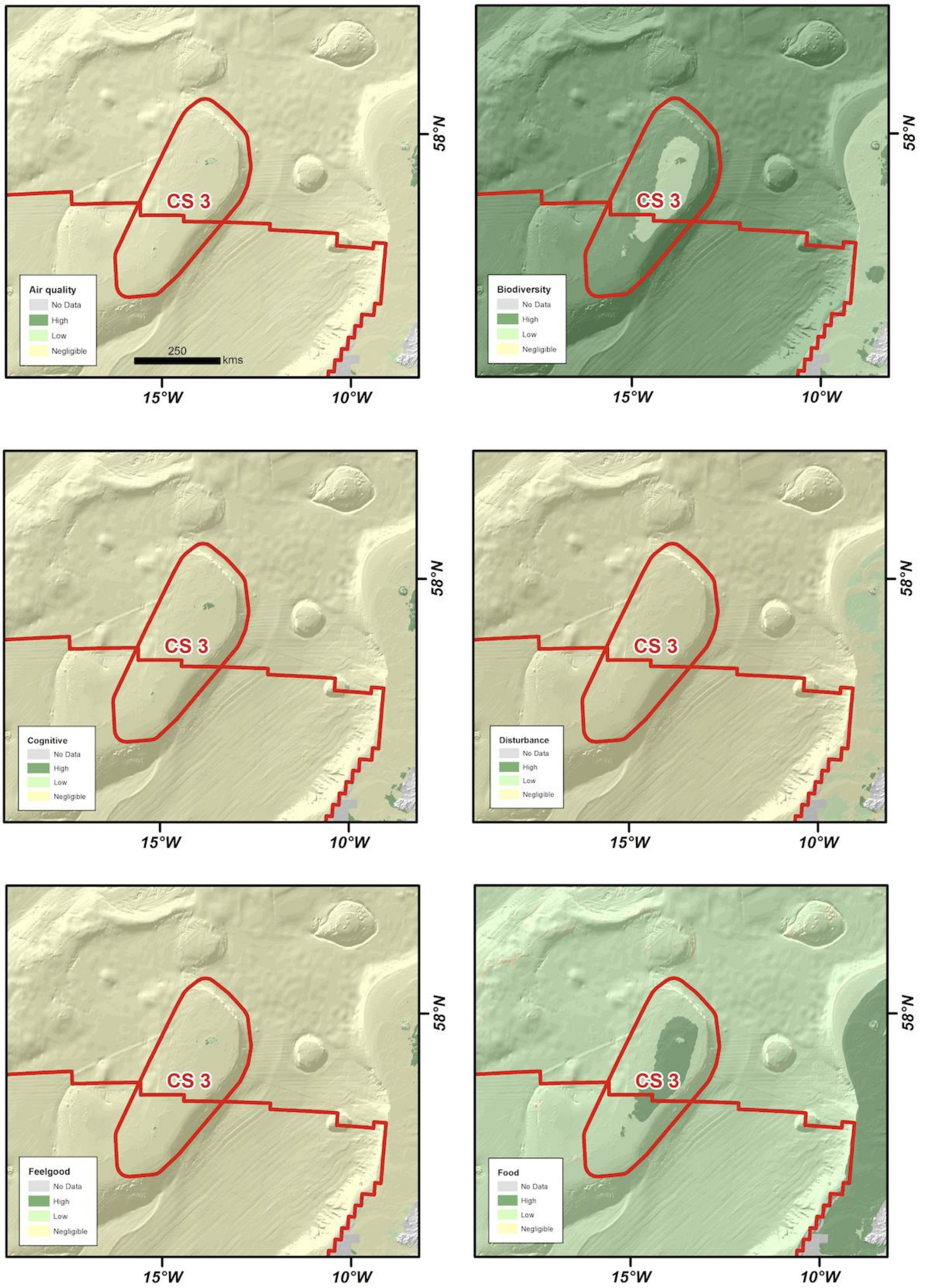


Figure 14. Ecosystem Service Scores for Rockall Bank, Northeast Atlantic Ocean (Air quality, Biodiversity, Cognitive, Disturbance, Feelgood, Food)

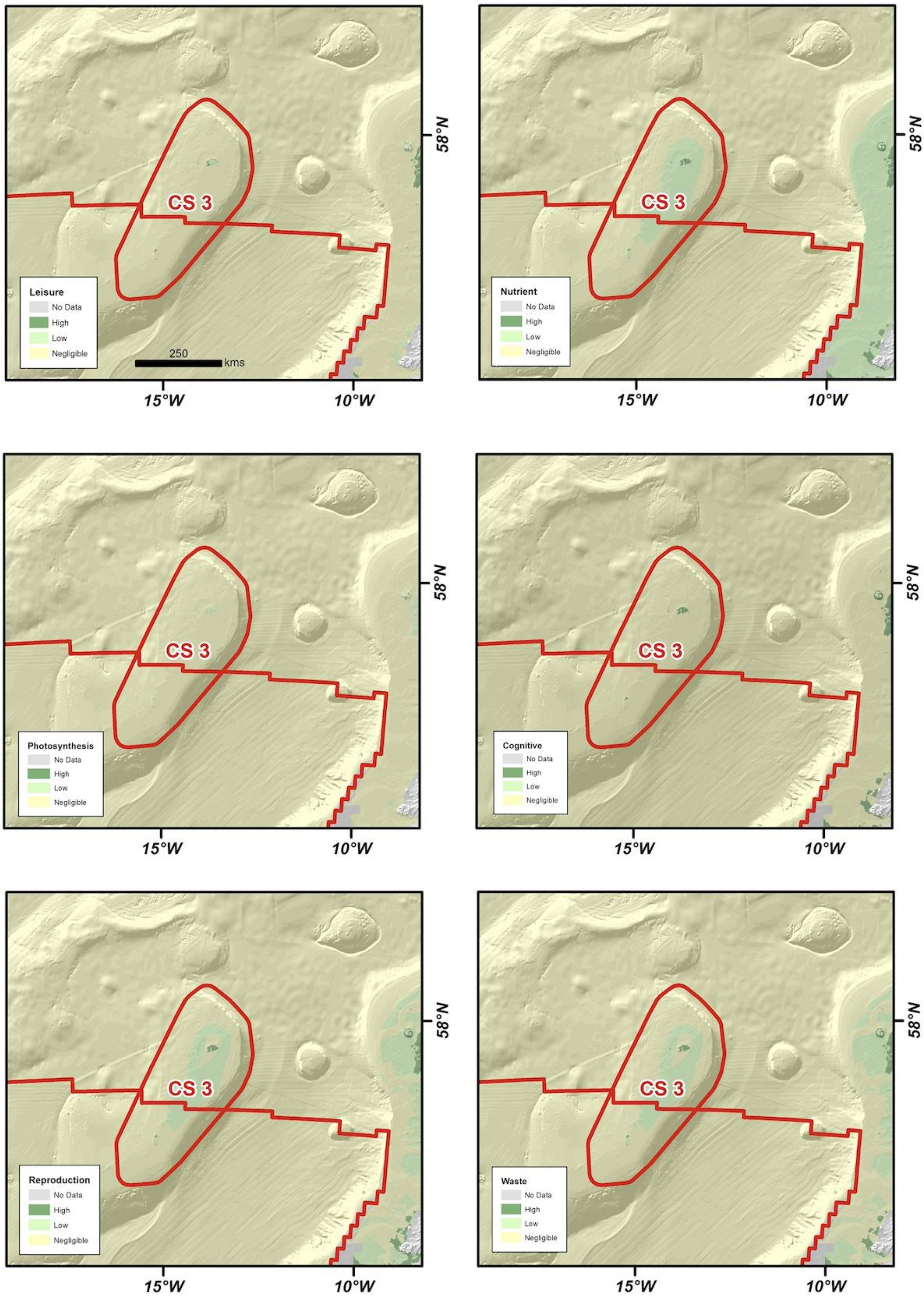


Figure 15. Ecosystem Service Scores for Rockall Bank, Northeast Atlantic Ocean (Leisure, Nutrient, Photosynthesis, Raw material, Reproduction, Waste)

1.4.6.4. Mingulay Reef, Western Scotland, United Kingdom

Mingulay is a small deep-sea reef community off the northern coast of the United Kingdom. Mingulay Reef is known for its cold-water corals which have been growing for at least 7,000 years. Their depth is relatively shallow, at 100 – 200m underwater (ATLAS, 2018).

Table 11. Mingulay Reef, UK, Habitats by percentage of area, Ecosystem Service Scores

Habitat	% of total Area	Food	Raw Material	Air Quality	Disturbance	Photosynthesis	Nutrient	Reproduction	Biodiversity	Water	Cognitive	Leisure	Feelgood
A4.33	67.3%	H	L	H	N	L	H	H	H	H	H	H	H
A5.37	30.6%	H	N	N	N	N	L	L	L	L	N	N	N
A5.45	2.1%	H	L	N	N	N	L	L	H	L	N	N	N
Total	100%												

A4.33 (faunal communities on deep low energy circalittoral rock) make up the overwhelming majority (Table 11) of the sea-floor habitats in this case study (Figure 16). This represents the area with the cold-water coral specimens.

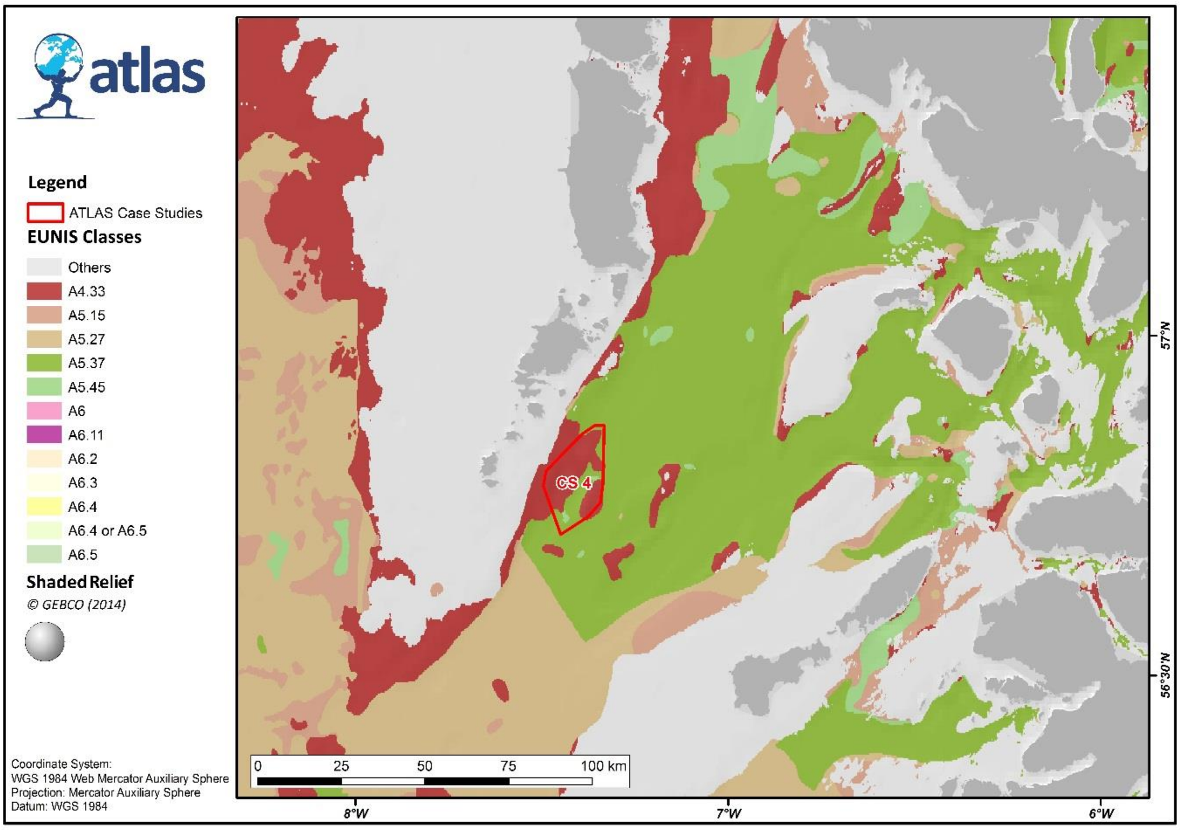


Figure 16. Mingulay Reef EUNIS sea-floor habitats

The uniqueness of Mingulay Reef for future study is evident with the species located there, and the benefits they provide, despite the small size of the region.

Demersal fishing data was not available for this region due to the small size, but it should be noted that bottom trawling could have a devastating impact to these benthic habitats. Significant, too, are the ages and slow re-growth rates of deep-sea corals, if damaged, or destroyed, long-term impacts to deep-sea ecology could occur (Hall-Spencer et al., 2002). However as most the case study is within an Nature 2000 site this is highly unlikely. Figures 17 and 18 show the spatial distribution of the predicted supply of ES.

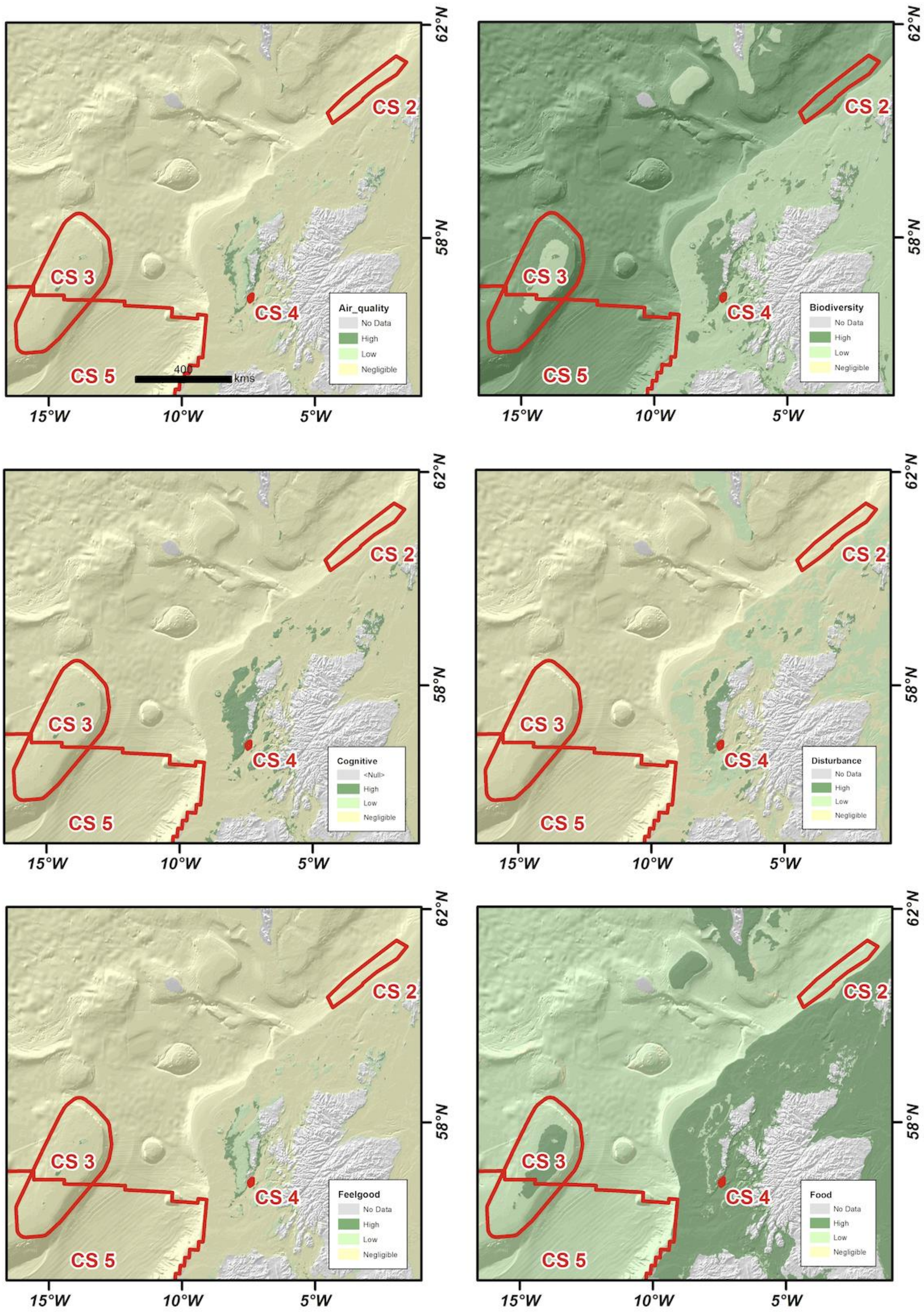


Figure 17. Ecosystem Service Scores for Mingulay Reef, Western Scotland, United Kingdom (Air quality, Biodiversity, Cognitive, Disturbance, Feelgood, Food)

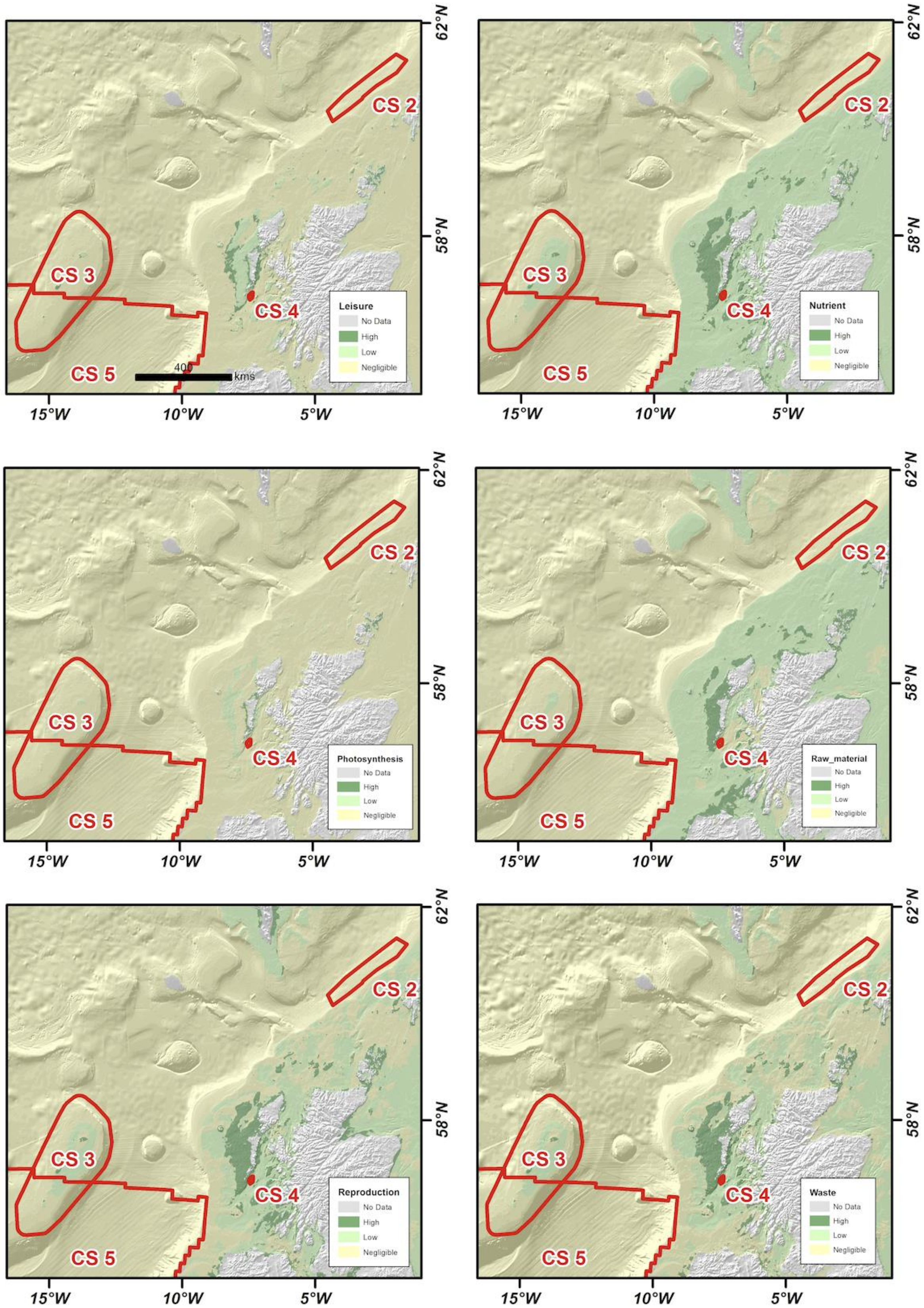


Figure 18. Ecosystem Service Scores for Mingulay Reef, Western Scotland, United Kingdom (Leisure, Nutrient, Photosynthesis, Raw material, Reproduction, Waste)

1.4.6.5. Porcupine Seabight, Ireland

A productive fisheries region off the western coast of Ireland, the Porcupine Seabight (PSB) has been thoroughly researched for decades. Increases in oil-and-gas development makes the PSB a location of exceptional interest for marine spatial planning, and diverse sea-floor habitats are an integral facet of this case study area (ATLAS 2018). There are 10 total sea-floor habitats in the PSB, with a high percentage, over 94 %, (Table 12) classified as being in the deep-sea (Figure 19). The main ES in this case study with high levels are biodiversity with limited areas of high food provision (Figures 20 and 21).

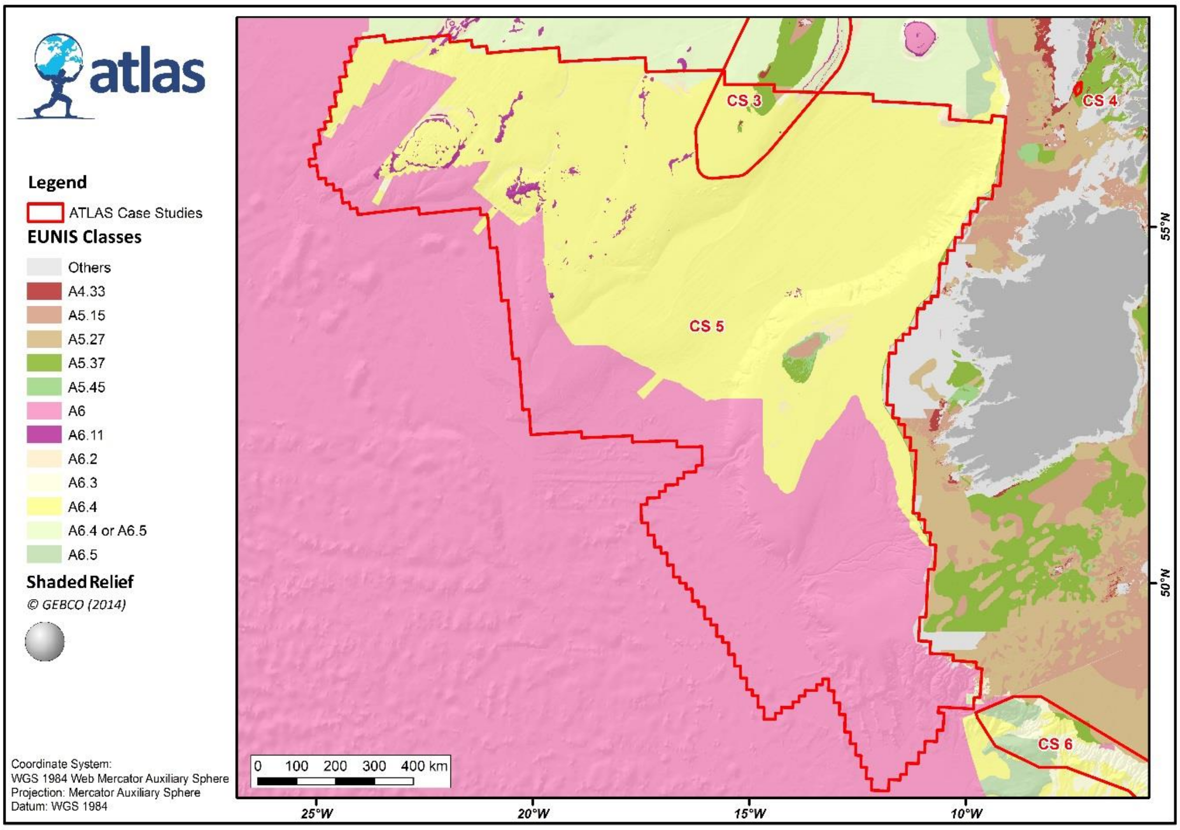


Figure 19. Porcupine Seabight EUNIS sea-floor habitats

Table 12. Porcupine Seabight, IE, Habitats by percentage of area, Ecosystem Service Scores

Habitat	% of total Area	Food	Raw Material	Air Quality	Disturbance	Photosynthesis	Nutrient	Reproduction	Biodiversity	Water	Cognitive	Leisure	Feelgood
A4.33	0.01%	H	L	H	N	L	H	H	H	H	H	H	H
A5.15	0.27%	H	L	N	N	N	L	N	L	N	N	N	N
A5.27	0.29%	H	L	N	L	N	L	L	L	L	N	N	N
A5.37	0.67%	H	N	N	N	N	L	L	L	L	N	N	N
A5.45	0.21%	H	L	N	N	N	L	L	H	L	N	N	N
A6	52.9%	L	N	N	N	N	N	N	H	N	N	N	N
A6.11	0.77%	N	N	N	N	N	N	N	H	N	N	N	N
A6.2	0.94%	L	N	N	N	N	N	N	H	N	N	N	N
A6.3	0.12%	L	N	N	N	N	N	N	H	N	N	N	N
A6.4	42.0%	L	N	N	N	N	N	N	H	N	N	N	N
A6.4 or A6.5	1.10%	L	N	N	N	N	N	N	H	N	N	N	N
Na	0.71%												
Total	100%												

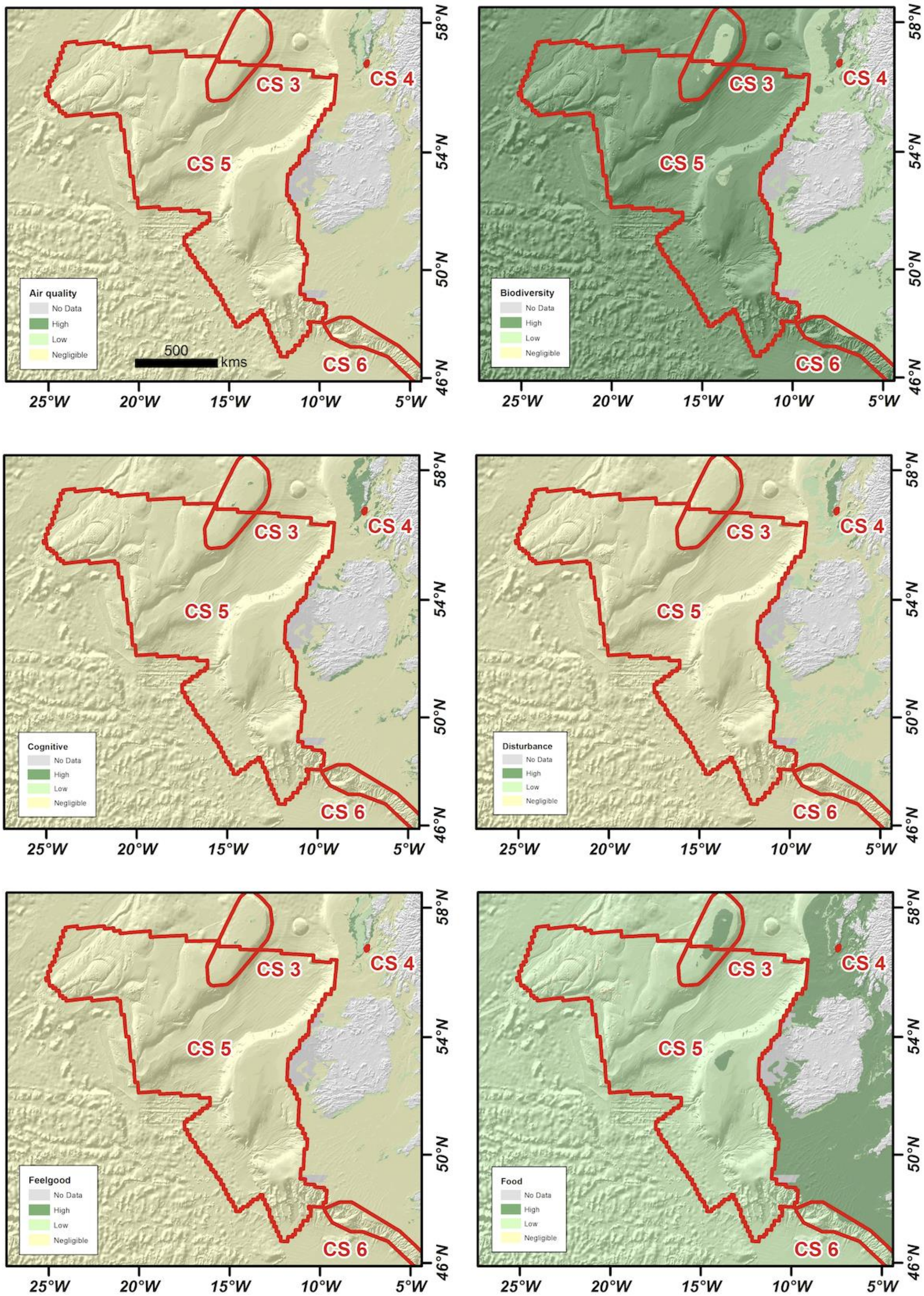


Figure 20. Ecosystem Service Scores for Porcupine Seabight, Ireland (Air quality, Biodiversity, Cognitive, Disturbance, Feelgood, Food)

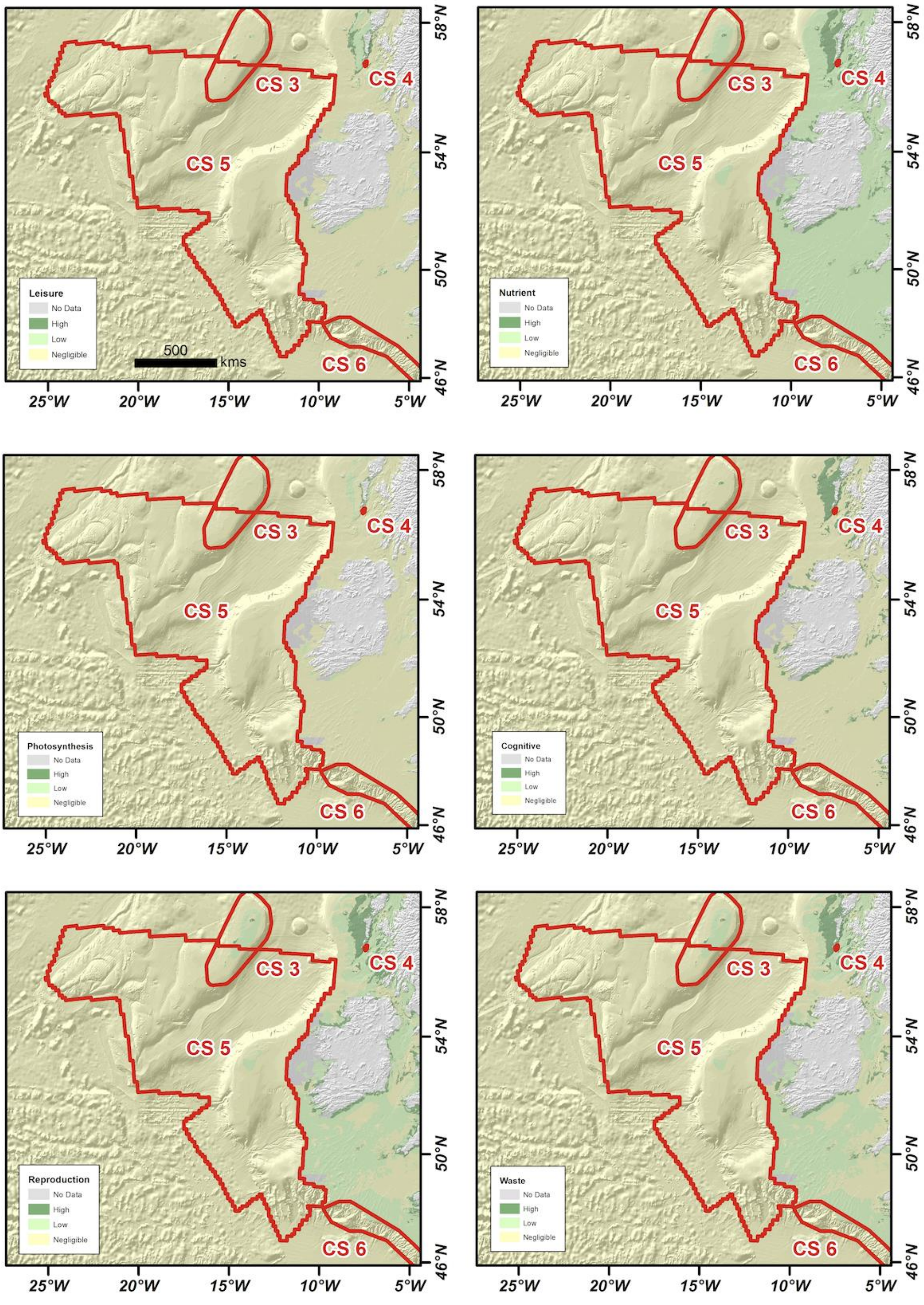


Figure 21. Ecosystem Service Scores for Porcupine Seabight, Ireland (Leisure, Nutrient, Photosynthesis, Raw material, Reproduction, Waste)

1.4.6.6. Bay of Biscay, France/Spain

The Bay of Biscay is well known for its turbulent waters as it is connected to the open Atlantic Ocean off the western coast of France and the northern coast of Spain. The largest of these, by area, is A6.3, (Table 13) or the deep-sea sand (Figure 22). For food provisioning, the small area of habitats at the edge of the shelf contribute towards higher ES values due to the upwelling while the deeper benthic habitats have a higher ES score for biodiversity (Figures 23 and 24).

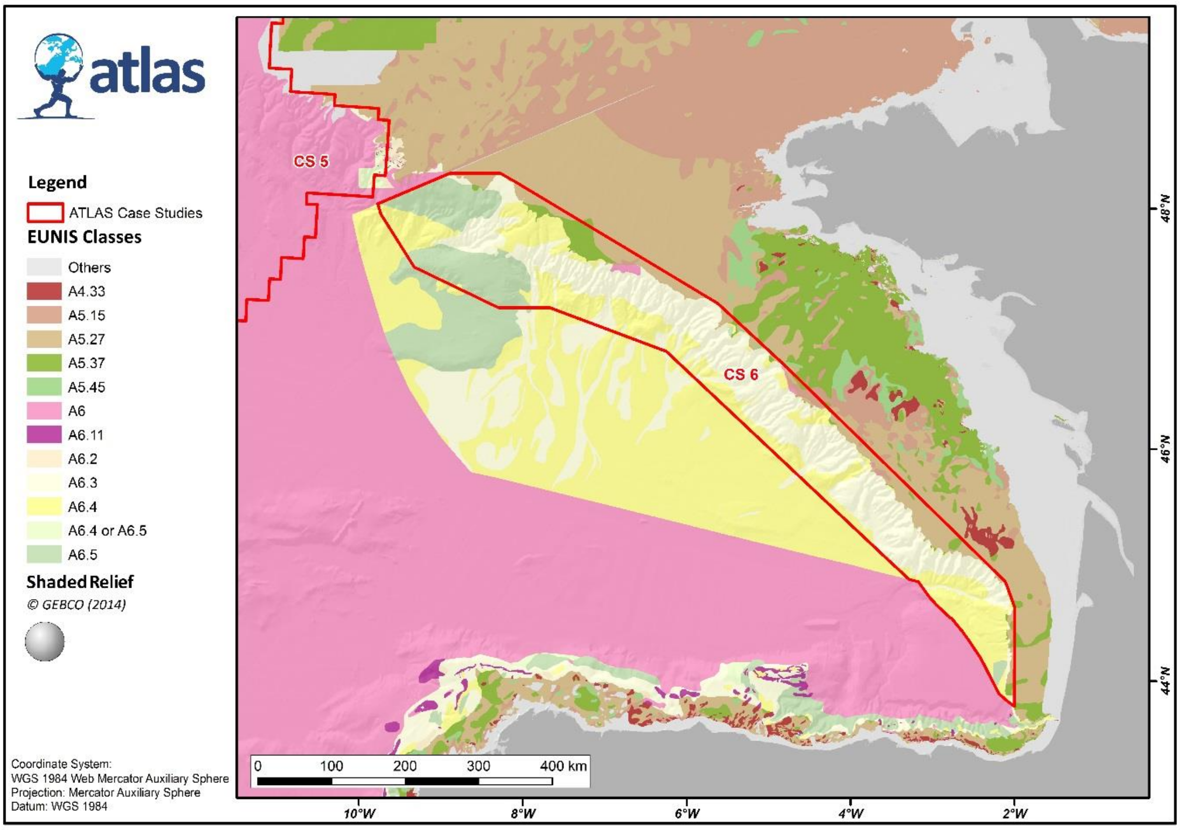


Figure 22. Bay of Biscay EUNIS sea-floor habitats

Table 13. Bay of Biscay, Habitats by percentage of area, Ecosystem Service Scores

Habitat	% of total area	Food	Raw Material	Air Quality	Disturbance	Photosynthesis	Nutrient	Reproduction	Biodiversity	Water	Cognitive	Leisure	Feelgood
A5.15	0.85%	H	L	N	N	N	L	N	L	N	N	N	N
A5.27	9.95%	H	L	N	L	N	L	L	L	L	N	N	N
A5.37	3.02%	H	N	N	N	N	L	L	L	L	N	N	N
A5.45	0.13%	H	L	N	N	N	L	L	H	L	N	N	N
A6	0.53%	L	N	N	N	N	N	N	H	N	N	N	N
A6.2	0.04%	L	N	N	N	N	N	N	H	N	N	N	N
A6.3	43.4%	L	N	N	N	N	N	N	H	N	N	N	N
A6.4	28.6%	L	N	N	N	N	N	N	H	N	N	N	N
A6.5	13.5%	L	N	N	N	N	N	N	H	N	N	N	N
Total	100%												

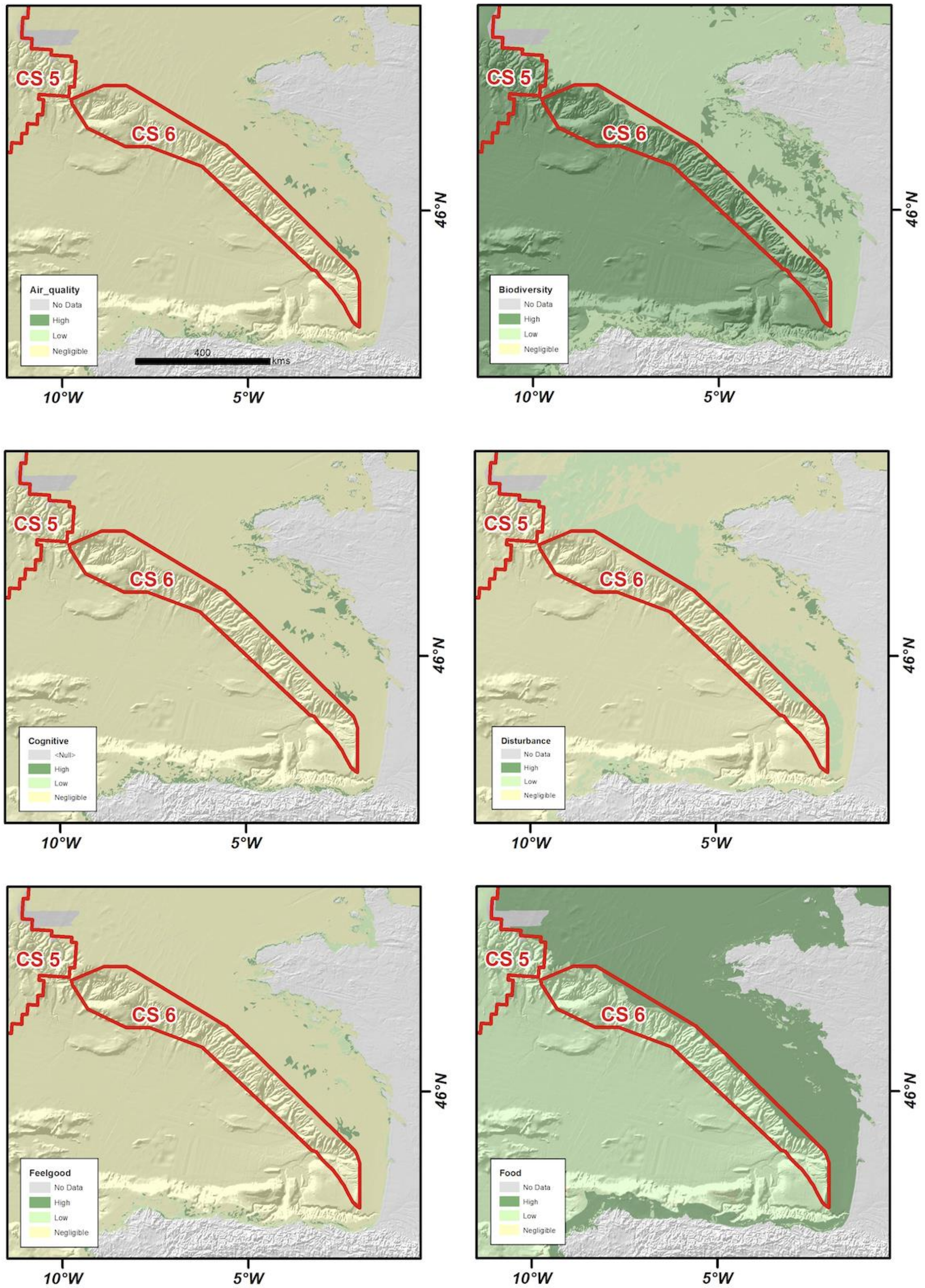


Figure 23. Ecosystem Service Scores for Bay of Biscay, France/Spain (Air quality, Biodiversity, Cognitive, Disturbance, Feelgood, Food)

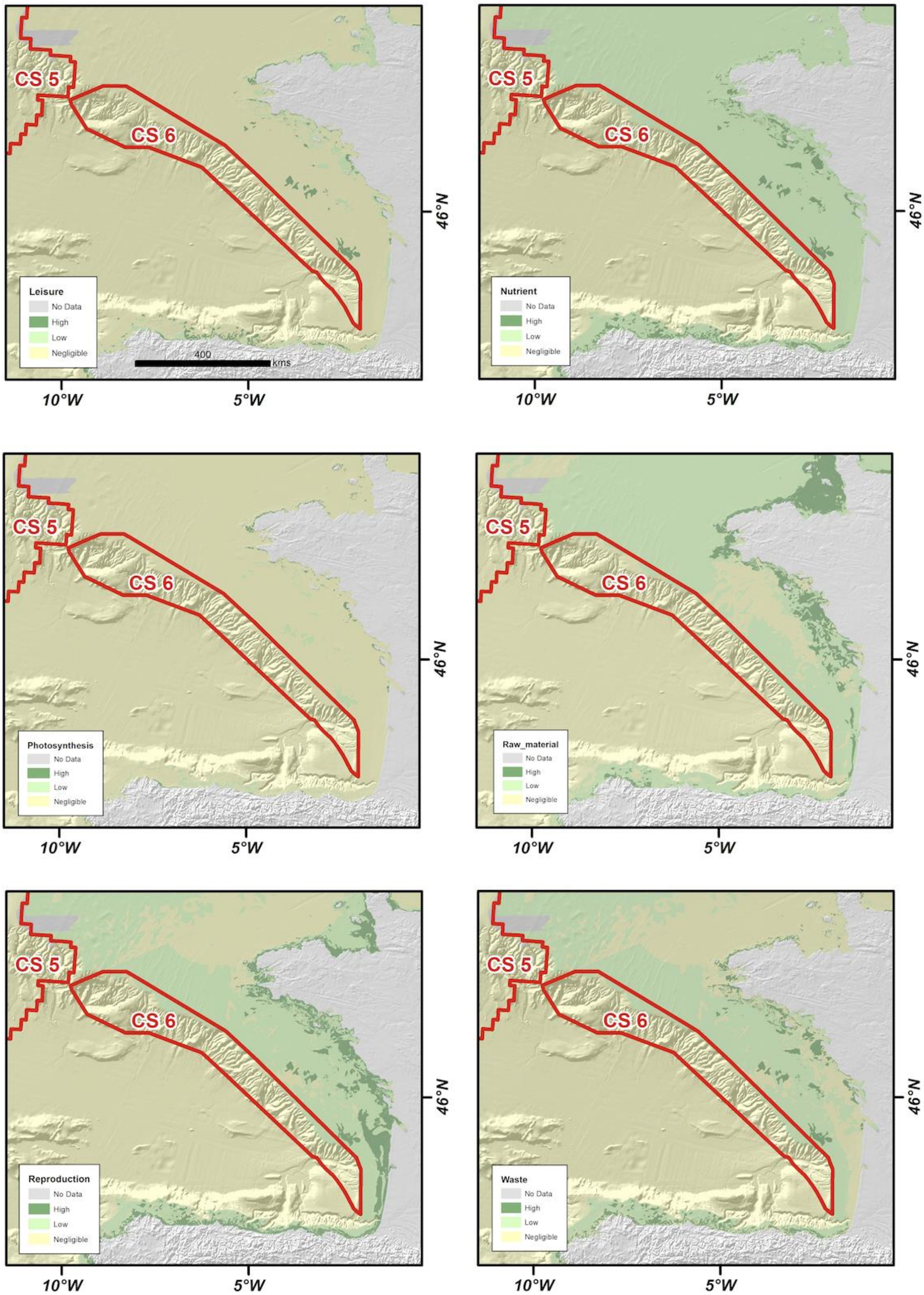


Figure 24. Ecosystem Service Scores for Bay of Biscay, France/Spain (Air quality, Biodiversity, Cognitive, Disturbance, Feelgood, Food)

1.4.6.7. Gulf of Cadiz – Strait of Gibraltar – Alborán Sea, Spain/Morocco

These regions are off the western coast of Portugal, north of Morocco, and also include the Alborán islands. This case study exhibits diverse habitats from the coastal regions to the abyssal plain, with 39 total entries (Figure 25). In Table 14, these habitats are listed with a percentage of total area of the case study with deep sea habitats A6.3, and A6.51 accounting for most of the total area. Figures 26 and 27 show the spatial distribution of the predicted supply of ES.

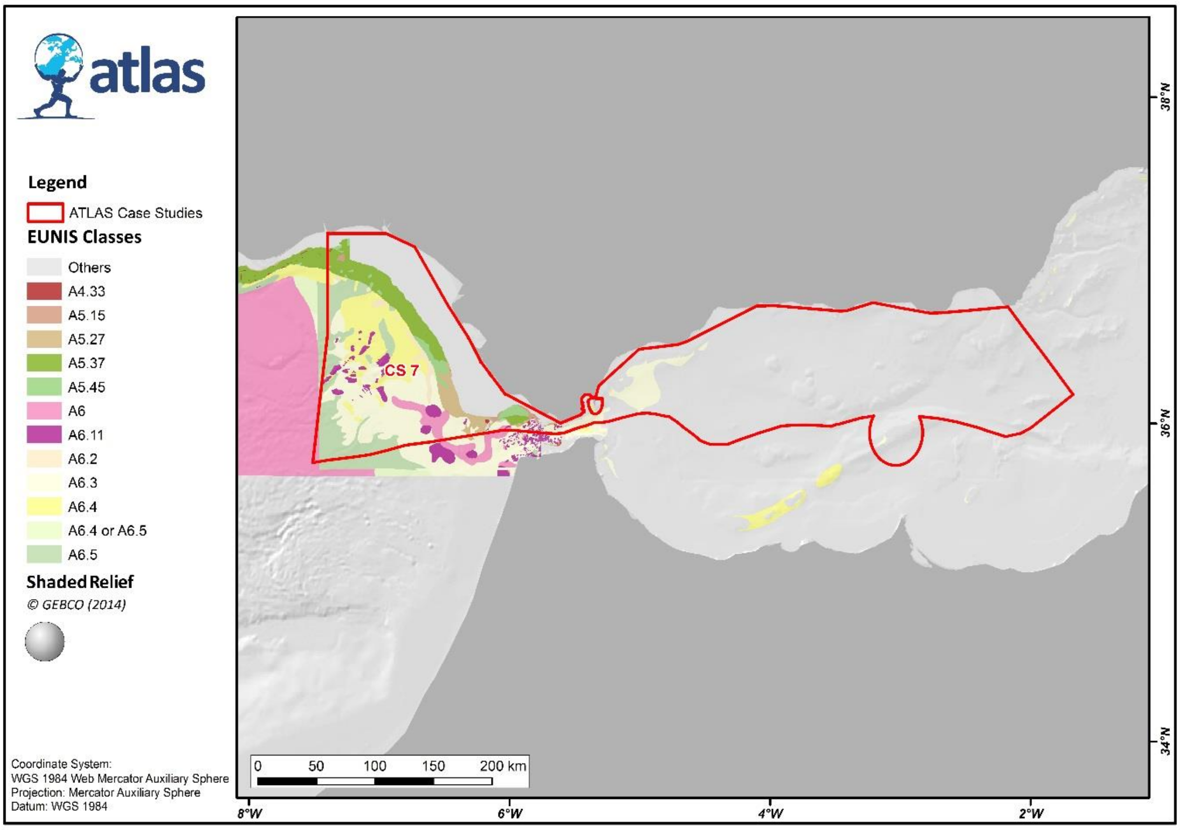


Figure 25. Gulf of Cadiz – Strait of Gibraltar – Alborán Sea EUNIS sea-floor habitats

Table 14. Strait of Gibraltar and Alboran Sea, Spain, Morocco, Habitats by percentage of area, Ecosystem Service Scores

Habitat	% of total area	Food	Raw Material	Air Quality	Disturbance	Photosynthesis	Nutrient	Reproduction	Biodiversity	Water	Cognitive	Leisure	Feelgood
A3	0.05%	H	H	H	H	H	L	H	H	H	H	H	H
A3.1	0.12%	H	H	H	H	H	L	H	H	H	H	H	H
A3.2	0.17%	H	H	H	L	H	H	H	H	H	H	H	L
A3.3	0.18%	H	H	H	L	H	H	H	H	H	H	H	L
A4.1	0.33%	H	H	L	H	N	H	H	H	H	H	L	L
A4.2	0.30%	L	L	L	N	N	H	H	H	H	H	L	L
A4.26 or A4.32	0.20%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
A4.27	0.90%	L	L	L	N	L	H	H	H	H	H	L	L
A4.3	0.21%	H	L	H	N	L	H	H	H	H	H	H	L
A4.33	0.04%	H	L	H	N	L	H	H	H	H	H	H	H
A5.13	0.36%	H	H	N	N	N	L	H	N	N	N	L	L
A5.14	0.70%	H	H	N	N	N	L	L	L	N	N	N	N
A5.15	0.20%	H	L	N	N	N	L	N	L	N	N	N	N
A5.23	0.14%	H	L	N	N	N	L	H	L	N	N	L	L
A5.23 or A5.24	0.64%	H	L	N	N	N	L	H	L	N	N	L	L
A5.25 or A5.26	1.53%	H	L	N	N	N	L	H	L	N	N	N	N
A5.27	1.41%	H	L	N	L	N	L	L	L	L	N	N	N
A5.33	0.14%	H	N	N	N	N	L	L	L	L	N	N	N
A5.34	0.10%	L	N	N	N	N	L	N	L	L	N	N	N
A5.35	1.22%	H	N	N	N	N	L	L	L	L	N	N	N
A5.36	3.37%	H	N	N	N	N	L	L	L	L	N	N	N
A5.37	3.43%	H	N	N	N	N	L	L	L	L	N	N	N
A5.39	1.25%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
A5.44	0.50%	H	L	N	N	N	L	L	H	L	N	N	N
A5.45	0.97%	H	L	N	N	N	L	L	H	L	N	N	N
A5.46	1.34%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
A5.47	2.06%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
A5.535	0.09%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

A6	1.18%	L	N	N	N	N	N	N	H	N	N	N	N
A6.1	4.84%	L	N	N	N	N	N	N	H	N	N	N	N
A6.11	1.29%	N	N	N	N	N	N	N	H	N	N	N	N
A6.2	0.68%	L	N	N	N	N	N	N	H	N	N	N	N
A6.3	11.5%	L	N	N	N	N	N	N	H	N	N	N	N
A6.4	5.54%	L	N	N	N	N	N	N	H	N	N	N	N
A6.5	4.97%	L	N	N	N	N	N	N	H	N	N	N	N
A6.51	47.8%	L	N	N	N	N	N	N	H	N	N	N	N
Grand Total	100%												

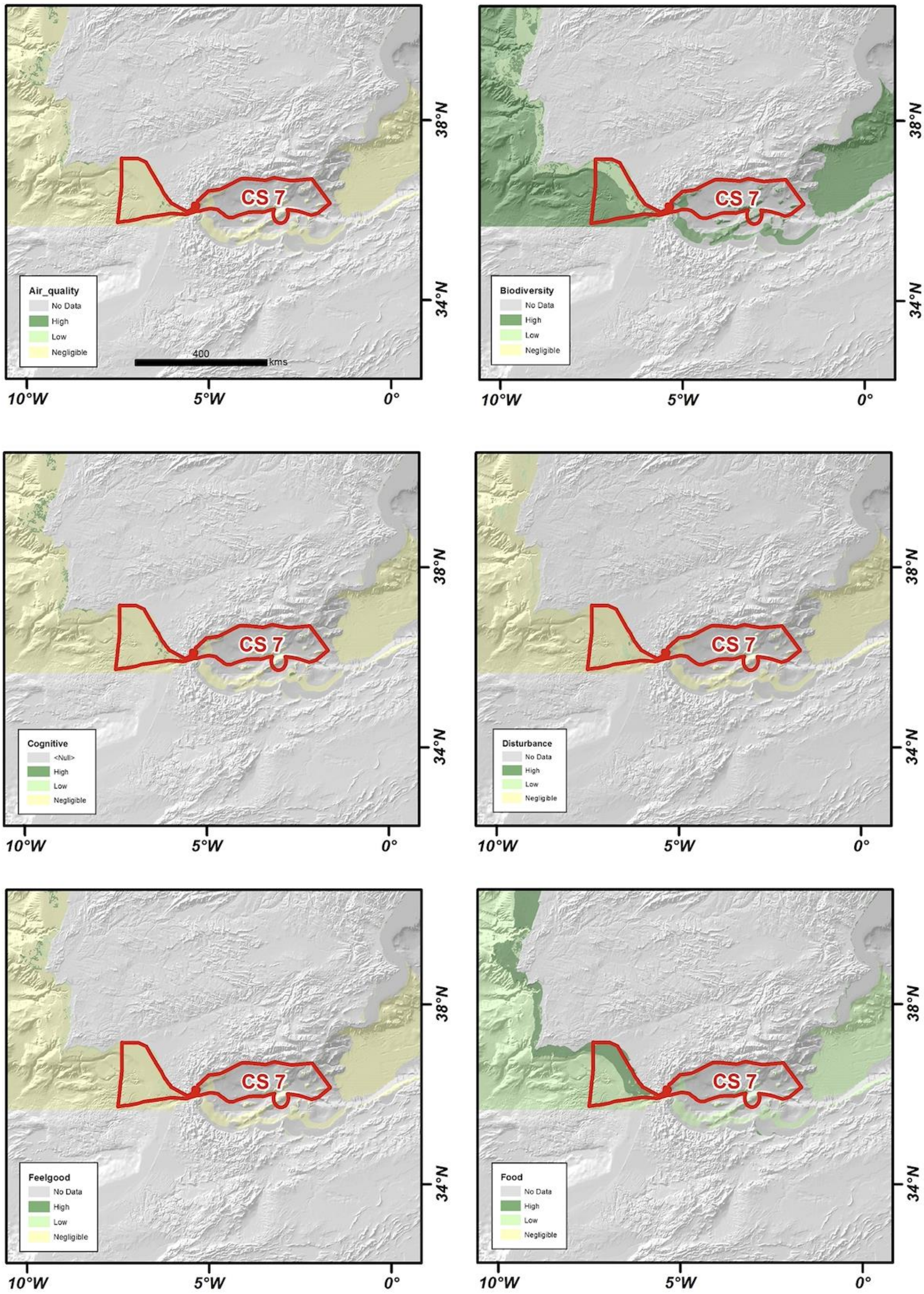


Figure 26. Ecosystem Service Scores for Gulf of Cadiz – Strait of Gibraltar – Alborán Sea, Spain/Morocco (Air quality, Biodiversity, Cognitive, Disturbance, Feelgood, Food)

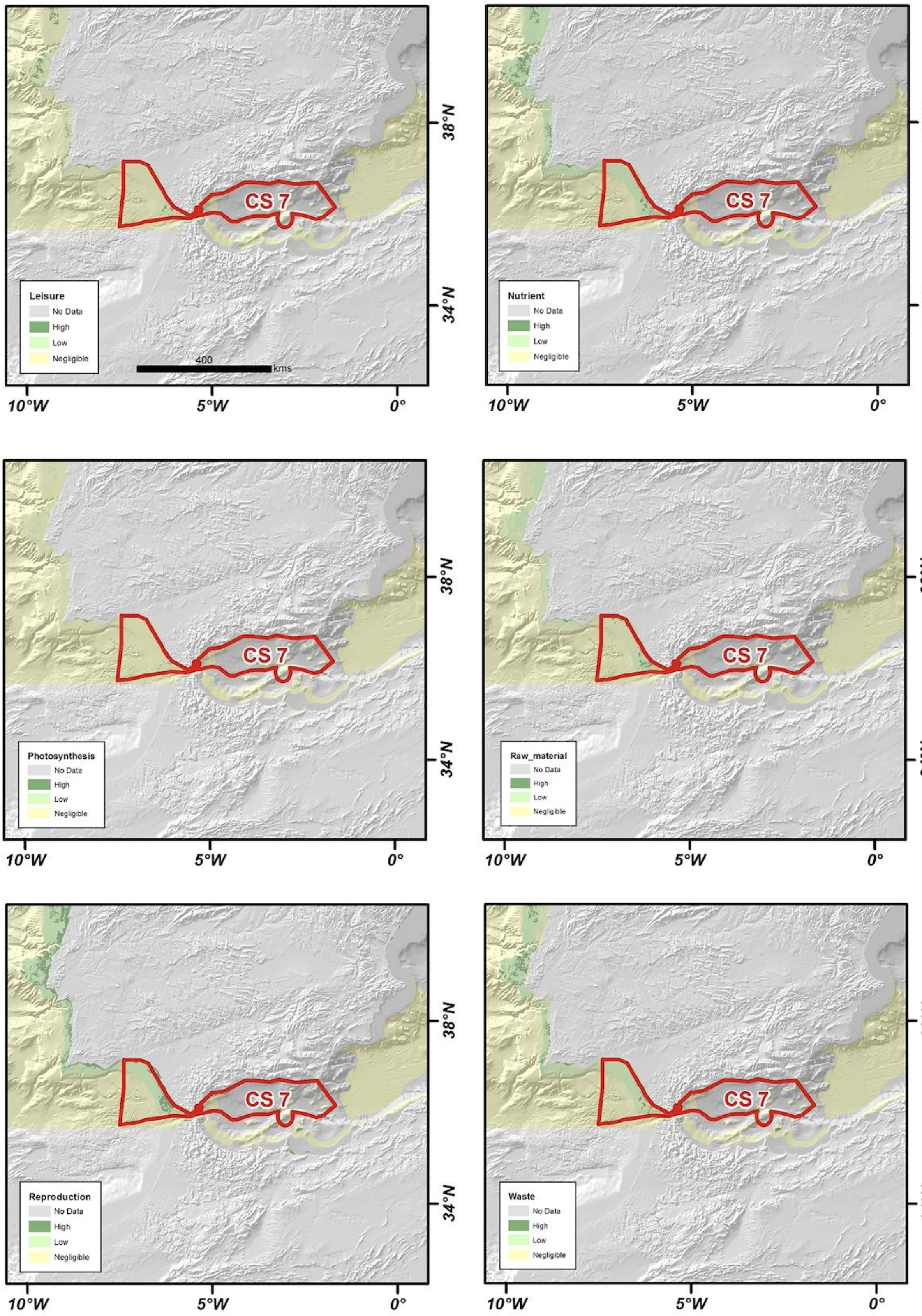


Figure 27. Ecosystem Service Scores for Gulf of Cadiz – Strait of Gibraltar – Alborán Sea, Spain/Morocco (Leisure, Nutrient, Photosynthesis, Raw material, Reproduction, Waste)

1.4.6.8. Autonomous Region of the Azores, Portugal

The Autonomous Region of the Azores are off the western coast of Morocco and volcanic in nature. The islands are separated from each other by vast expanses of the deep sea (ATLAS, 2018).

By area, nearly 99% of the region is deep-sea bed, with small infralittoral and circalittoral regions near the coasts of the island chain (Figure 28). The rest of the sea-floor substrate includes the rocky shores of the volcanic islands and mixed substrata leading down the slopes of the islands to the deep sea.

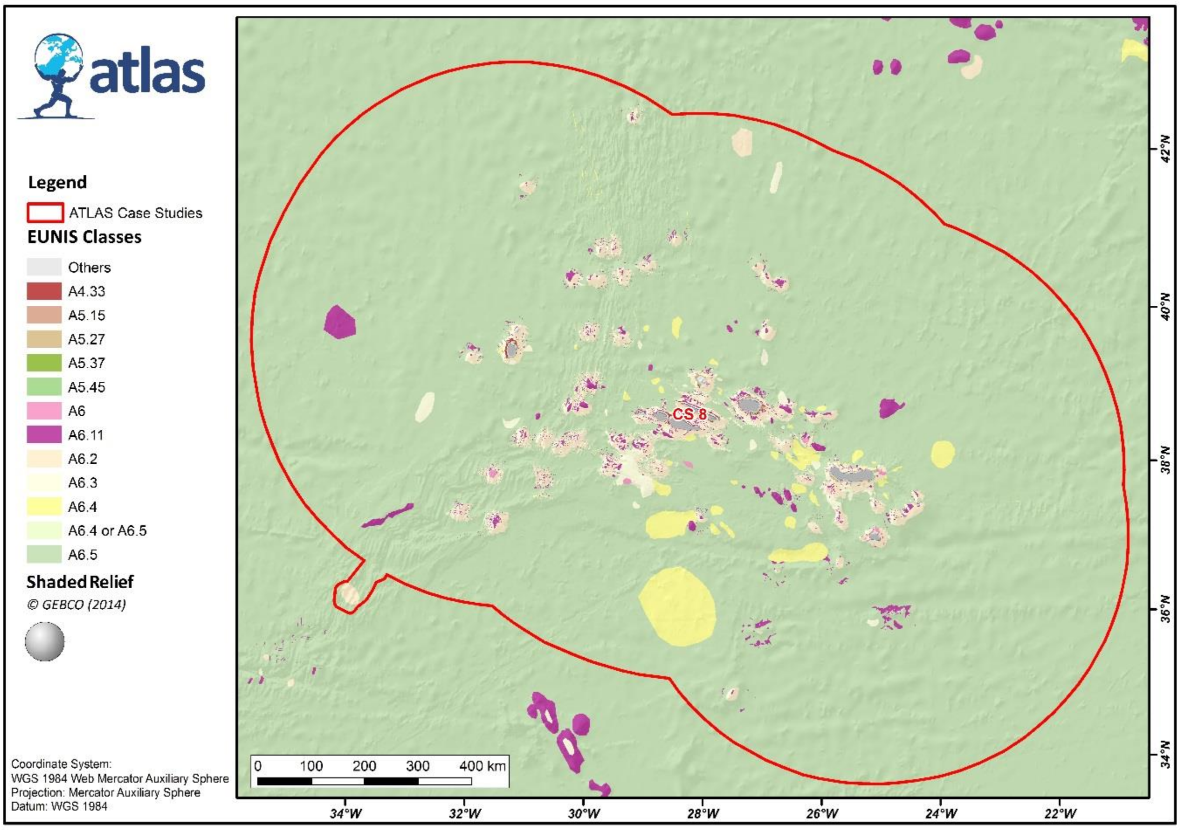


Figure 28. Azores EUNIS sea-floor habitats

Table 15. The Azores Habitats by percentage of area, Ecosystem Service Scores

Habitat	Percentage of total area	Food	Raw Material	Air Quality	Disturbance	Photosynthesis	Nutrient	Reproduction	Biodiversity	Wate	Cognitive	Leisure	Feelgood
A3.1	0.05%	H	H	H	H	H	L	H	H	H	H	H	H
A3.2	0.04%	H	H	H	L	H	H	H	H	H	H	H	L
A3.3	0.02%	H	H	H	L	H	H	H	H	H	H	H	L
A4.12	0.01%	H	H	N	H	N	H	H	H	H	H	L	L
A4.27	0.01%	L	L	L	N	L	H	H	H	H	H	L	L
A4.3	0.01%	H	L	H	N	L	H	H	H	H	H	H	L
A4.33	0.09%	H	L	H	N	L	H	H	H	H	H	H	H
A5.13	0.02%	H	H	N	N	N	L	H	N	N	N	L	L
A5.15	0.04%	H	L	N	N	N	L	N	L	N	N	N	N
A5.23 or A5.24	0.04%	H	L	N	N	N	L	H	L	N	N	L	L
A5.25 or A5.26	0.01%	H	L	N	N	N	L	L	L	L	N	N	N
A5.27	0.03%	H	L	N	L	N	L	L	L	L	N	N	N
A5.43	0.03%	H	L	N	N	N	L	L	H	L	N	N	N
A5.44	0.01%	H	L	N	N	N	L	L	H	L	N	N	N
A5.45	0.08%	H	L	N	N	N	L	L	H	L	N	N	N
A6	0.21%	L	N	N	N	N	N	N	H	N	N	N	N
A6.11	3.07%	N	N	N	N	N	N	N	H	N	N	N	N
A6.2	6.80%	L	N	N	N	N	N	N	H	N	N	N	N
A6.3	3.80%	L	N	N	N	N	N	N	H	N	N	N	N
A6.4	6.12%	L	N	N	N	N	N	N	H	N	N	N	N
A6.5	79.50%	L	N	N	N	N	N	N	H	N	N	N	N
Na	0.03%												
Grand Total	100%												

On a map that is projected at this scale, it is difficult to see where food provisioning primarily occurs but it is predicted near the islands (Figure 29). As most of this case study's ES scores from Galparsoro's synthesis was the deep-sea, these regions would have "Low" score for food provisioning, and "High" or a score of 3 for biodiversity (Table 15). Only infralittoral or circalittoral habitats closer to the islands will indicate scores in the other 10 ES factors (Figure 30).

Ecologically, the Azores lie above a productive volcanic triple junction between the North American, Eurasian, and North African plates. Throughout the deep are many communities of deep-sea corals and hydrothermal vents (ATLAS 2018). As the abyssal plain here extends deeper than 5,000m, little is known about the taxonomic diversity and potential for deep-sea mining or bio-prospecting. However, this region is significant for its combination of unique deep-sea habitats and has potential for blue growth development, as well as potentially impacting climatic conditions (Sweetman et al., 2018).

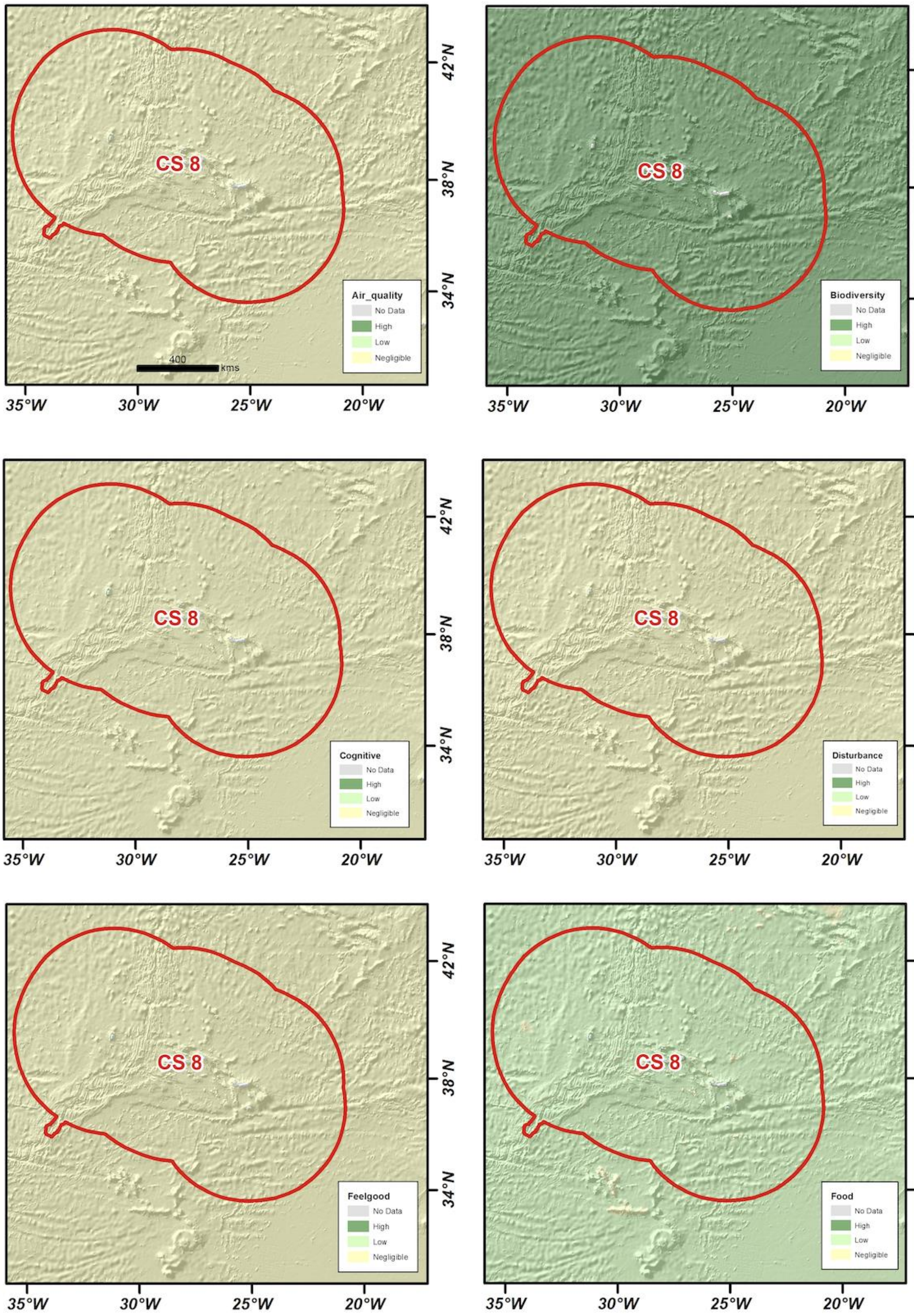


Figure 29. Ecosystem Service Scores for Azores, Autonomous Region of the Azores, Portugal (Air quality, Biodiversity, Cognitive, Disturbance, Feelgood, Food)

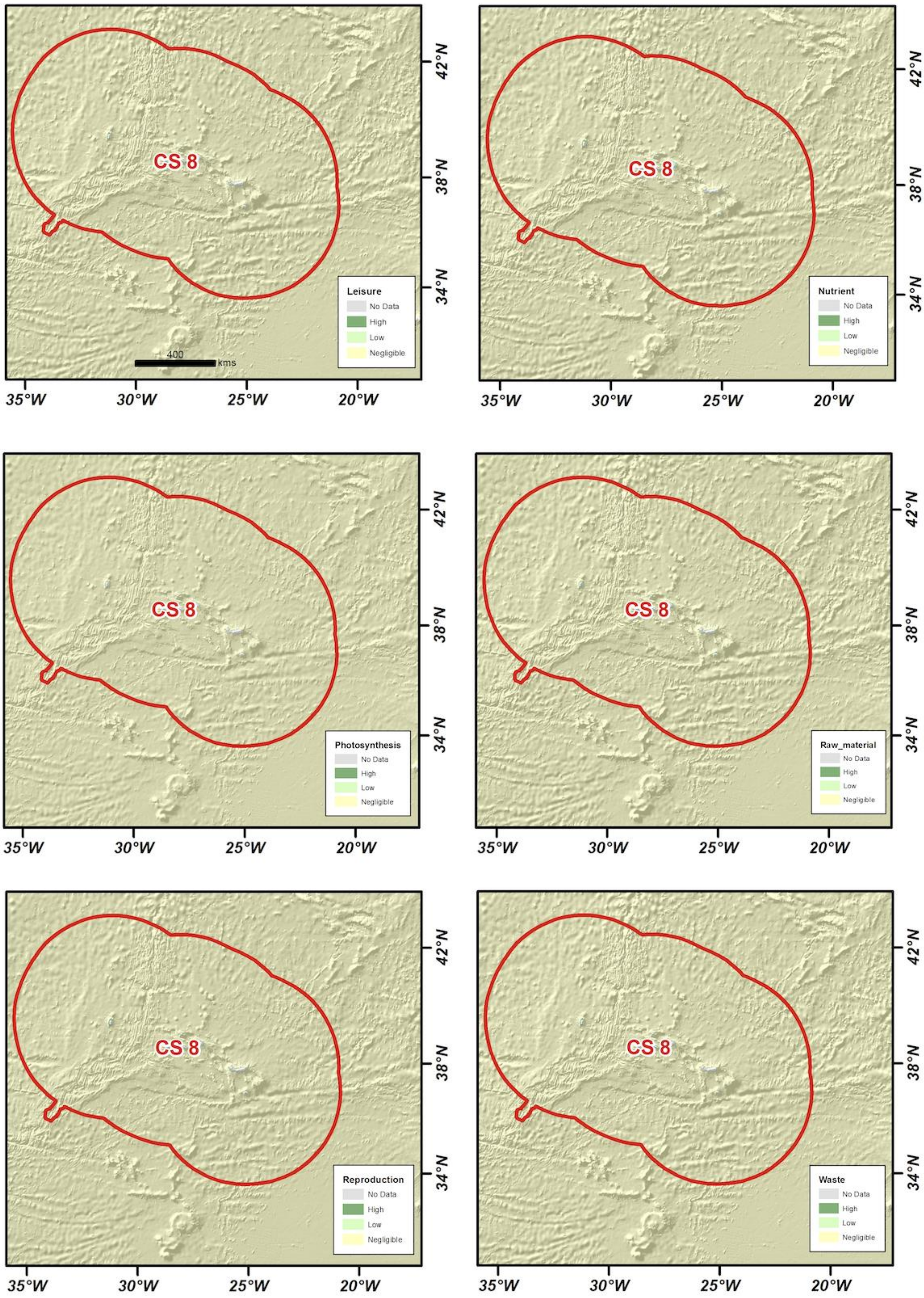


Figure 30. Ecosystem Service Scores for Azores, Autonomous Region of the Azores, Portugal (Leisure, Nutrient, Photosynthesis, Raw material, Reproduction, Waste)

1.4.6.9. Reykjanes Ridge, Iceland

This is a large case study region to the south of the Icelandic mainland known for productive fisheries for the Icelandic people and on the high-seas, outside of the Icelandic EEZ (ATLAS, 2018). This region is entirely within the deep-sea, with A6, deep-sea bed and A6.4, deep-sea mud contributing to 98% of the total area of this case study region (Figure 31, Table 16). Also, there was not complete coverage of EMODNet sea-floor mapping in this region, leading to a significant portion of the case study left absent with ES Scores from Galparsoro et al., (2014). The known area was used in this report.

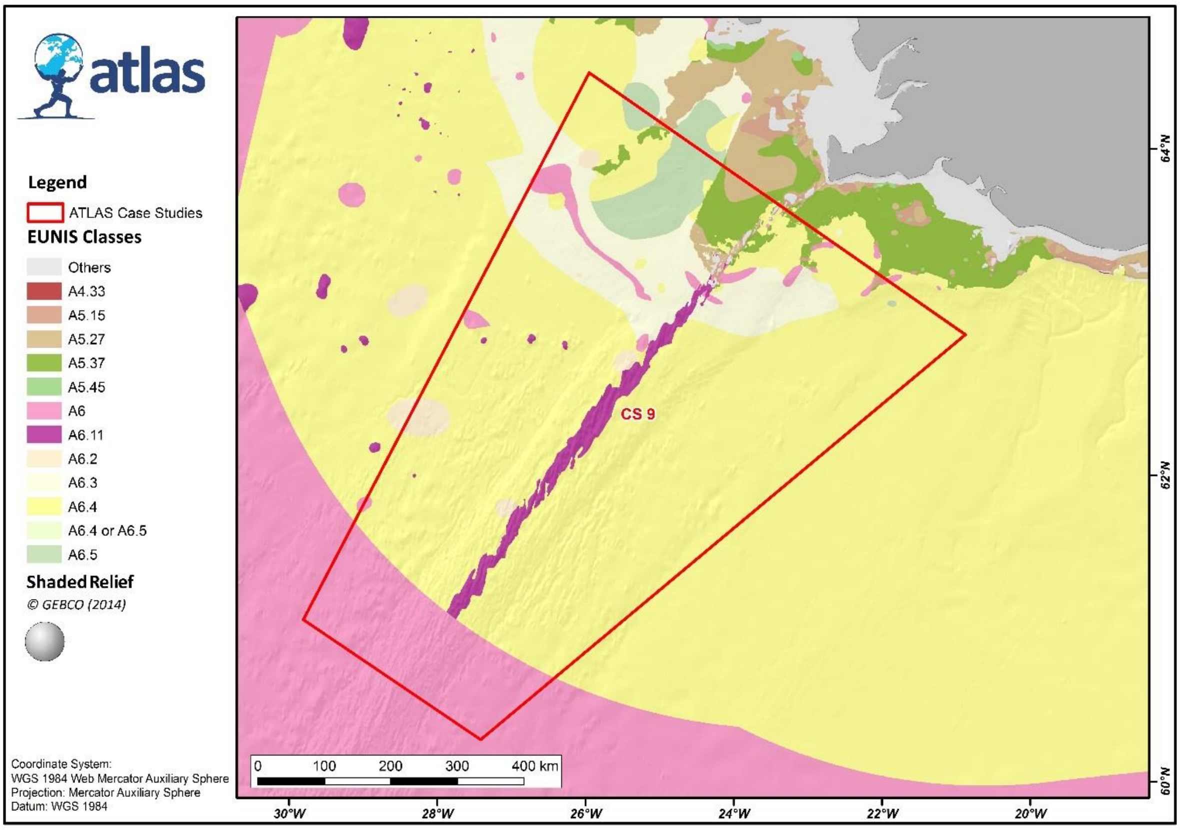


Figure 31. Reykjanes Ridge, Iceland EUNIS sea-floor habitats

Table 16. Reykjanes, Iceland, Habitats by percentage of area, Ecosystem Service Scores

Habitat	% of total Area	Food	Raw Material	Air Quality	Disturbance	Photosynthesis	Nutrient	Reproduction	Biodiversity	Water	Cognitive	Leisure	Feelgood
A4	0.02%	H	H	L	H	N	H	H	H	H	H	L	L
A4.12 or A4.27 or A4.33	0.13%	H	H	H	H	L	H	H	H	H	H	L	L
A5.14	0.01%	H	H	N	N	N	L	L	L	N	N	N	N
A5.15	0.19%	H	L	N	N	N	L	N	L	N	N	N	N
A5.27	0.66%	H	L	N	L	N	L	L	L	L	N	N	N
A5.35	0.01%	H	N	N	N	N	L	L	L	L	N	N	N
A5.37	2.05%	H	N	N	N	N	L	L	L	L	N	N	N
A5.45	0.01%	H	L	N	N	N	L	L	H	L	N	N	N
A6	12.9%	L	N	N	N	N	N	N	H	N	N	N	N
A6.11	2.88%	N	N	N	N	N	N	N	H	N	N	N	N
A6.2	1.14%	L	N	N	N	N	N	N	H	N	N	N	N
A6.3	9.47%	L	N	N	N	N	N	N	H	N	N	N	N
A6.4	67.3%	L	N	N	N	N	N	N	H	N	N	N	N
A6.5	3.19%	L	N	N	N	N	N	N	H	N	N	N	N
Grand Total	100%												

EU STECF data did not extend into this case study region. Figure 26 indicates the EU-ATLAS Project case study region for Reykjanes, and what areas were not included in this report.

With the entirety of this region being in the deep-sea, Galparsoro ES Scores are 1 (Low) for food provisioning, and 3 (High) for biodiversity. All other scores are 0 (Negligible) (Figures 32 and 33).

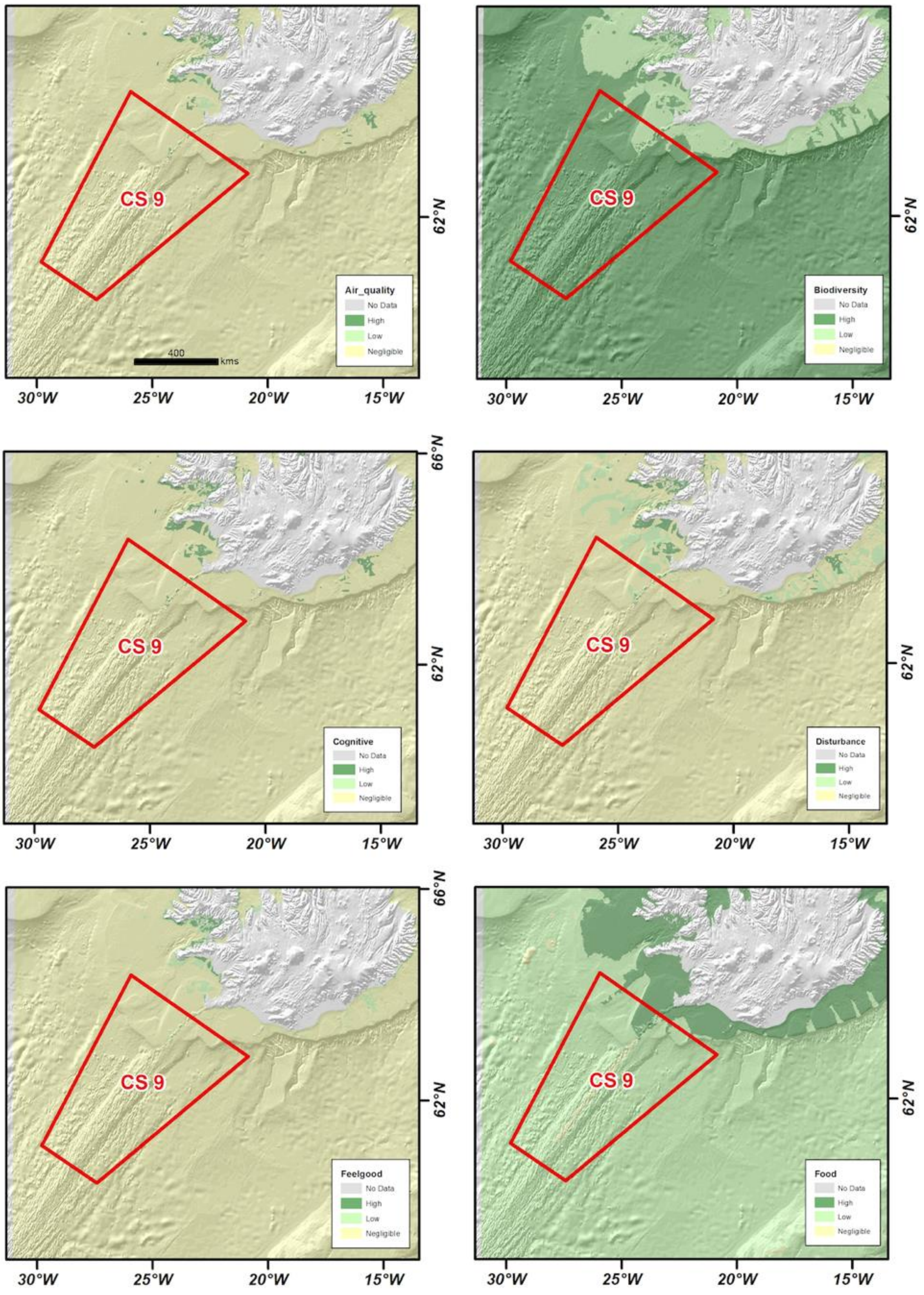


Figure 32. Ecosystem Service Scores for Reykjanes Ridge, Iceland (Air quality, Biodiversity, Cognitive, Disturbance, Feelgood, Food)

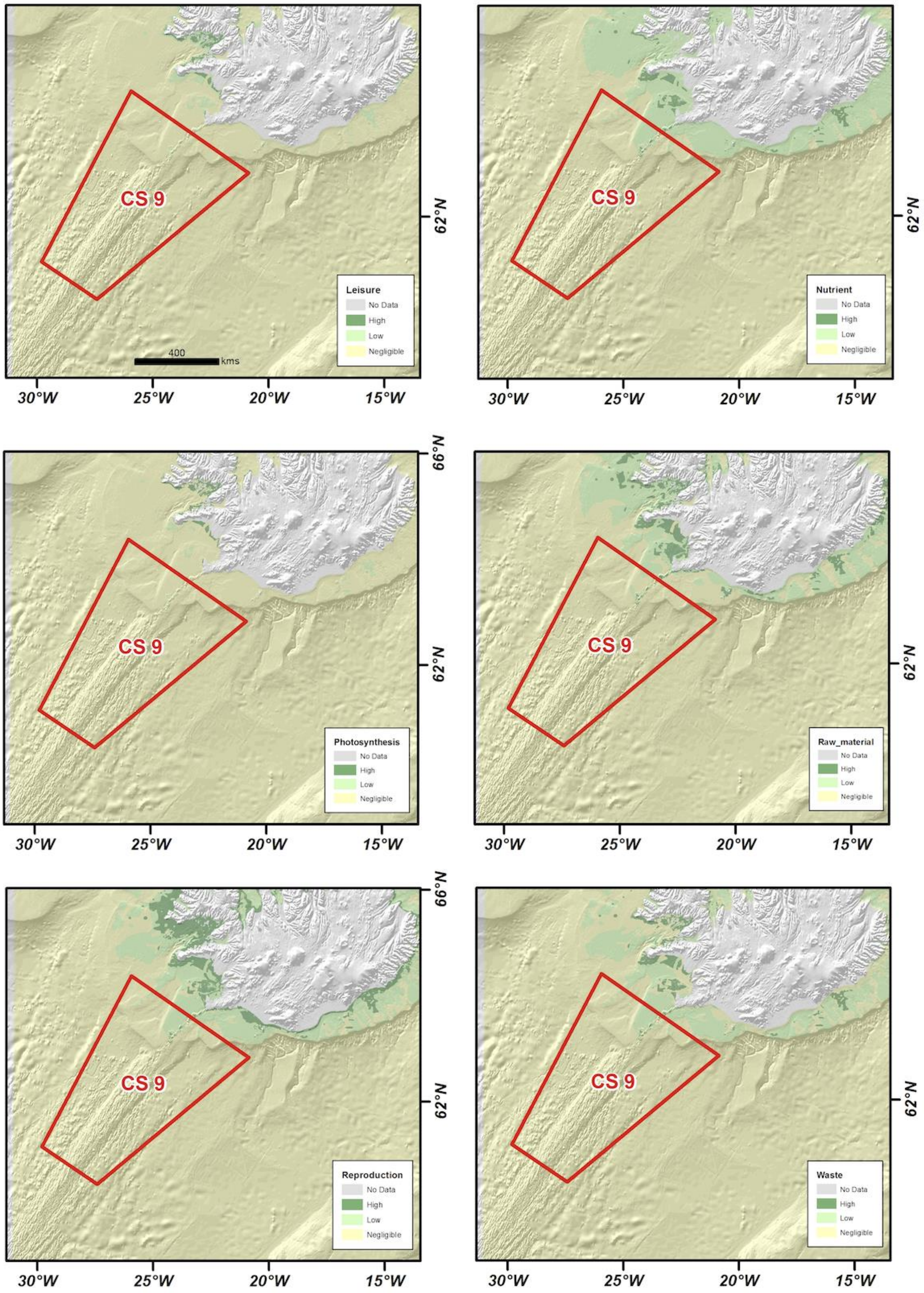


Figure 33. Ecosystem Service Scores for Reykjanes Ridge, Iceland (Leisure, Nutrient, Photosynthesis, Raw material, Reproduction, Waste)

1.4.7. Measuring a deep sea ecosystem service: Fisheries and food

This section shows the best estimates of actual landings by EU vessels and may be compared to the potential ecosystem provisioning service of food from the qualitative analysis above for a number of the case studies. The fisheries data is generated by combining landings information across species from the EU STECF dataset and effort data based on AIS data from Global Fishing Watch (GFW; https://globalfishingwatch.org). Note that this approach favours study sites which are predominately within EU member states EEZs as only EU landings are in the dataset and they dominate within EU member states EEZs. The only other nation fishing in EU member state's EEZs is Norway (EU, 2016) which mainly focuses on pelagic species (Blue Whiting (*Micromesistius poutassou*)) and shallow water Norwegian pout, (*Trisopterus esmarkii*) although they do have quotas for some deep-water species such as ling (*Molva dypterygia*) and argentine (*Argentina silus*) (EU, 2016). The estimated aggregate value of the landings in tonnes and monetary value from each case study area is shown in Table 17.

Table 17. Estimated Value of the Deep Sea Demersal Species Landings per case study

	Estimated EU Landings (tonnes)	Estimated EU Landings (Value)
LoVe Observatory, Lofosten-Vesterålen, Norway	-	-
Faroe Shetland Channel, United Kingdom	373	€1,286,883.37
Rockall Bank, Northeast Atlantic Ocean	1409	€4,456,657.46
Mingulay Reef, Western Scotland, UK	-	-
Porcupine Seabight, Ireland	47,212	€120,295,704.83
Bay of Biscay, France/Spain	12,836	€33,442,414.04
Gulf of Cadiz – Strait of Gibraltar – Alborán Sea	-	-
Autonomous Region of the Azores, Portugal	465	€77,943.37
Reykjanes Ridge, Iceland	-	-

Source: calculated based on EU STECF and AIS data. A dash indicates insufficient data.

The STECF data only covers vessels over 12m so it is not representative of the inshore fishing ecosystem service as that is dominated by smaller fishing vessels which may be relevant for Mingulay and Lofosten-Vesterålen. The main issue for the AIS data is that it doesn't distinguish between pelagic and demersal vessels so demersal effort may be spatially more concentrated than shown here.

A limitation in the qualitative mapping approach is that it maps potential ecosystem services rather than the actual ecosystem services. Unless humans are interacting with an ecosystem function or placing a demand on an ecosystem for a service then no ecosystem service is generated. This means that the maps of the actual landings can show a spatially distinct pattern when compared to the qualitative provisioning services shown previously for each case study. While the pattern is similar for Sheltand-Faroes, the Porcupine Bight, the Bay of Biscay and the Azores, the pattern of this provisioning service across qualitative and quantitative metrics is less comparable for the other case studies. For these latter case studies the discrepancy may arise due to limited data. For example there are differences between measured landings and that predicted by the qualitative mapping approach in the Lofosten-Vesterålen case study that are most likely due to location of case study in Norwegian territorial waters. Misund and Olsen, (2013) noted that this case study area is an important fishery for cod in particular.

1.4.7.1. LoVe Observatory, Lofosten-Vesterålen, Norway

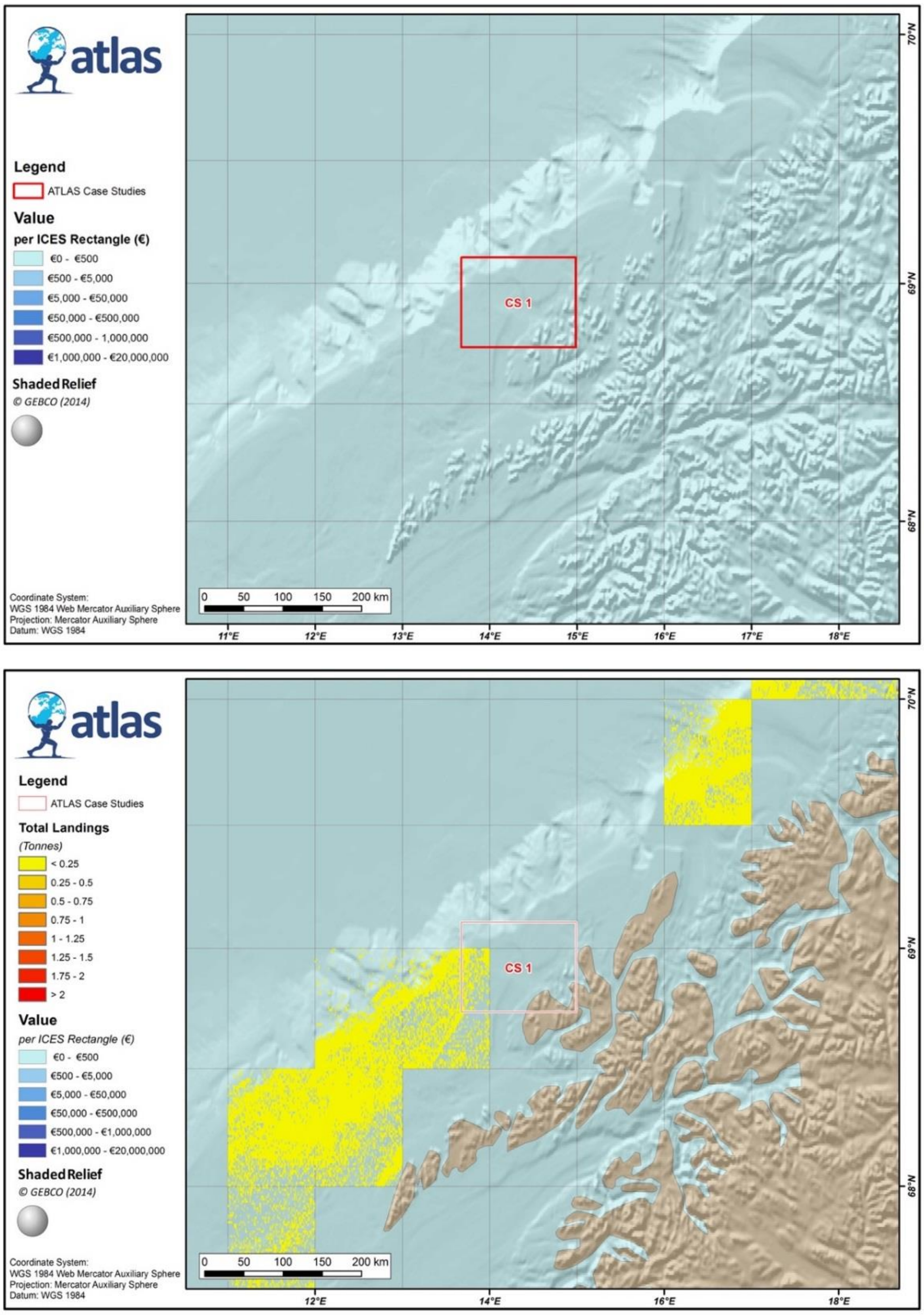
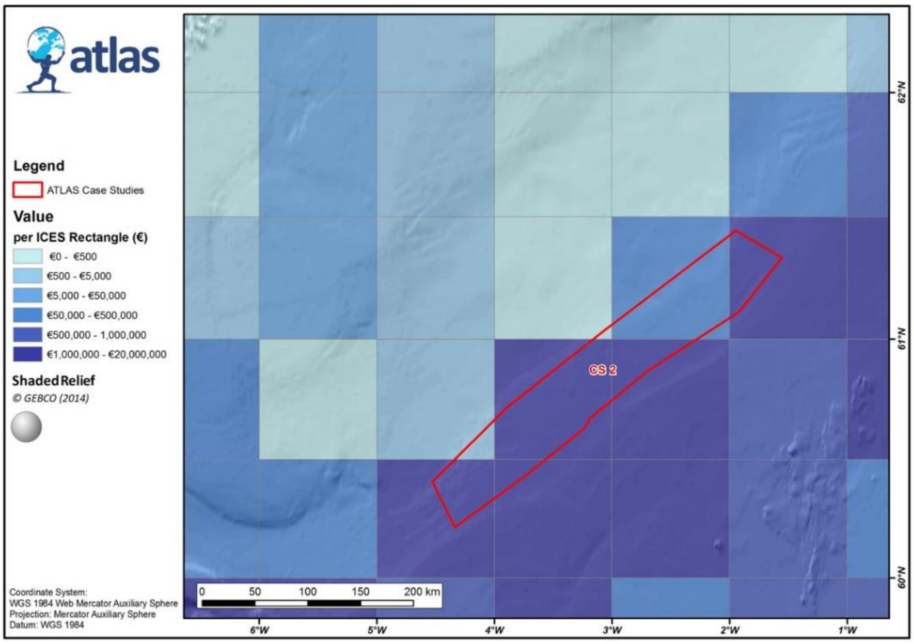


Figure 34. Value per ICES rectangle and deep sea demersal species landings in the Lofosten-Vesterålen

There is little deep-sea fishing activity due to the inshore nature of the case study and its location in non-EU waters (Figure 34).

1.4.7.2. Faroe Shetland Channel, United Kingdom



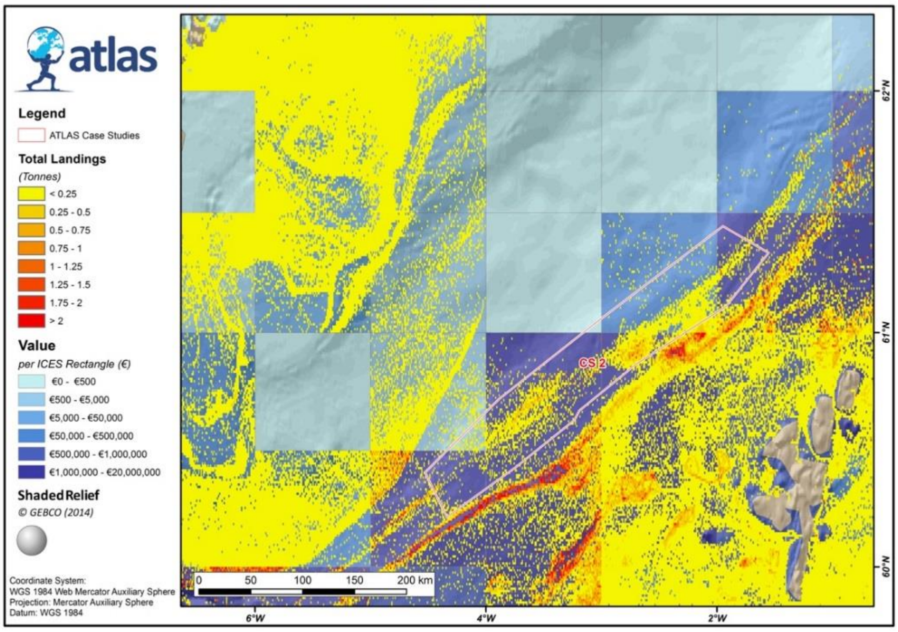


Figure 35. Value per ICES rectangle and deep sea demersal species landings in the Faroe Shetland Channel

Figure 35 shows significant fishing activity at the border of the case study area along the shelf slope into the deep sea with less activity within the case study area. This pattern matches that for the predicted food ES in Figure 11.

1.4.7.3. Rockall Bank, Northeast Atlantic Ocean

As in the previous case study of Faroe Shetland Channel, Figure 36 (below) shows some similarities in the pattern of predicted food ES shown in Figure 14 with landings concentrated around upwelling surrounding the Rockall Bank in the centre of the case study.

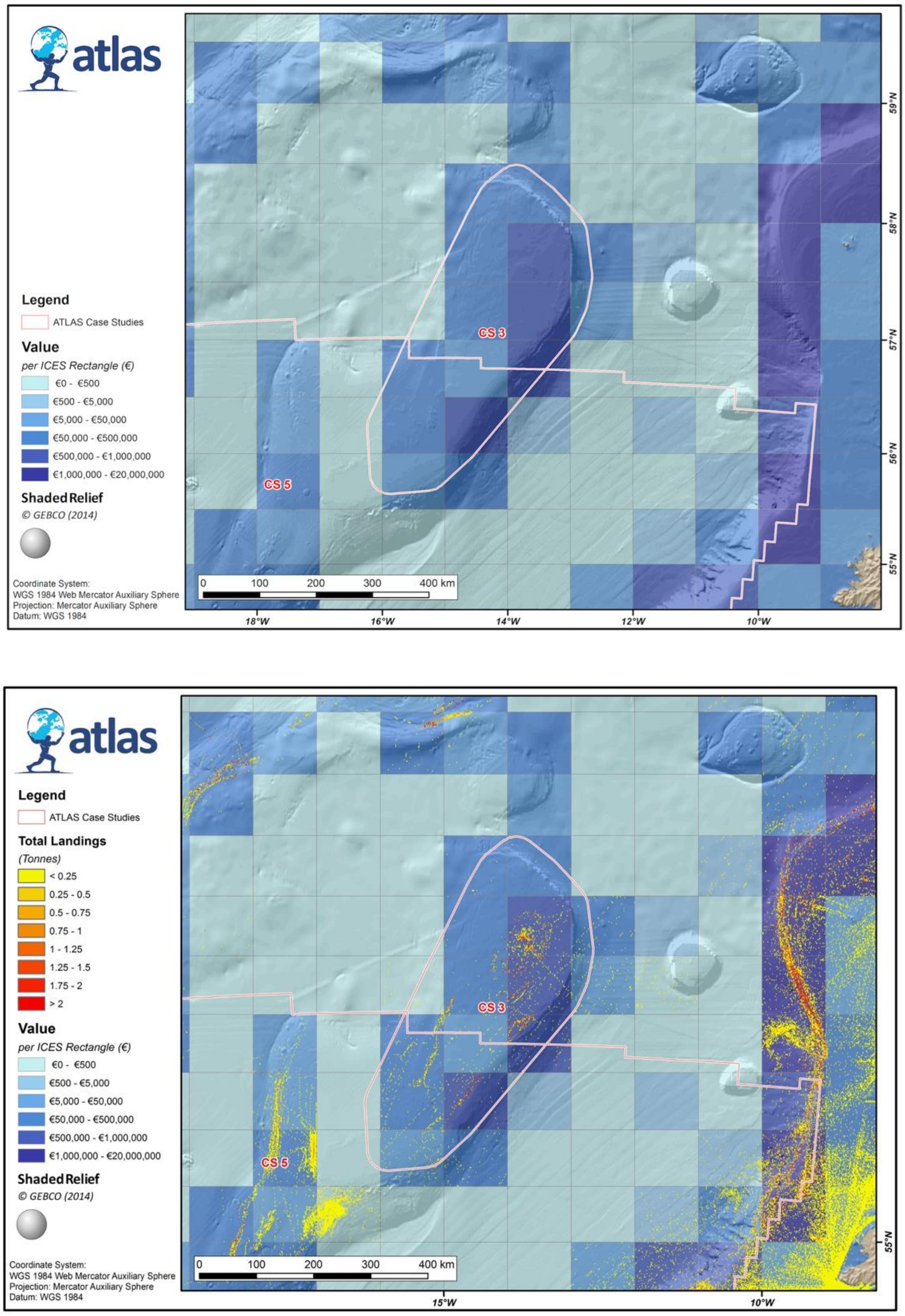


Figure 36. Value per ICES rectangle and deep sea demersal species landings in the Rockall Bank

1.4.7.4. Mingulay Reef, Western Scotland, United Kingdom

Most of the case study area for the Mingulay Reef is a protected area where there is no demersal fishing. The apportioning landings approach using AIS suggests low levels of landings (Figure 37) in the area which demonstrates the limitation of using the approach at small scale and in inshore areas.

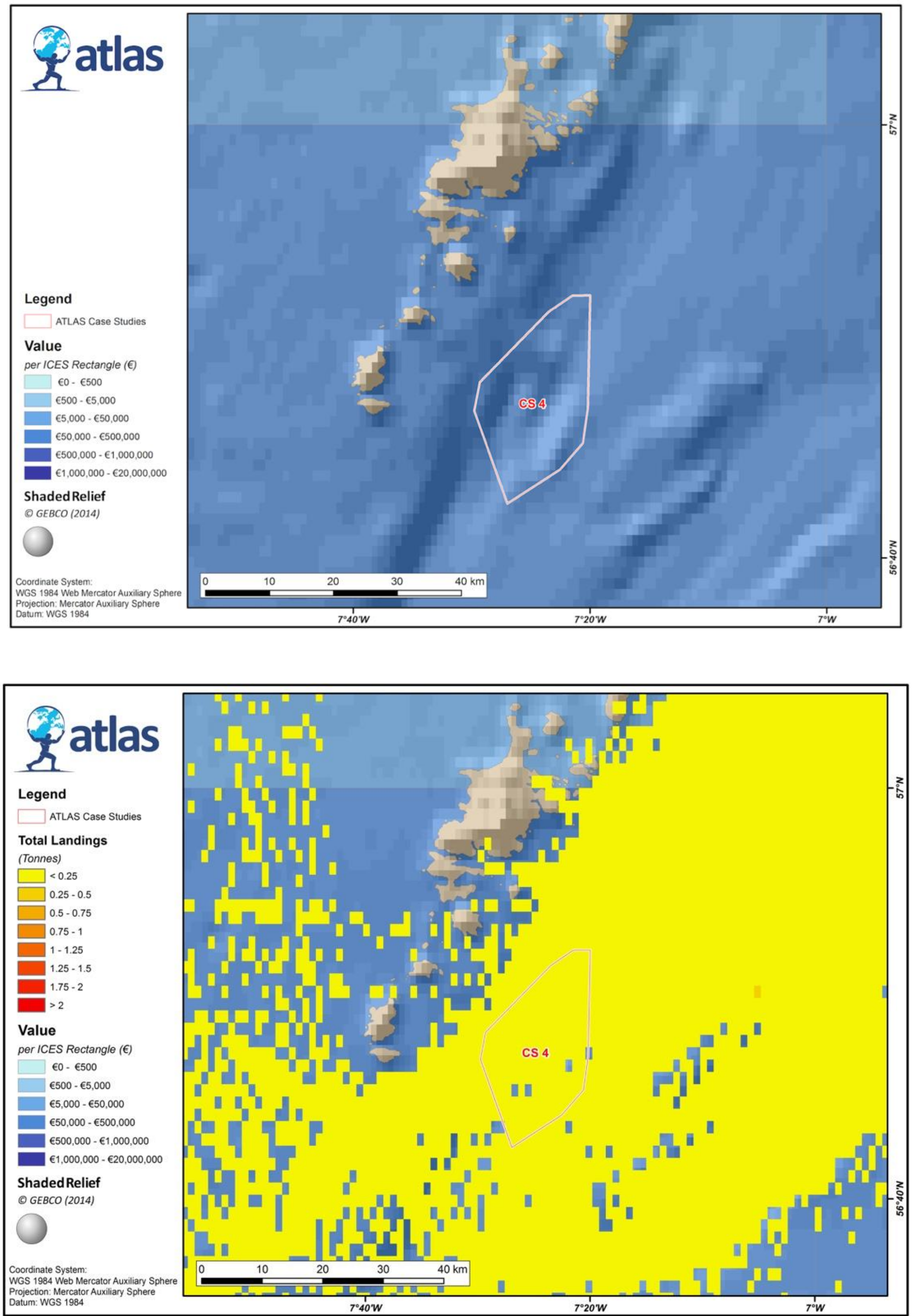
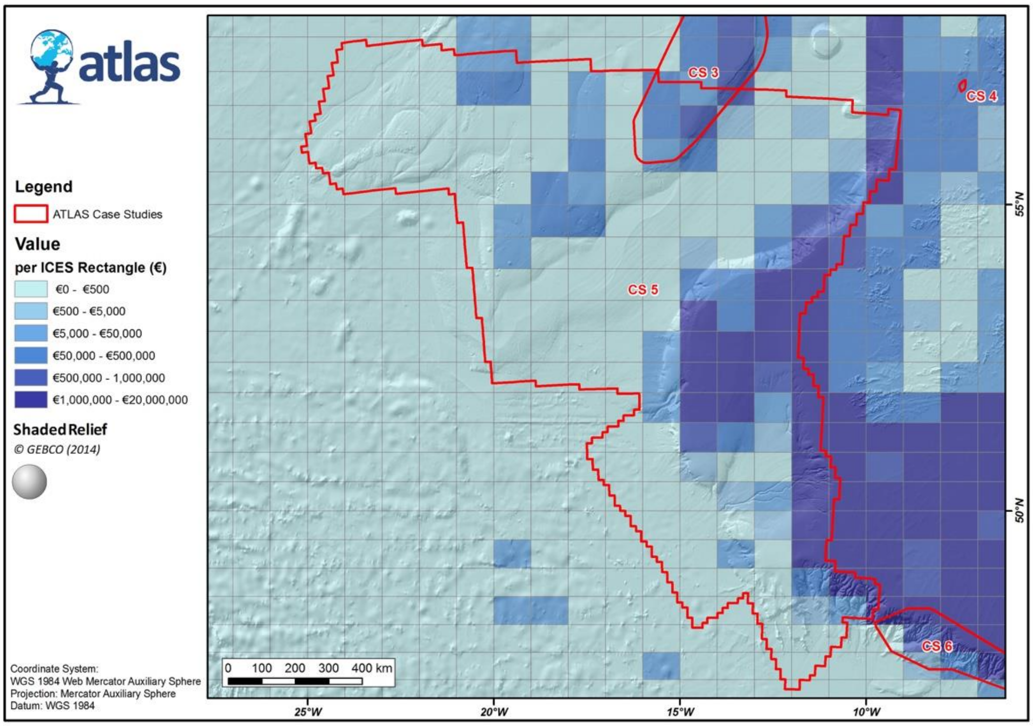


Figure 37. Value per ICES rectangle and deep sea demersal species landings in the Mingulay Reef, Western Scotland

1.4.7.5. Porcupine, Ireland



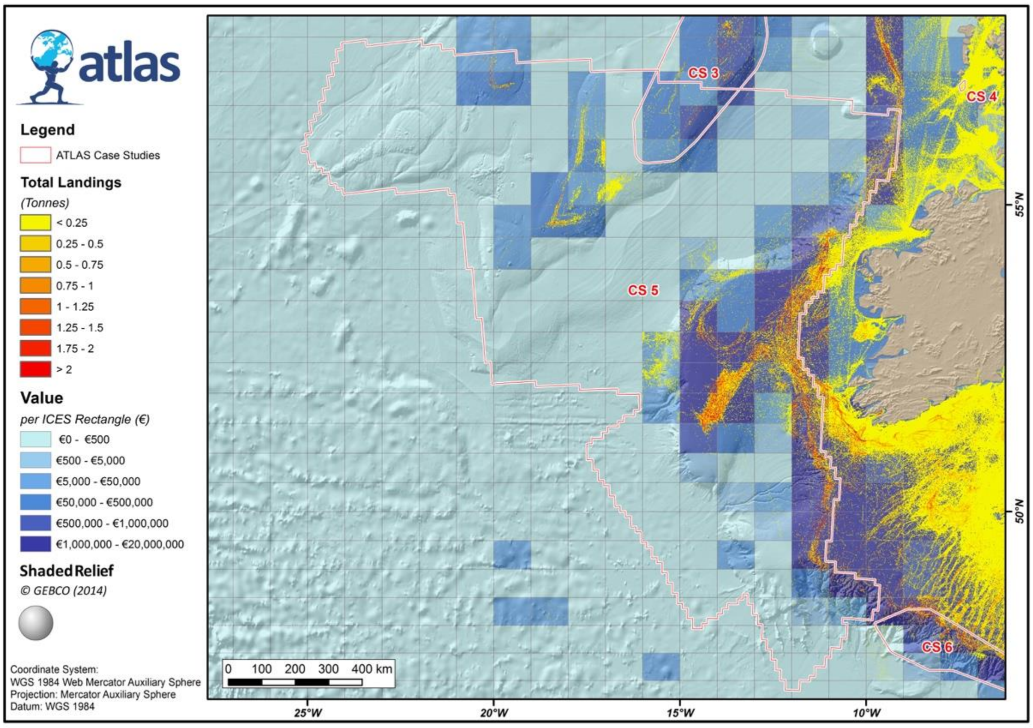
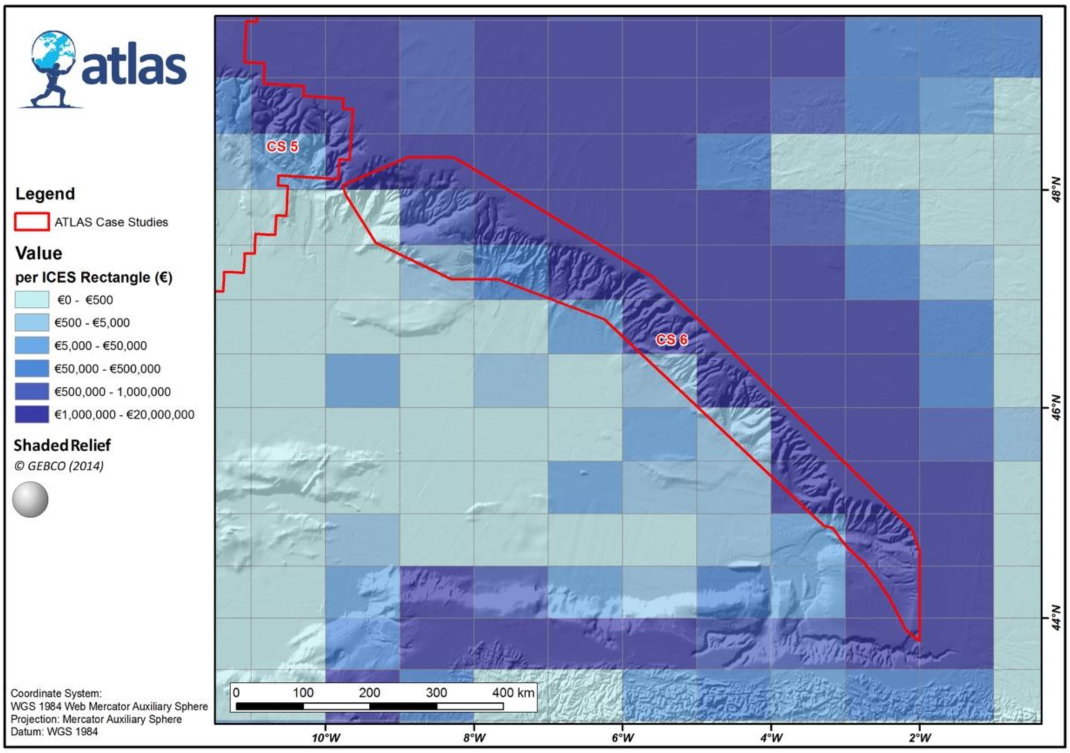


Figure 38. Value per ICES rectangle and deep sea demersal species landings in the Porcupine, Ireland

Despite the limitations of the AIS distribution approach for small scale level as demonstrated for the previous case study, this case study highlights that at large scale level the AIS approach gives a very good picture of where fishing activity occurs. Additionally, the predicted food ES in Figure 20 matches the fishing activity (Figure 38), highlighting that the main location of fishing activity happens on the Porcupine Bank in the centre of the case study as predicted as High in Figure 20.

1.4.7.6. Bay of Biscay, France/Spain



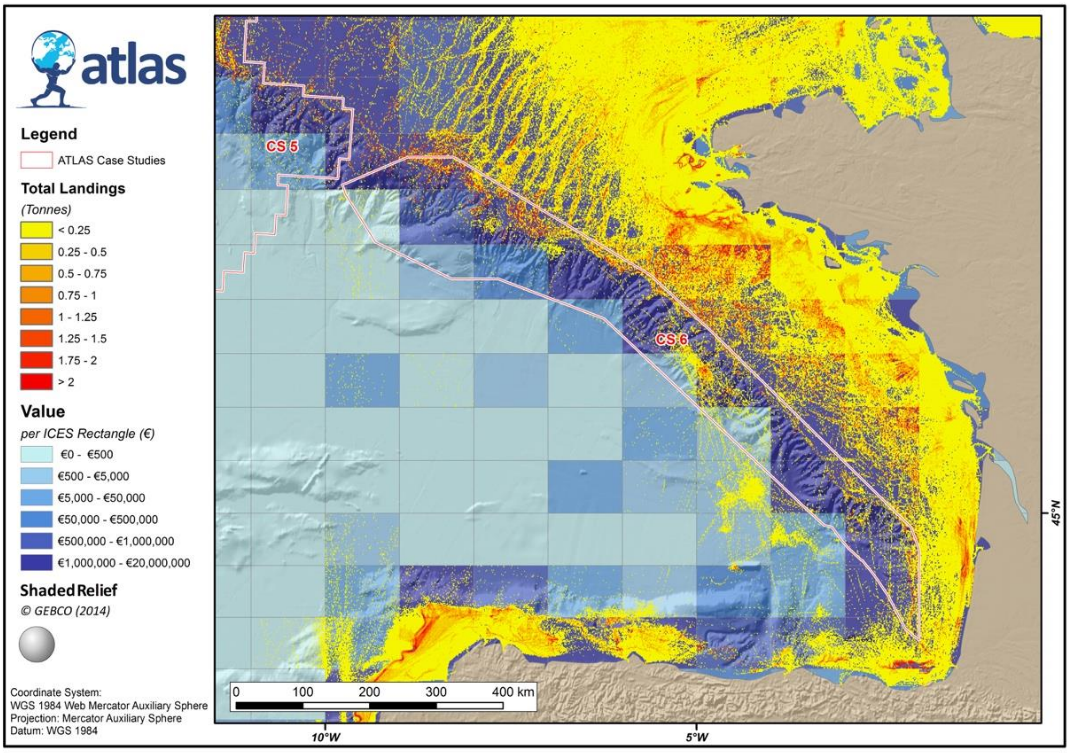


Figure 39. Value per ICES rectangle and deep sea demersal species landings in the Bay of Biscay, France

The fishing activity in this case study (Figure 39) again highlights the strength of this approach at large scale level within EU waters and again mirrors the predicted food ES shown in Figure 23. The area of High in Figure 23 matches the area of main fishing activity that occurs on shelf to the North East of the case study area while the Low predicted within the case study area by the qualitative approach is also demonstrated in Figure 39.

1.4.7.7. Gulf of Cadiz – Strait of Gibraltar – Alborán Sea, Spain/Morocco

The EU STECF dataset used is limited to the North East Atlantic region and this limits the recorded fishing activity in this case study area (Figure 40).

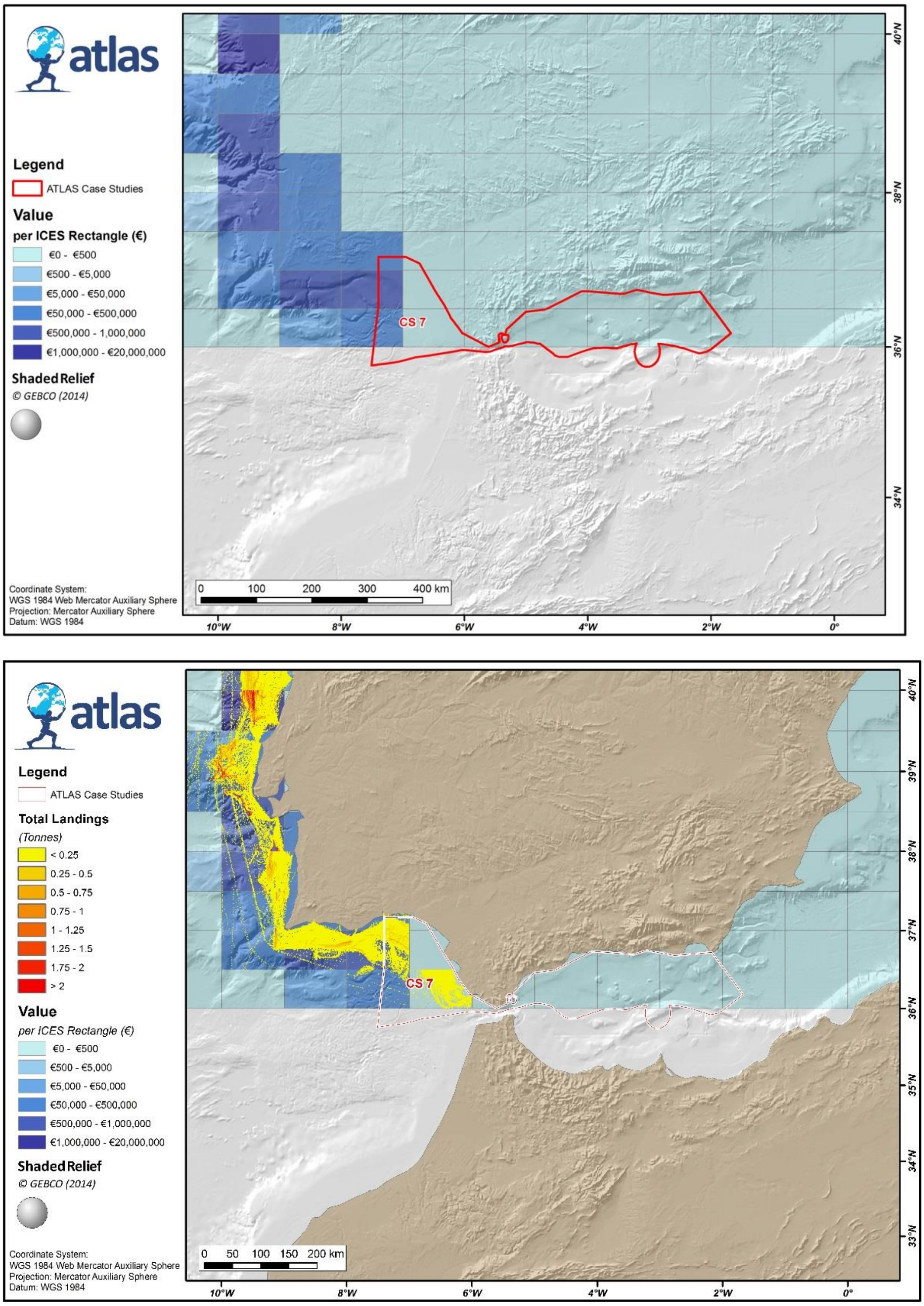


Figure 40. Value per ICES rectangle and deep sea demersal species landings in the Gulf of Cadiz/Strait of Gibraltar/Alborán Sea

1.4.7.8. Azores, Autonomous Region of the Azores, Portugal

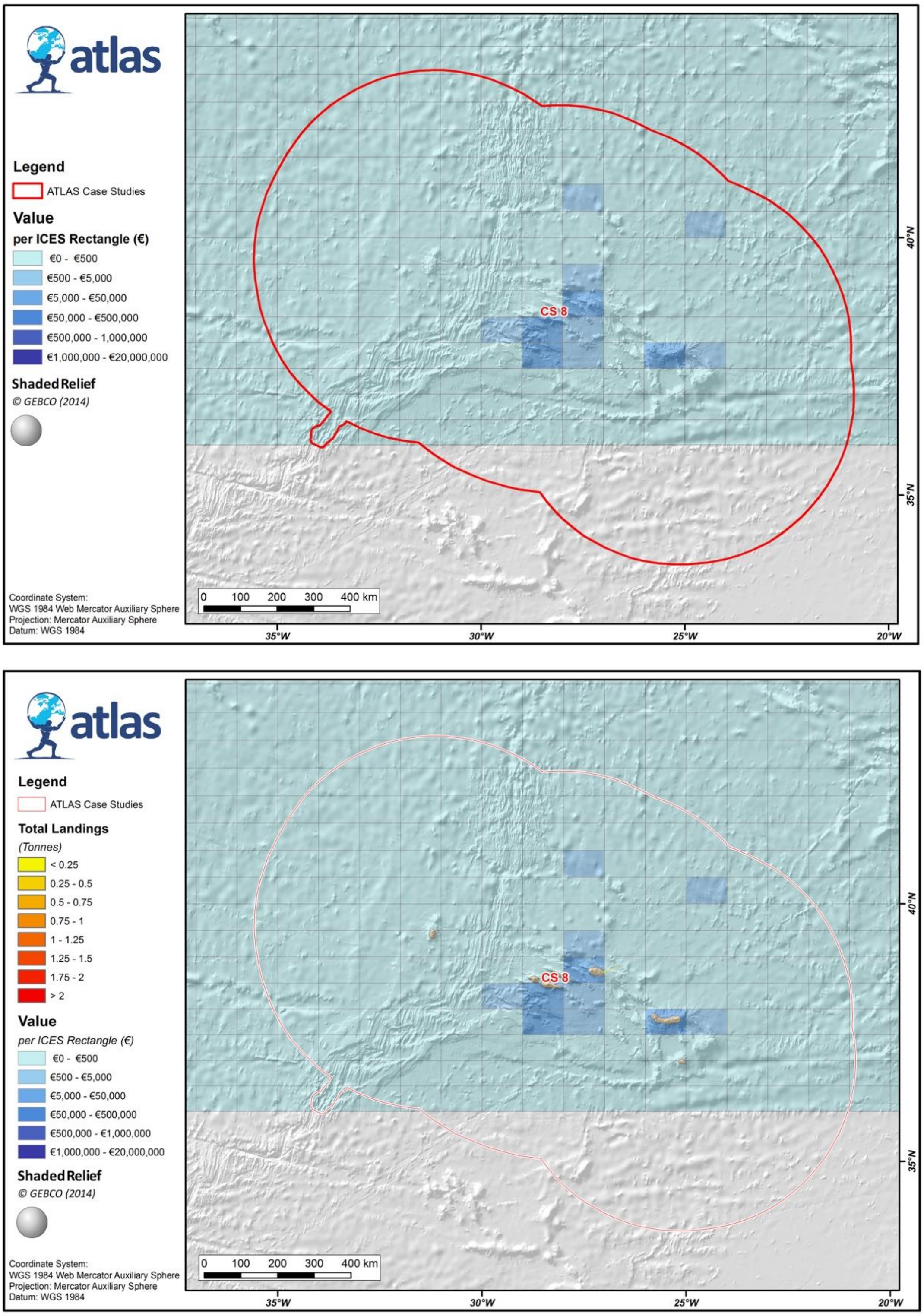


Figure 41. Value per ICES rectangle and deep sea demersal species landings in the Azores

The fishing activity in the case study (Figure 41) is at a low level and mostly occurring close to the Azores islands which is similar to that predicted as Low throughout the case study in qualitative exercise (Figure 29).

1.4.7.9. Reykjanes Ridge, Iceland

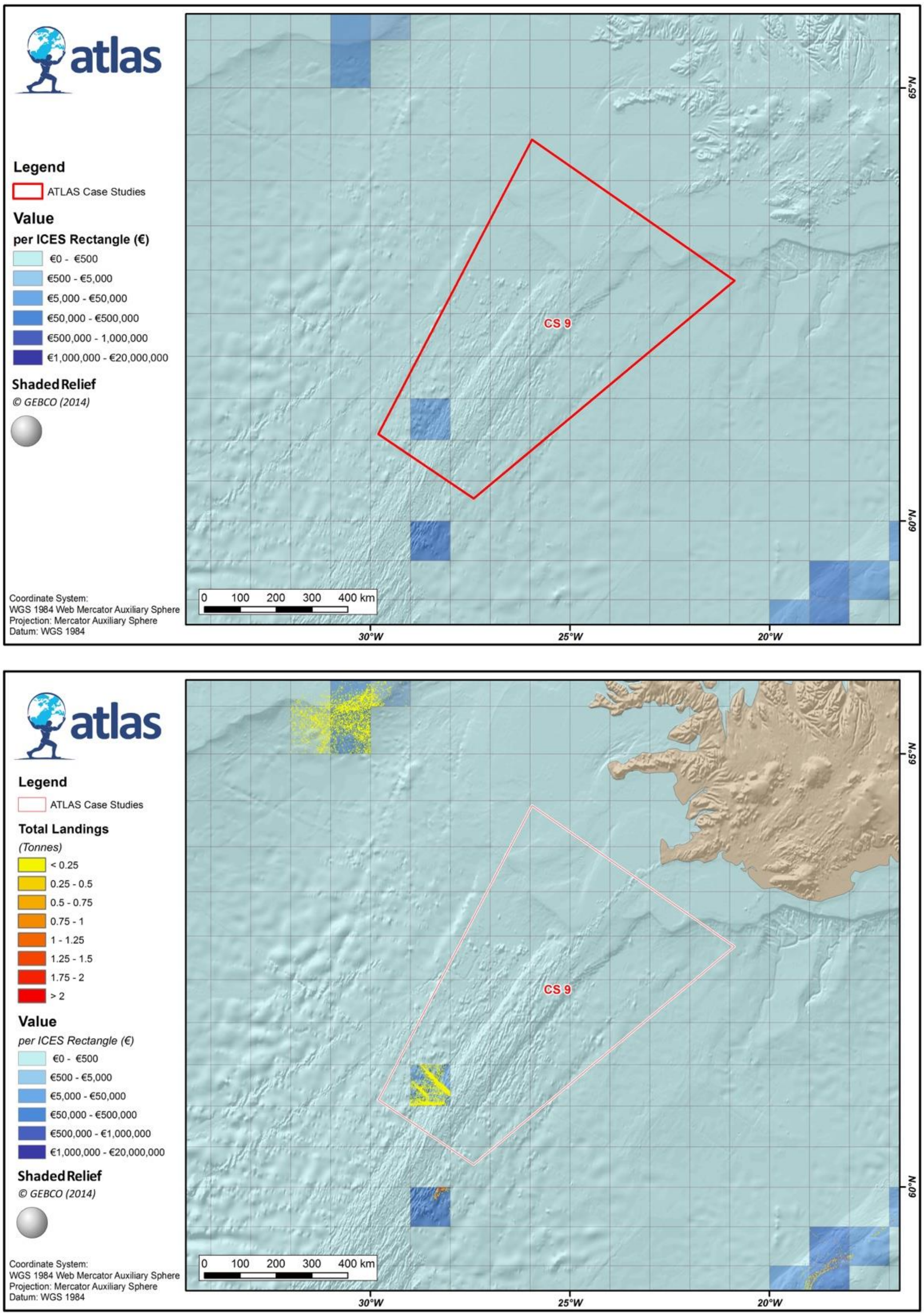


Figure 42. Value per ICES rectangle and deep sea demersal species landings from the Reykjanes Ridge, Iceland

The lack of EU STECF data on fisheries is evident in Figure 42 due to the remote nature of the case study area from the EU fisheries ports and the lack of Icelandic data available for this report.

2. Vulnerable marine ecosystem environmental risk assessment

2.1. Introduction

Globally, bottom trawling is the most widespread human activity causing physical disturbance of the seabed (Halpern et al. 2008; Clarke et al. 2015). The first comprehensive assessment of human activity footprint in the NE Atlantic (Benn et al. 2010) clearly demonstrated that fishing, and in particular demersal trawling, had by an order of magnitude, a greater footprint than the total extent of all other human activities potentially impacting deep-sea ecosystems. Fishing impacts are not solely confined to surface abrasion, Hiddink et al. (2017), in a global review of experimental and comparative studies of trawling impacts, showed that depletion of biota and trawl penetration were highly correlated. Ashford et al. (2018) in their recent study conclude that deep-sea ecosystems are highly sensitive to environmental change and direct human disturbance because they are both phylogenetically and functionally under-dispersed (i.e. taxa are more similar to each other than expected by chance) indicating that assemblages are physically rather than biologically mediated.

Work is on-going in ICES working groups and ad hoc workshops to develop impact assessment and trade-off analyses (*inter alia*: WGFBIT 2019; WKBENTH 2016, WKSTAKE, WKTRADE; WKBEDPRES1 2018; WKBEDLOSS 2019 – cf. www.ices.dk) in support of the implementation of Marine Strategy Framework Directive Good Environmental Status Descriptors D1 (biodiversity) and D6 (seafloor integrity). Equally, OSPAR has considered the same GES descriptors and produced advice on appropriate indicators (BH2 and BH3)(OSPAR 2017, 2018).

We carried out a preliminary assessment of the potential risk of impact on vulnerable marine ecosystems (VME) and deep-sea fish habitat posed by fishing in each ATLAS case study to provide baseline environmental information for use in the analysis of (e.g. environmental and industrial) constraints prior to zonation of future Blue Growth activities.

In order to quantify the degree of overlap between fishing effort and predicted VME/deep-sea fish habitat distributions, we carried out a risk analysis based on the Ecological Risk Assessment for Effects of Fishing (ERAEF) developed by Hobday *et al.* (2011). The ERAEF is primarily an exposure-effect analysis suited to assessing ongoing pressures like fishing, as opposed to the likelihood-consequence approach to estimating risk used in many ecological risk assessments (Williams *et al.* 2011). The ERAEF is increasingly being used to quantify the risk of different fishery impacts on the environment, including impacts on the benthos (Clark and Tittensor 2010; Williams *et al.* 2011; Penney and Guinotte 2013).

The ERAEF is a hierarchical framework consisting of three levels, each of increasing complexity. The analysis in each level serves to screen out low-risk impacts, allowing the higher-risk impacts to be evaluated at the next level. The first level is a qualitative assessment of all potential fishery-environment interactions, termed Scale, Intensity and Consequence Analysis (SICA). The second level is a semi-quantitative Productivity/Susceptibility Analysis (PSA). Finally, the third level is a fully quantitative model-based risk assessment (Hobday *et al.* 2011).

2.2. Methodology

Our risk analysis methodology follows Penney and Guinotte (2013) and is based on the second level PSA of the ERAEF. It consists of comparing the likelihood of VME/deep-sea fish habitat occurrence and the likelihood of fishery interaction. As a measurement of the likelihood of VME/deep-sea fish habitat occurrence we utilised the outputs of Ecological Niche Models (ENM) developed for six VME indicator taxa (*Lophelia pertusa, Madrepora oculata, Desmophyllum, Acanella arbuscula, Acanthogorgia armata,* and *Paragorgia arborea*) and six deep-sea fish indicator species (*Coryphaenoides rupestris*, *Gadus morhua*, *Helicolenus dactylopterus*, *Hippoglossoides platessoides*, *Reinhardtius hippoglossoides*, and *Sebastes mentella*). For developing absence/presence maps from each ENM, we selected thresholds that maximized the sum of sensitivity and specificity (i.e. thresholds that minimised omission and commission errors (Liu *et al.* 2016) and used these to transform the output of ENMs into a binary outputs (Liu *et al.* 2005; Elith *et al.* 2006), with predicted suitability indices below and above this threshold classified as absent and present, respectively. The PSA utilises a number of indicators to generate an integrated measure of productivity (Hobday *et al.* 2011). An ENM is analogous to the PSA because it provides an integrated measurement of the likelihood of favourable habitat (Penney and Guinotte 2013).

The PSA also requires a measurement of the likelihood of fisheries interaction. We used swept area ratio (SAR) estimates as a measure of fishing intensity. The rationale for this is that, for benthic organisms, the likelihood of impacts increases with fishing intensity. Risk evaluation was based on classifying the fishing intensity SAR values into four levels, with values indicating the number of times the grid cell is swept per year: low (>0–0.1), medium (0.1–0.2), high (0.2–2) and very high (>2). We selected these values based on what is known about the lifespans of other VME indicator species for which data on longevity is available. For example, the threshold between low and intermediate fishing intensity was based on the maximum life span of sea pens which is estimated to be 10 years. A cell with an SAR value of 0.1 would be totally covered by trawling within 10 years.

To calculate SAR, the total area swept in a cell is divided by the area of that cell. In this assessment, all bottom contacting gears were considered equally damaging to VME/deep-sea fish habitat, and so SAR values were calculated based on the sum of surface and subsurface abrasion values reported in spatial data layers of fishing intensity/pressure produced by ICES using VMS and logbook data (ICES WGSFD 2016) for all gears used in the OSPAR area. ICES cautions that these datasets are not entirely comprehensive as there were a number of countries which did not submit data (Spain, Greenland and Russia) or who submitted data in an unsuitable format (Iceland and Faroe Islands), and this means that ICES' maps of surface abrasion are incomplete for any areas where vessels from these countries operate. Also, many countries have fleets that are largely comprised of smaller vessels that are not equipped with VMS (boat length < 12 m) or logbooks (boat length <10 m for the EU fleet in the OSPAR area), and this too may result in an underestimation of SAR (however these smaller vessels are mainly confined to coastal, nearshore waters).

Assuming it to be the best data available, ICES measures of SAR were used for this risk assessment wherever possible, however, where these data were not available, Global Fishing Watch (GFW) fishing effort data were instead used as proxies for SAR. Because GFW data only provide a measure of fishing effort in "fishing hours", a Random Forest (RF) classification model was developed to assign risk scores to areas which are not covered by the ICES SAR dataset. To develop this model, risk scores were assigned to all 0.05° x 0.05 c-squares for which ICES SAR data were available, and a dataset comparing these risk scores to the fishing effort, as reported by GFW, within the same c-squares was prepared. This dataset was then split in two, with 70% of the data used to train the RF model, and the remaining 30% of the data used to test the model's performance. To train the RF model, not only was the fishing activity in a given cell considered, so too was fishing activity in adjacent cells – the maximum, minimum, mean, and standard deviation of adjacent values were all used as inputs into the RF model. The RF model performed well, predicting the correct risk scores (i.e. those based on SAR) for the test set with 69% accuracy (Figure 43). The model underestimated risk by one class (i.e. predicted high instead of very high or low instead of medium etc.) in 12.2% of the test predictions, and it underestimated by more than 1 class in only 5.2% of cases (Table 18).

Table 18. Global Fishing Watch Random Forest Model performance on test data set.

	Number of records	Percentage of records	Cumulative percentage
Accurate Predictions	3148	69.2%	69.2%
Overestimate by 1 class	521	11.5%	80.7%
Overestimate by 2 classes	87	1.9%	82.6%
Overestimate by 3 classes	3	0.1%	82.7%
Underestimate by 1 class	553	12.2%	94.8%
Underestimate by 2 classes	230	5.1%	99.9%
Underestimate by 3 classes	6	0.1%	100.0%
∑:	**4548**	**100.0%**	

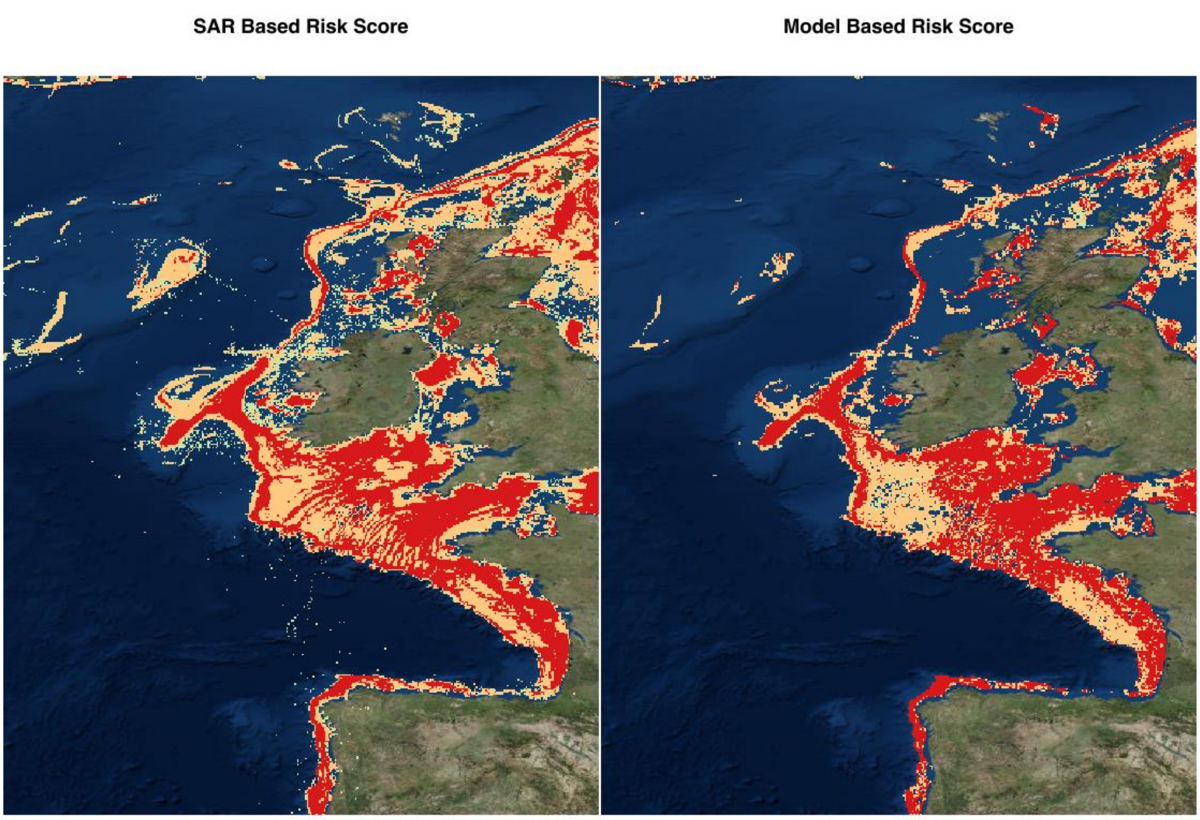


Figure 43. A comparison of the risk scores generated using i) swept area ratio (SAR) and ii) using Global Fishing Watch data modelled using Random Forest

Whether GFW or ICES data were used, the data were averaged across a 5 year period (2012-2016) to allow for and capture interannual variability in the spatial distributions of fishing activities. ICES data were only available at a resolution of 0.05° x 0.05° c-squares, so in order to apply a consistent risk assessment methodology in all areas, GFW data, where used, was aggregated to the same resolution.

2.3. Results/Discussion

Twelve model outputs were produced, one for each coral/deep-sea fish habitat using predicted presence/absence, for each case study (Figs. 44 to 56 below). Overall fishing risk is assigned one of 4 categories: (1) low, (2) medium, (3) high, (4) very high (Table 19). In addition, composite risk analyses were produced taking account of (1) all predicted VME (based on predicted presence of all 6 VME indicator taxa whose distributions were modelled), (2) all predicted deep-sea fish habitat (based on predicted presence of 6 deep-sea fish species whose distributions were modelled), and (3) the risk to all of these VME and deep-sea fish habitats considered collectively.

In Case Study 1, the LoVe Observatory, almost all predicted VME/fish habitat present within the bounds of the case study was found to be impacted to some degree by fishing. The deep-sea fish *Sebastes mentella* was the most severely impacted, with fishing activity posing a very high risk to 36.4% of predicted suitable habitat for this species, and a further 58.6% of this suitable area estimated to be at high risk of being impacted by fishing activity. It is important to note, however, that *Sebastes mentella* habitat covers only a relatively small portion of the case study area (~6% total coverage). Over 95% of the case study area is predicted to be suitable habitat for *Acanella arbuscula*, with almost 60% of this habitat assessed to be at high risk of being impacted by fishing, and a further 15.6% at very high risk. The outputs of the basin-scale habitat suitability models (HSMs) do not indicate any presence of *Lophelia pertusa*, *Madrepora oculata*, *Desmophyllum dianthus*, or *Helicolenus dactylopterus* within the bounds of Case Study 1. A chart summarising the results of the risk assessment for Case Study 1 has been included as Figure A3.1 of Appendix 3.

In Case Study 2, the Faroe-Shetland Channel, all predicted VME/fish habitats present within the bounds of the case study were impacted by fishing to some degree, with the exception of *Sebastes* *mentella* habitat, which was not assessed to be currently at risk; only a very small area (8km2) of *Sebastes mentella* habitat was predicted to be present in the Faroe-Shetland Channel, however, with only ~0.15% of the case study area predicted to be suitable for the species. Almost the entirety of the case study area (>98%) was predicted to be suitable habitat for *Lophelia pertusa*, and all of the case study area was predicted to be suitable for *Coryphaenoides rupestris*. Fishing posed a high risk to slightly over half of the case study area, with a further 21-22% found to be moderately at risk; less than 25% of the case study is at little to no risk due to fishing activities. The outputs of the basin-scale HSMs do not indicate any presence of *Madrepora oculata*, or *Desmophyllum dianthus* within the bounds of Case Study 2. A chart summarising the results of the risk assessment for Case Study 2 has been included as Figure A3.2 of Appendix 3.

In Case Study 3, the Rockall Bank, all predicted VME/fish habitats present within the bounds of the case study were impacted by fishing to some degree. The entirety of the case study area is predicted to be suitable for *Lophelia pertusa*, and a large portion of this area (approx. 43%) is at high risk of being impacted by fishing activity. There is also, however, a similarly sized area of predicted *Lophelia* habitat which is either not currently at risk from fishing activity, or is at low risk of being impacted by fishing activity (28% and 13% respectively). Fishing activity poses similar levels of risks to *Madrepora oculata* and Helicolenus *dactylopterus* habitats, as these are also predicted to be present across the majority of the case study area, with 95% and 92% coverage respectively. There is marked difference in average depths in areas which have a high or very high risk of being impacted by fishing, and areas of medium, low, and negligible risk of negative impacts. On average, areas of habitat in Case Study 3 which have a very high risk of being impacted by fishing are found at depths of less than 200m, and habitat areas which have a high risk of being impacted are at depths of less than 300m. In contrast, areas of habitat to which fishing poses a medium, low, or negligible risk are found at average depths of about 450-700m. The outputs of the basin-scale HSMs do not indicate any presence of *Reinhardtius* *hippoglossoides*, or *Sebastes mentella* within the bounds of Case Study 3. A chart summarising the results of the risk assessment for Case Study 3 has been included as Figure A3.3 of Appendix 3.

Lophelia pertusa was the only VME whose presence was predicted in Case Study 4, the Mingulay Reef; this is likely a consequence of the relatively shallow depth of the reef (approx. 100-200m), as well as the broad-scale nature of the HSMs on which this assessment depends, compared to the case study's small size relative to the other case studies. Similarly, only three species of deep-sea fish were predicted to have suitable habitat within the bounds of Case Study 4: *Gadus morhua*, *Helicolenus dactylopterus*, and *Hippoglossoides platessoides*. More than half the extents of all four of these habitats were found to be at high risk from fishing activities, with only very small portions (5-15%) of each habitat subject to low or negligible risk. A chart summarising the results of the risk assessment for Case Study 4 hs been included as Figure A3.4 of Appendix 3.

In Case Study 5, the Porcupine Seabight, there is a very strong correlation between depth and the level of risk to VME/fish habitat posed by fishing activity. The average depth in areas where fishing was found to pose a very high risk to VME/fish habitat is approximately 360m, while in contrast, the average depth in areas where fishing was found to pose no risk to VME/fish habitat is approximately 2900m; areas of low, medium and high risk were found to be at intermediate average depths of between 1100-1900m. The fishing data used to calculate risks to VME and fish habitat were from the period 2012-2016, and these patterns may now be even more pronounced following the European Parliament's adoption of a ban bottom trawling below 800m at the end of 2016. According to the basin-scale HSMs, *Desmophyllum dianthus* is the most widespread VME in Case Study 5, with 40% of the case study area predicted to provide suitable habitat for the taxa. There is roughly a 50:50 split between the extent of the area where fishing poses a medium or high to very high risk to *Desmophyllum dianthus* habitat, and areas with little to no risk to the species. A chart summarising the results of the risk assessment for Case Study 5 has been included as Figure A3.5 of Appendix 3.

In Case Study 6, the Bay of Biscay, there is also a very strong correlation between depth and the level of risk to VME/fish habitat posed by fishing activity. The average depth in areas where fishing was found to pose a very high risk to VME/fish habitat was observed to be approximately 250m, while in contrast, the average depth in areas where fishing was found to pose no risk to VME/fish habitat is approximately 3400m; areas of low, medium and high risk were found to be at average depths of between 1400-2900m. According to the basin-scale HSMs, *Acanella arbuscula* is the most widespread VME in Case Study 6, with 75% of the case study area predicted to provide suitable habitat for this particular taxa. Fishing was found to pose little to no risk to approximately one third of predicted *Acanella arbuscula* habitat in Case Study 6, while the majority was at moderate risk (39%), high risk (24%), or very high risk (3%). Of the deep-sea fish species whose distributions were modelled, fish habitat was found to be relatively poorly represented within the bounds of Case Study 6. *Helicolenus dactylopterus* is the most widely distributed of these species, predicted to occur in 36% of the case study area, though the majority of this habitat is at high (37%) or very high (40%) risk due to fishing activity. The outputs of the basin-scale HSMs do not indicate any presence of *Hippoglossoides platessoides, Reinhardtius hippoglossoides*, or *Sebastes mentella* within the bounds of Case Study 6. A chart summarising the results of the risk assessment for Case Study 6 has been included as Figure A3.6 of Appendix 3.

Of the deep-sea fish species distributions modelled, *Helicolenus dactylopterus* was the only species whose presence was predicted in Case Study 7, encompassing the northern portion of the Strait of Gibraltar as well as adjacent portions of the Gulf of Cádiz and the Alborán Sea. Also, only three VME taxa were predicted to be present within the bounds of Case Study 7: *Lophelia pertusa, Madrepora oculata,* and *Desmophyllum dianthus.* As in many of the other case studies, there was a notable correlation between depth and the risk caused by fishing activity; areas where fishing posed a very high risk were at an average depth of 330m, whereas the average depth for all other risk categories -

high risk to no risk - was 2-3 times greater (approximately 660-1000m). *Desmophyllum dianthus* is predicted by the HSMs to be the most widely distributed of the VME/deep-sea fish species habitats in Case Study 7, and much of this habitat is at moderate (26%), high (24%), or very high risk (16%) due to fishing. A chart summarising the results of the risk assessment for Case Study 7 has been included as Figure A3.7 of Appendix 3.

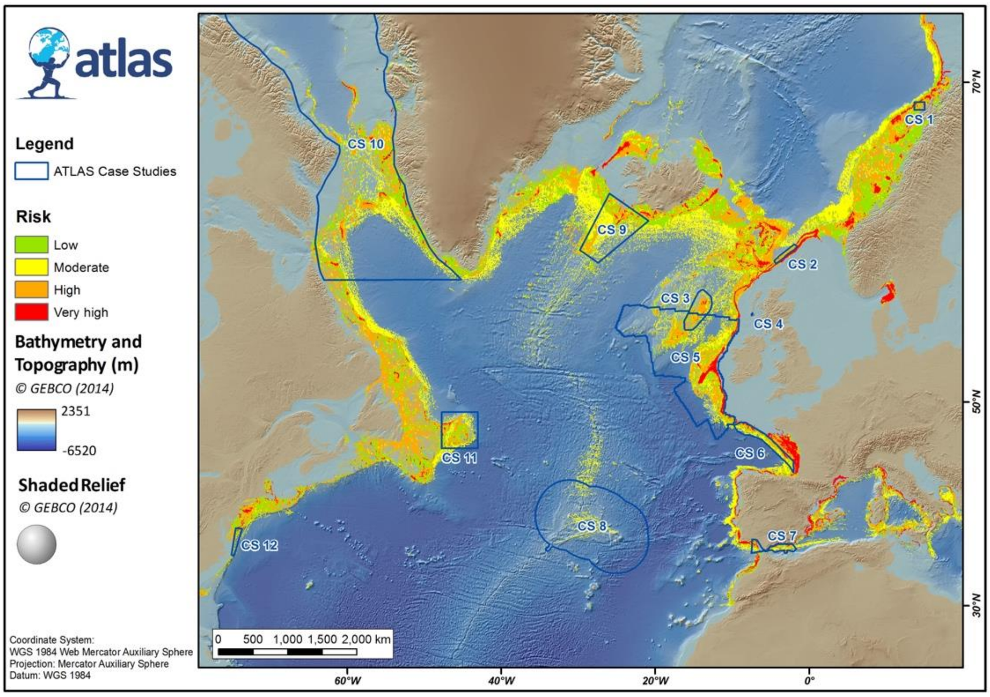
Case Study 8, the Azores, is strikingly different to all other case studies in that, for each of VME/deep-sea fish species habitat predicted to occur there, there was found to be no risk to the majority of their extents. Also unusual, was that there are no portions of these VME/deep-sea fish species habitats which are at low risk from fishing, yet there are 15-25% of all habitats were found to be at moderate risk. The outputs of the basin-scale HSMs do not indicate any presence of *Paragorgia arborea*, *Gadus morhua*, *Hippoglossoides platessoides*, *Reinhardtius hippoglossoides*, or *Sebastes mentella* within the bounds of Case Study 8. A chart summarising the results of the risk assessment for Case Study 8 has been included as Figure A3.8 of Appendix 3.

Case study 9, the Reykjanes Ridge, is the only case study predicted to have areas of suitable habitat for all 6 VME taxa and all 6 deep-sea fish for which HSMs were developed, however the area of *Reinhardtius hippoglossoides* habitat predicted to occur in the case study is very small (128km^2). *Lophelia pertusa* is the most widely distributed of the VME/deep-sea fish species habitats predicted to occur in Case Study 9, with 78% of the case study area predicted to be suitable for the species. The majority of the predicted distribution of *Lophelia pertusa* habitat in Case Study 9 was found to be at moderate (37%), high (19%), or very high (2%) risk from negative impacts associated with fishing activity, with just 24% found to not currently be at risk of impact. As was the case in many other case study areas, a correlation between depth and the risk caused by fish activity was observed; areas where fishing was found to pose a very high risk to VME/fish habitat were, on average, at a depth of approximately 370m, while the average depth for areas where there is no current risk was 1350m. A chart summarising the results of the risk assessment for Case Study 9 has been included as Figure A3.9 of Appendix 3.

Reinhardtius hippoglossoides is the most widely distributed of the VME/deep-sea fish species habitats predicted to occur in the Davis Strait/Baffin Bay, Case Study 10, with 32% of the case study area predicted to be suitable for the species. The majority of the predicted distribution of *Reinhardtius hippoglossoides* in Case Study 10 was found to be at low risk (46%) to no risk (20%) risk from negative impacts associated with fishing activity, however approximately 25% of the species' habitat was at high risk of being impacted. None of the *Lophelia pertusa* predicted to occur in Case Study 10 was currently at risk from fishing, however the areal extent of this habitat was negligible. *Acanella arbuscula* was predicted to be the most abundant of the modelled VME taxa in Case Study 10, covering 26% of the case study area; more than half of this was found to be at low (14%), moderate (23%), high (17%), or very high (1.5%) risk from negative impacts associated with fishing activity. Areas where fishing was found to pose either a high or a very high risk to VME/fish habitat were at an average depth of 420-425m, while the average depth for areas where there is no current risk was 1550m. The outputs of the basin-scale HSMs do not indicate any presence of *Helicolenus dactylopterus* within the bounds of Case Study 10. A chart summarising the results of the risk assessment for Case Study 10 has been included as Figure A3.10 of Appendix 3.

Acanella arbuscula is the most widely distributed of the VME/deep-sea fish species habitats predicted to occur in the Flemish Cap, Case Study 11, with 76% of the case study area predicted to be suitable for the species. The majority of the predicted distribution of *Acanella arbuscula* in Case Study 11 was found to be risk due to fishing activity, with 22% at low risk, 23.5% moderately at risk, 28.5% highly at risk, and 2.3% very highly at risk. *Reinhardtius hippoglossoides* is predicted to occur in 58% of the case study area and its habitat shares a similar risk profile to *Acanella arbuscula's*, with only 11% of its distribution not currently experiencing some degree of risk from fishing. The outputs of the basin-scale HSMs do not indicate any presence of *Lophelia pertusa* or *Madrepora oculata* within the bounds of Case Study 11. Fishing poses a greater risk to VME/fish habitat in shallower areas of the case study with areas that have very high risk found at an average depth of 515m, while the average depth for areas where there is no current risk was almost five times that, at 2540m. A chart summarising the results of the risk assessment for Case Study 11 has been included as Figure A3.11 of Appendix 3.

Madrepora oculata is the most widely distributed of the VME/deep-sea fish species habitats predicted to occur in the Mid-Atlantic Canyons of Case Study 12, with 88% of the case study area predicted to be suitable for the species. The majority of *Madrepora oculata's* distribution in Case Study 12 is exposed to some degree of risk from fishing activity, with 27% at low risk, 10% moderately at risk, 24% highly at risk, and 2.7% very highly at risk. While all 6 VME taxa modelled are predicted to occur in Case Study 12, *Helicolenus dactylopterus* is the only one of the deep-sea fish whose habitat is predicted to occur within the bounds of the case study, where it is found in 52% of the case study. Only 16% of habitat predicted to be suitable for *Helicolenus dactylopterus* is not at risk due to fishing, with 40% at low risk, 7% moderately at risk, 33% highly at risk, and 4% very highly at risk. The correlation between the risk posed by fishing and depth is more pronounced in Case Study 12 than in any of the other case studies. Areas where fishing poses a very high risk to VME/fish habitat are found at an average depth of 91m, while the average depth for areas where there is no current risk was more than 15 times that, at 1370m. The outputs of the basin-scale HSMs do not indicate any presence of *Coryphaenoides rupestris*, *Gadus morhua*, *Hippoglossoides platessoides*, *Reinhardtius hippoglossoides*, or *Sebastes mentella* within the bounds of Case Study 12. A chart summarising the results of the risk assessment for Case Study 12 has included as Figure A3.12 of Appendix 3.



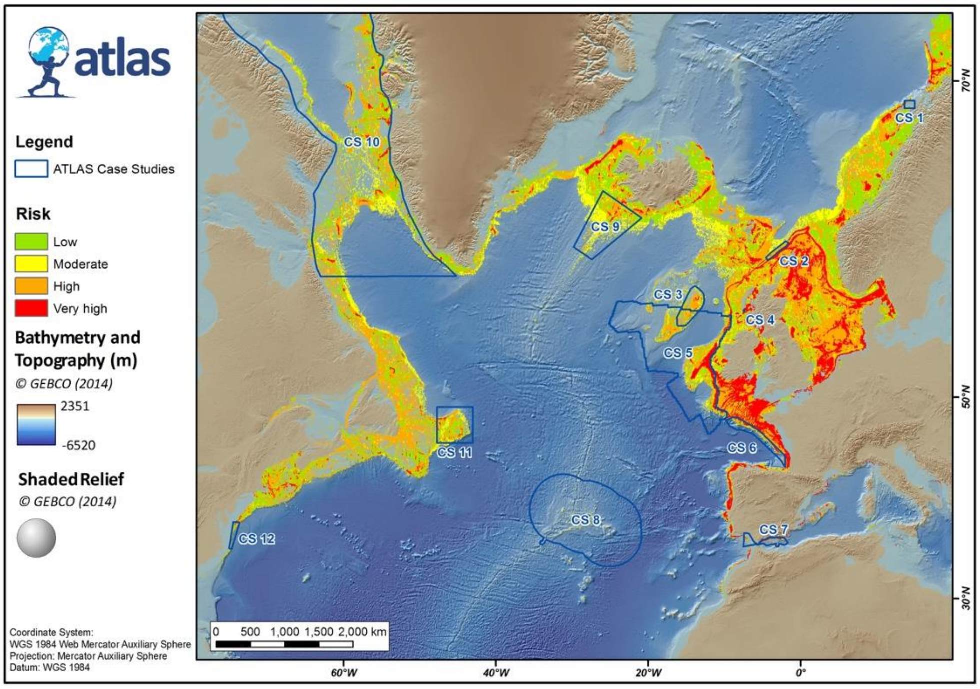


Figure 44. Assessment of risk posed to VME and fish habitat (using the predicted distribution of 6 VME indicator species (A) and 6 deep-sea fish (B) as proxies) from pressures due to fishing activity across the North Atlantic Basin

Table 19. Percentage of each risk category per total area in each case study.

Case Study	Location	Total Area (km^2)	Risk Score				
			% Not currently at risk	% low	% medium	% high	% very high
1	Lofoten-Vesteralen (LoVe)	2175	16.44%	19.59%	5.03%	48.34%	10.60%
2	Faroe Shetland Channel	5279	2.24%	22.44%	21.80%	50.80%	2.72%
3	Rockall Bank	38859	28.22%	12.45%	13.81%	42.68%	2.84%
4	Mingulay Reef Complex	115	0.74%	25.59%	29.42%	40.58%	3.67%
5	Porcupine Seabight and Bank	595278	56.80%	8.88%	12.99%	16.31%	5.01%
6	Bay of Biscay	53031	10.22%	19.90%	30.14%	25.47%	14.26%
7	Cádiz/Gibraltar/Alborán Sea	38301	31.39%	15.24%	22.05%	16.58%	14.75%
8	Azores	958036	95.89%	0.01%	3.99%	0.11%	0.00%
9	Reykjanes Ridge	99648	26.42%	16.41%	35.31%	20.39%	1.47%
10	Davis Strait and Baffin Bay	1124613	74.11%	7.79%	7.36%	10.00%	0.74%
11	Flemish Cap	124859	37.13%	18.68%	18.28%	23.67%	2.25%
12	South-Eastern U.S.	16556	40.96%	24.60%	9.95%	22.20%	2.29%

2.3.1. Case Study VME Fishing Impact Risk Assessment Atlas

2.3.1.1. Lofoten-Vesteralen (LoVe) VME Fishing Impact Risk Assessment

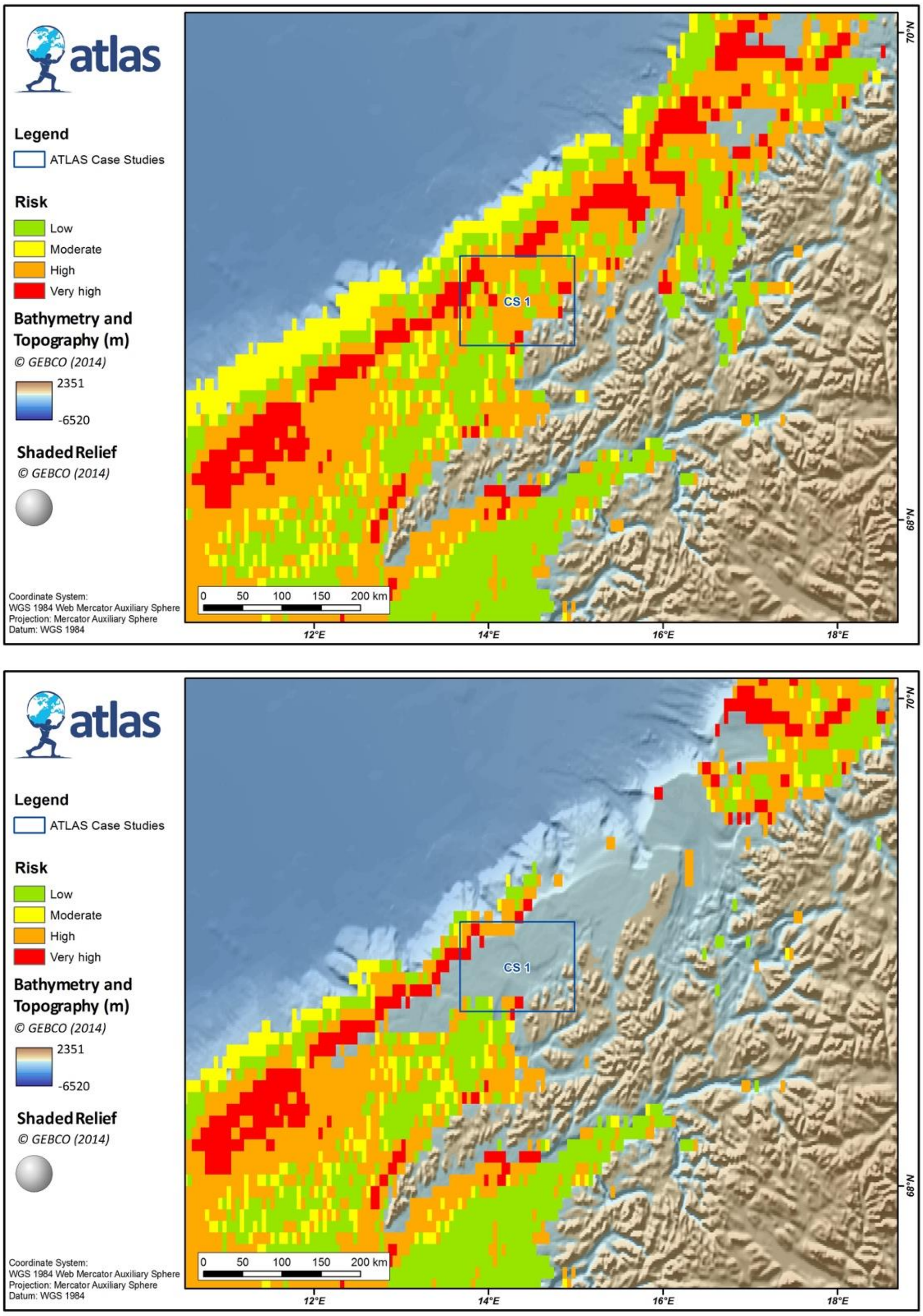
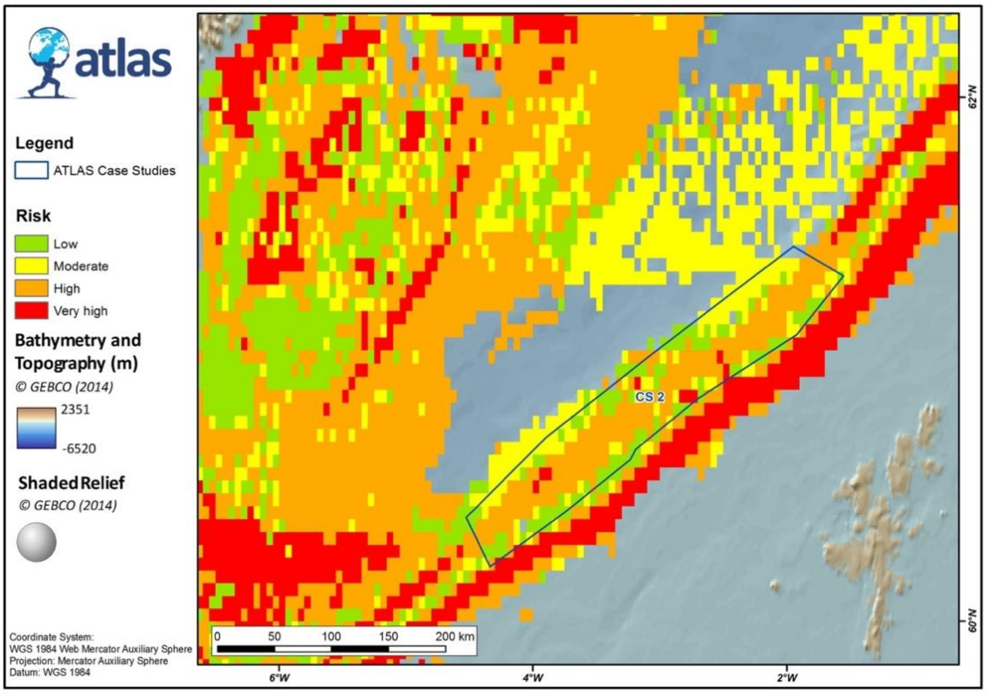


Figure 45. Assessment of risk posed to VME and fish habitat (using the predicted distribution of 6 VME indicator species (A) and 6 deep-sea fish (B) as proxies) from pressures due to fishing activity across the Lofoten-Vesteralen

2.3.1.2. Faroe Shetland Channel VME Fishing Impact Risk Assessment



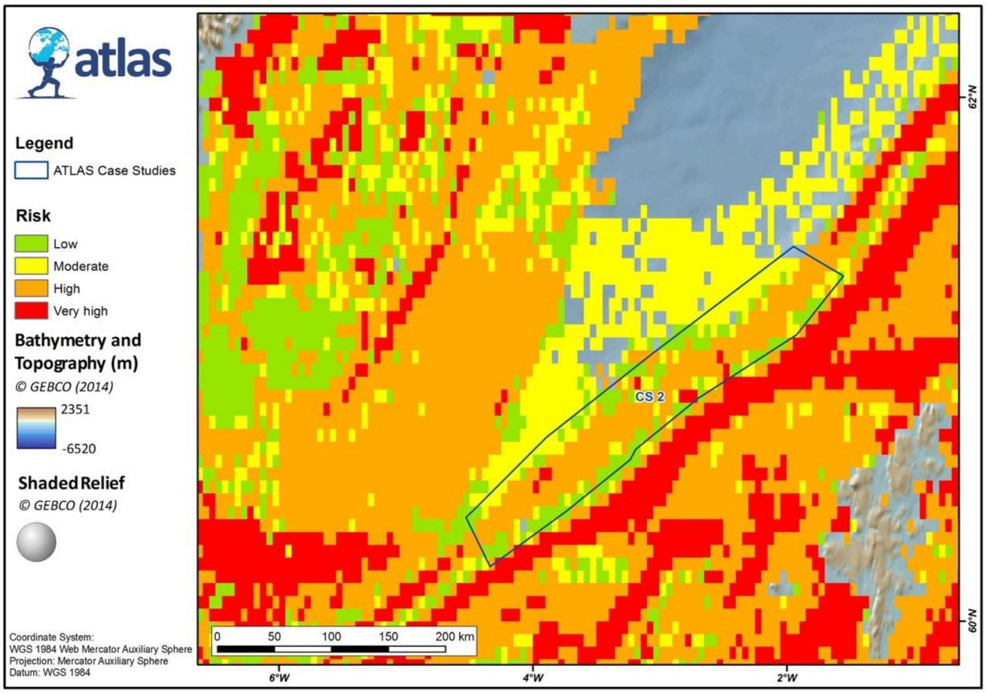
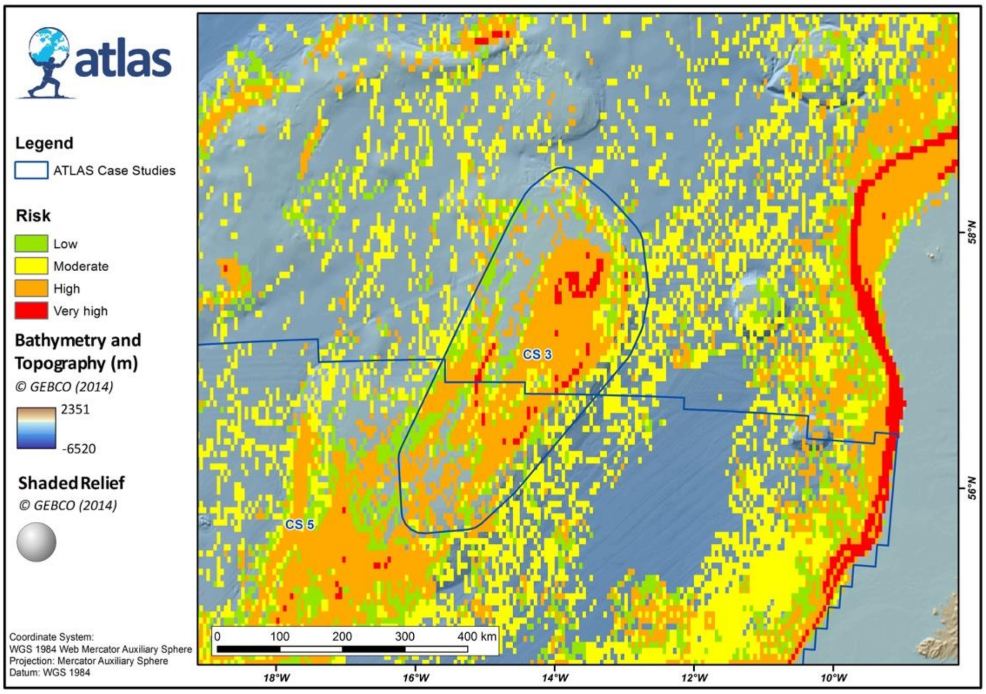


Figure 46. Assessment of risk posed to VME and fish habitat (using the predicted distribution of 6 VME indicator species (A) and 6 deep-sea fish (B) as proxies) from pressures due to fishing activity across the Faroe Shetland Channel

2.3.1.3. Rockall Bank VME Fishing Impact Risk Assessment



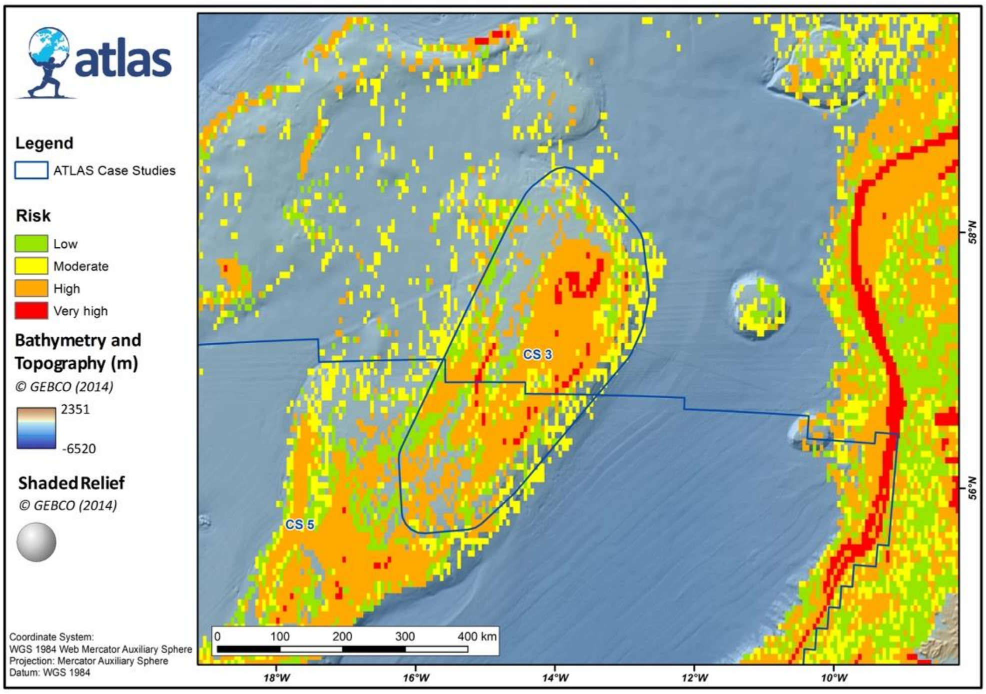
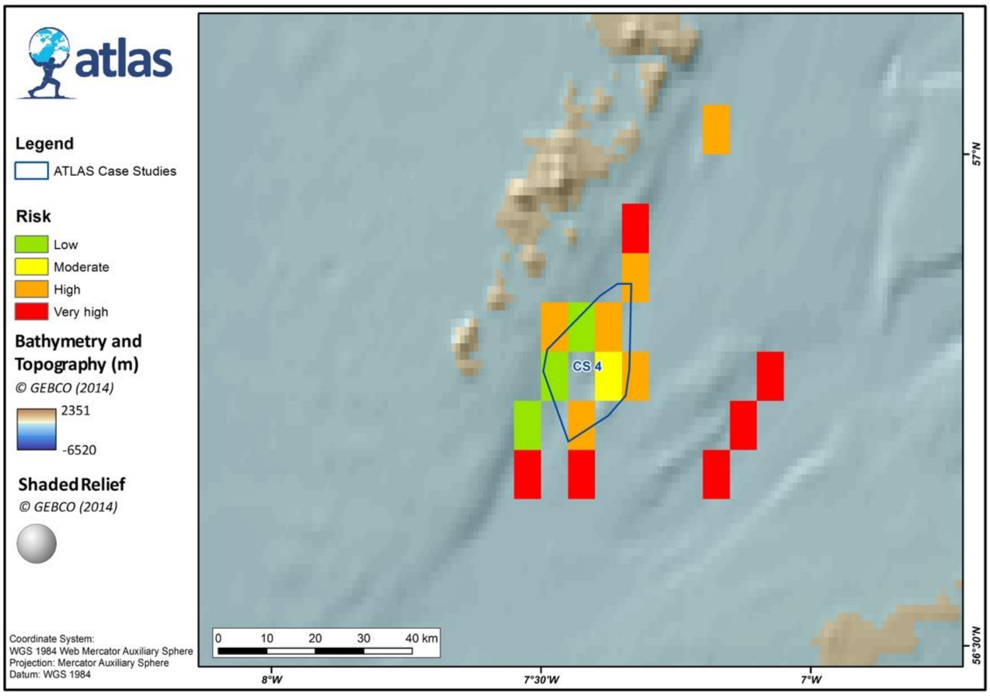


Figure 47. Assessment of risk posed to VME and fish habitat (using the predicted distribution of 6 VME indicator species (A) and 6 deep-sea fish (B) as proxies) from pressures due to fishing activity across the Rockall Bank

2.3.1.4. Mingulay Reef Complex VME Fishing Impact Risk Assessment



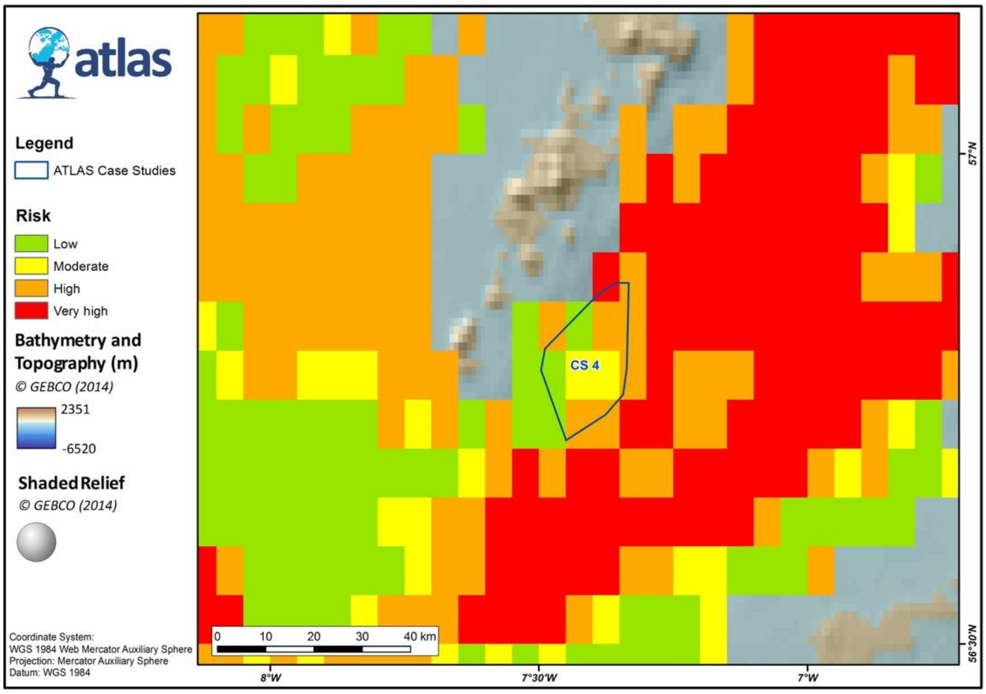
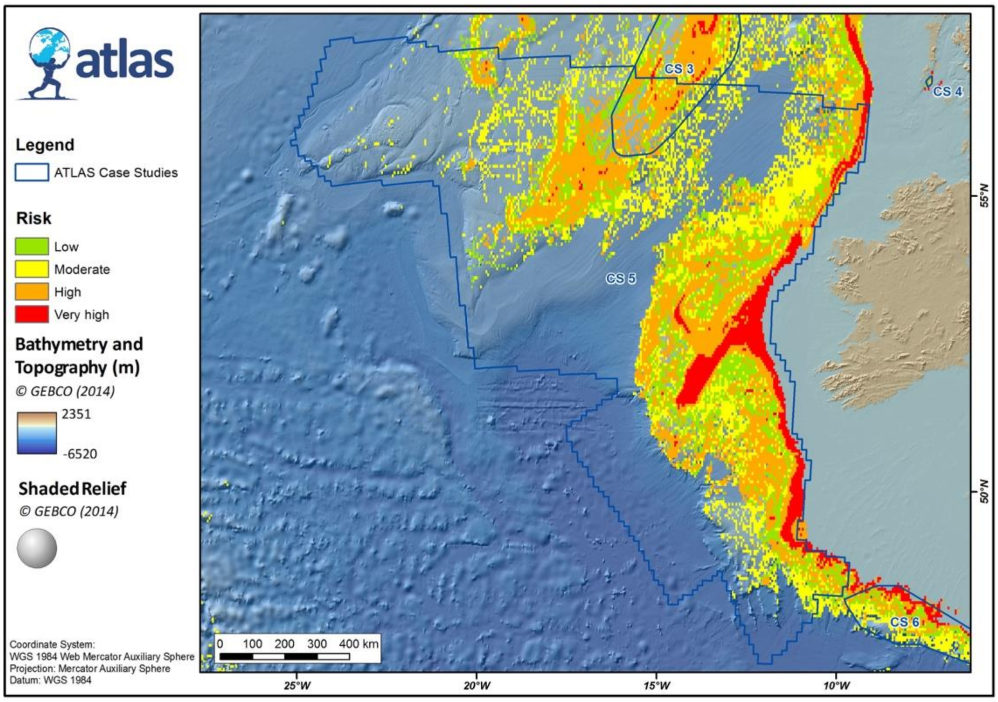


Figure 48. Assessment of risk posed to VME and fish habitat (using the predicted distribution of 6 VME indicator species (A) and 6 deep-sea fish (B) as proxies) from pressures due to fishing activity across the Mingulay Reef

2.3.1.5. Porcupine Seabight and Bank VME Fishing Impact Risk Assessment



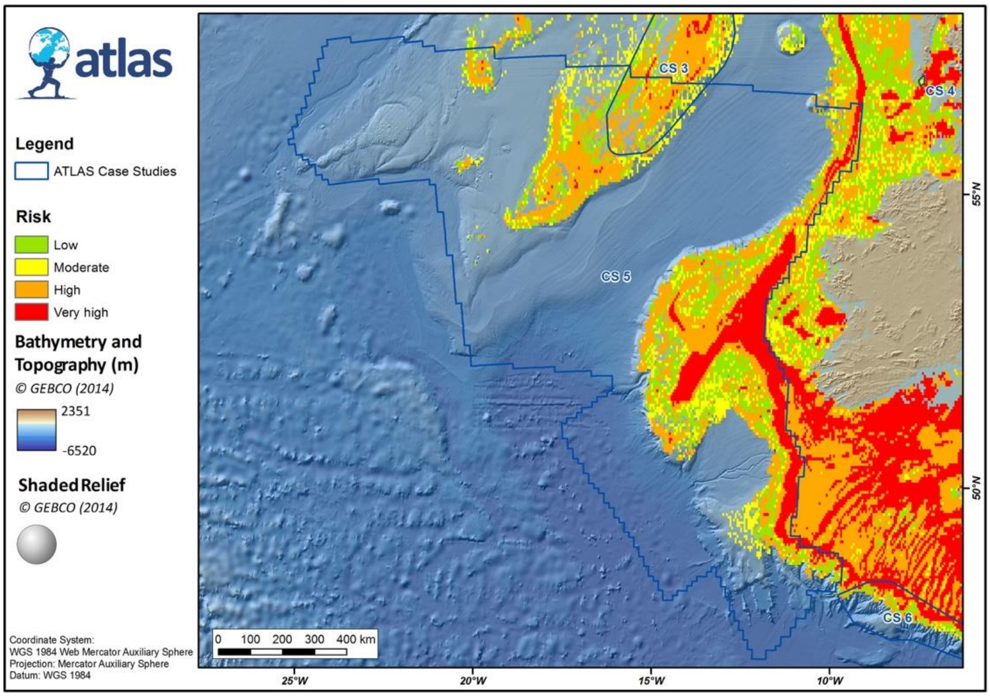
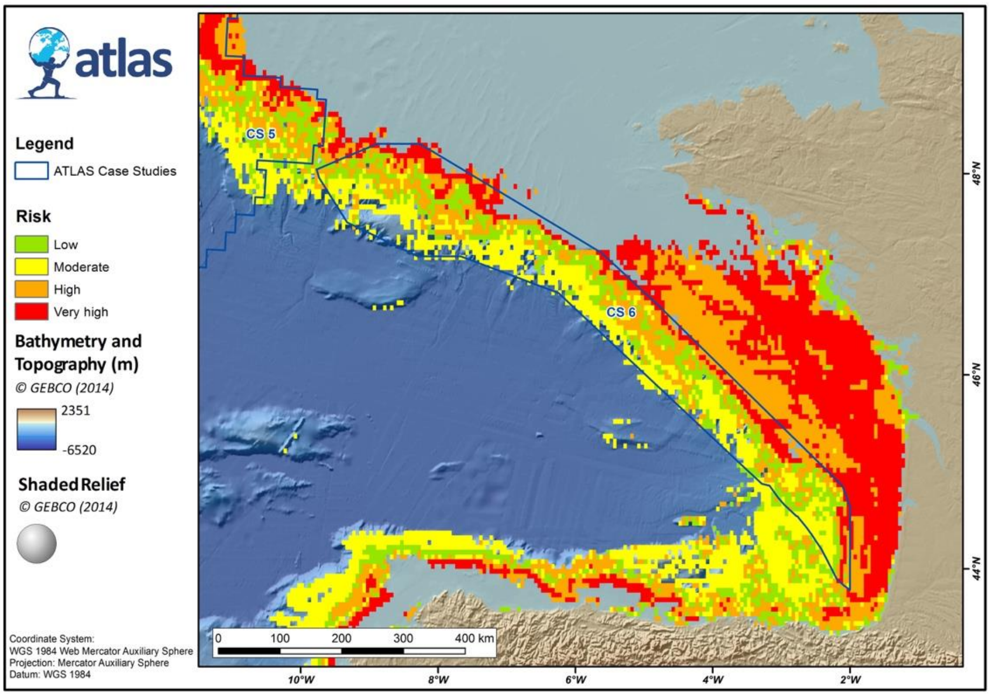


Figure 49. Assessment of risk posed to VME and fish habitat (using the predicted distribution of 6 VME indicator species (A) and 6 deep-sea fish (B) as proxies) from pressures due to fishing activity across the Porcupine Seabight and Bank

2.3.1.6. Bay of Biscay VME Fishing Impact Risk Assessment



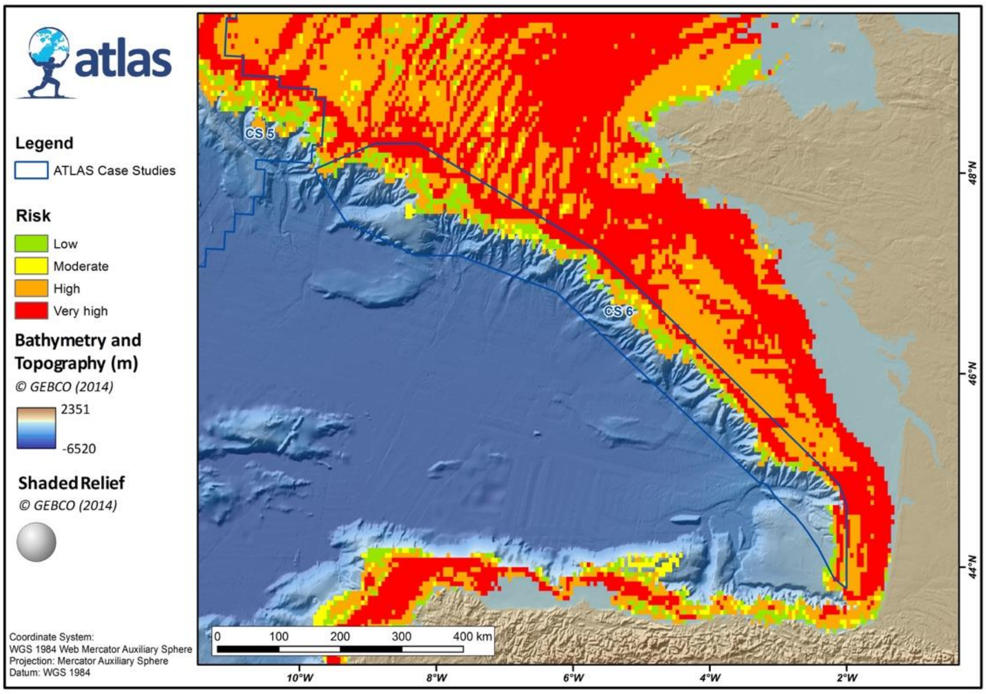


Figure 50. Assessment of risk posed to VME and fish habitat (using the predicted distribution of 6 VME indicator species (A) and 6 deep-sea fish (B) as proxies) from pressures due to fishing activity across the Bay of Biscay

2.3.1.7. Gulf of Cádiz/Strait of Gibraltar/Alborán Sea VME Fishing Impact Risk Assessment

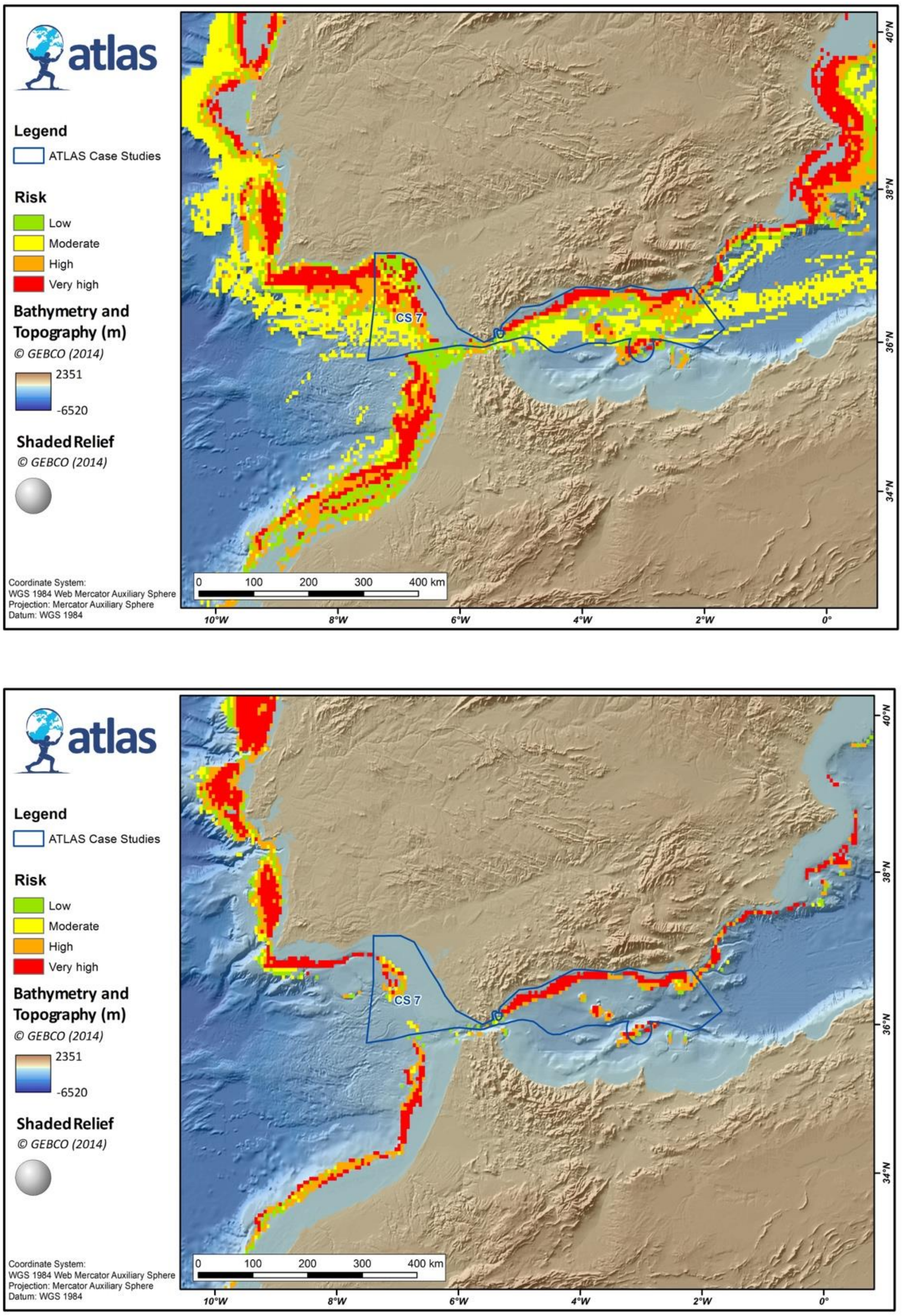
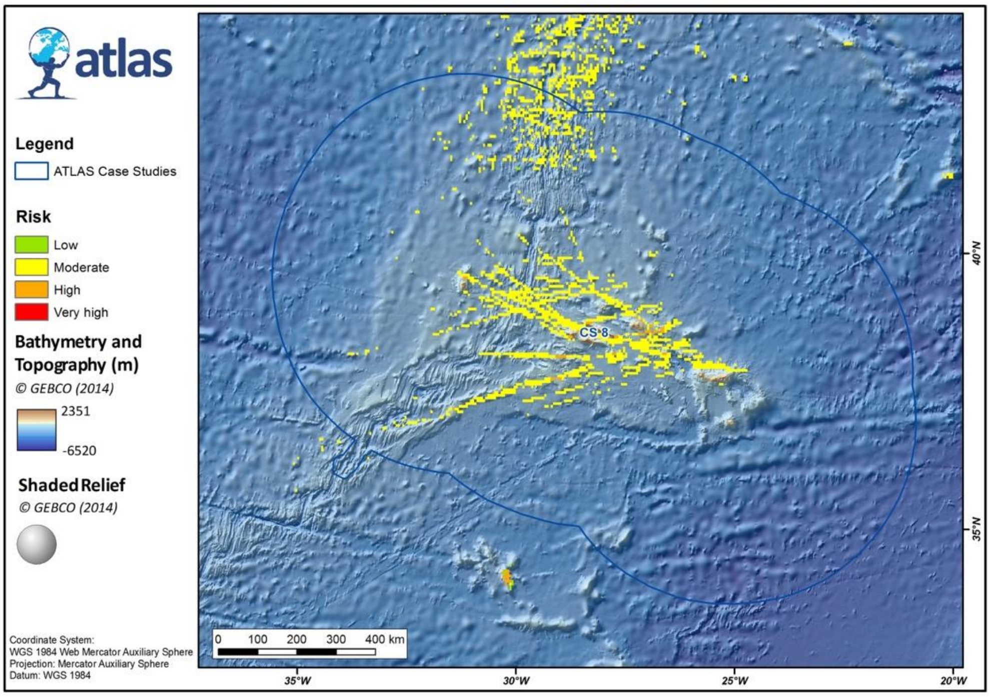


Figure 51. Assessment of risk posed to VME and fish habitat (using the predicted distribution of 6 VME indicator species (A) and 6 deep-sea fish (B) as proxies) from pressures due to fishing activity across the Gulf of Cádiz/Strait of Gibraltar/Alborán Sea

2.3.1.8. Azores VME Fishing Impact Risk Assessment



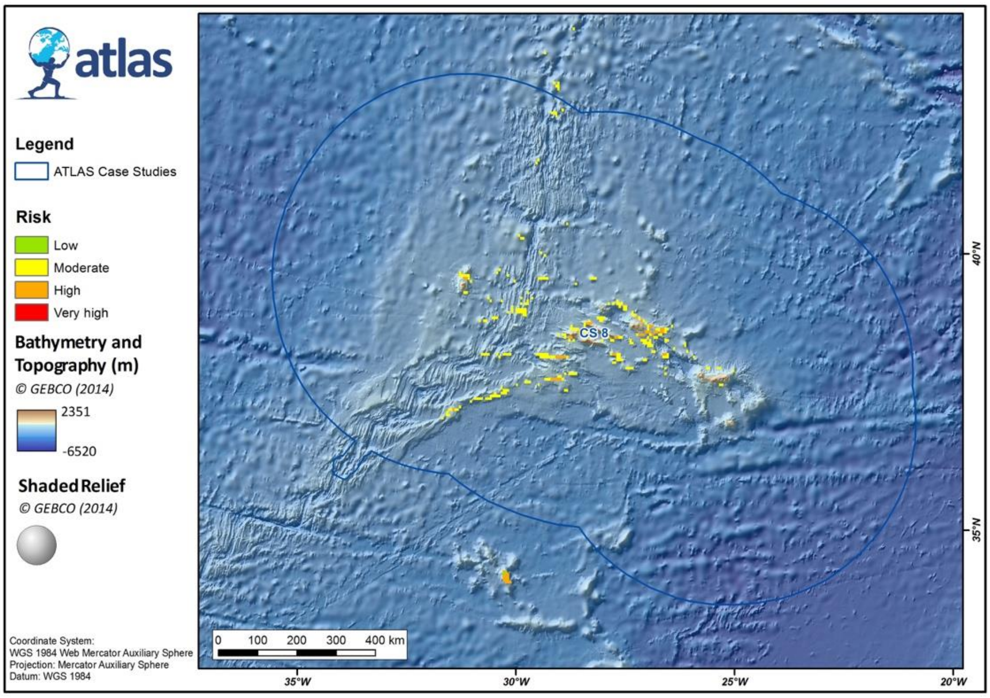
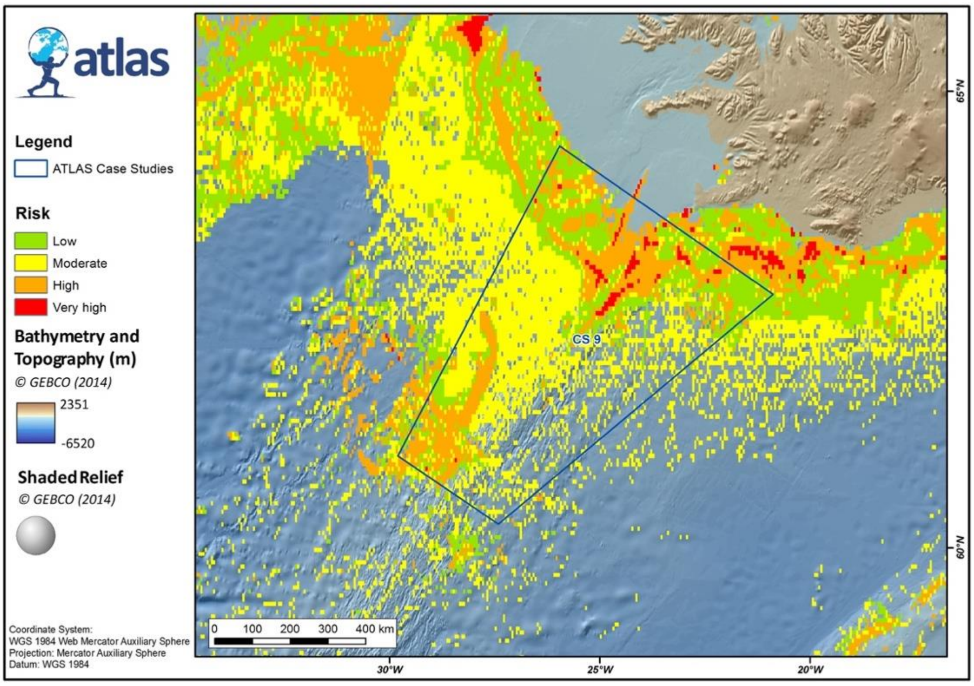


Figure 52. Assessment of risk posed to VME and fish habitat (using the predicted distribution of 6 VME indicator species (A) and 6 deep-sea fish (B) as proxies) from pressures due to fishing activity across the Azores

2.3.1.9. Reykjanes Ridge VME Fishing Impact Risk Assessment



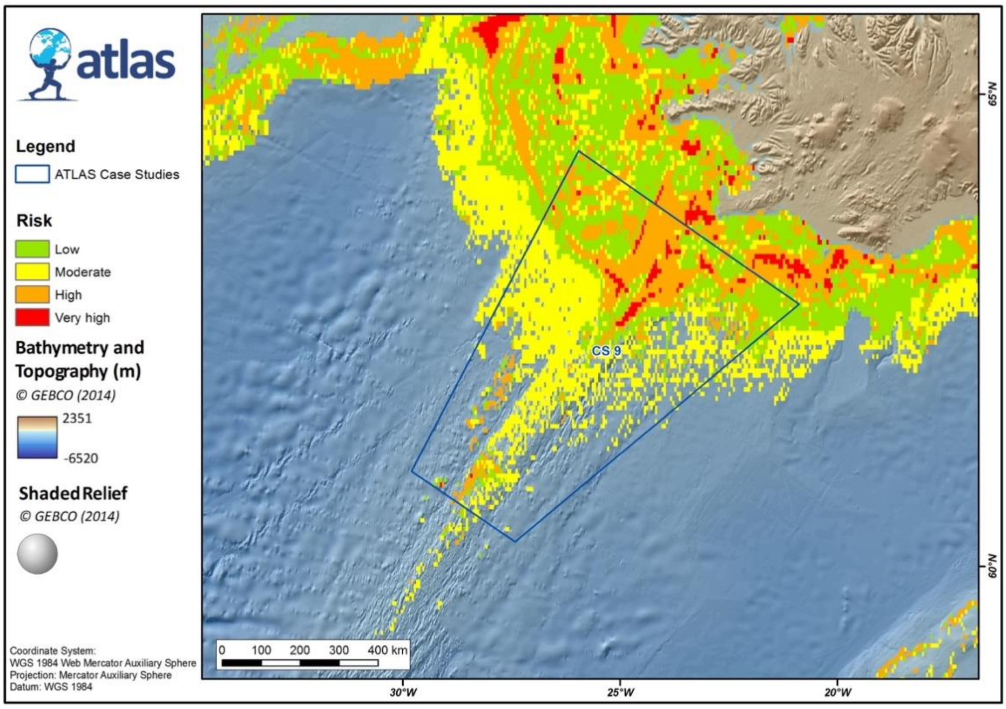
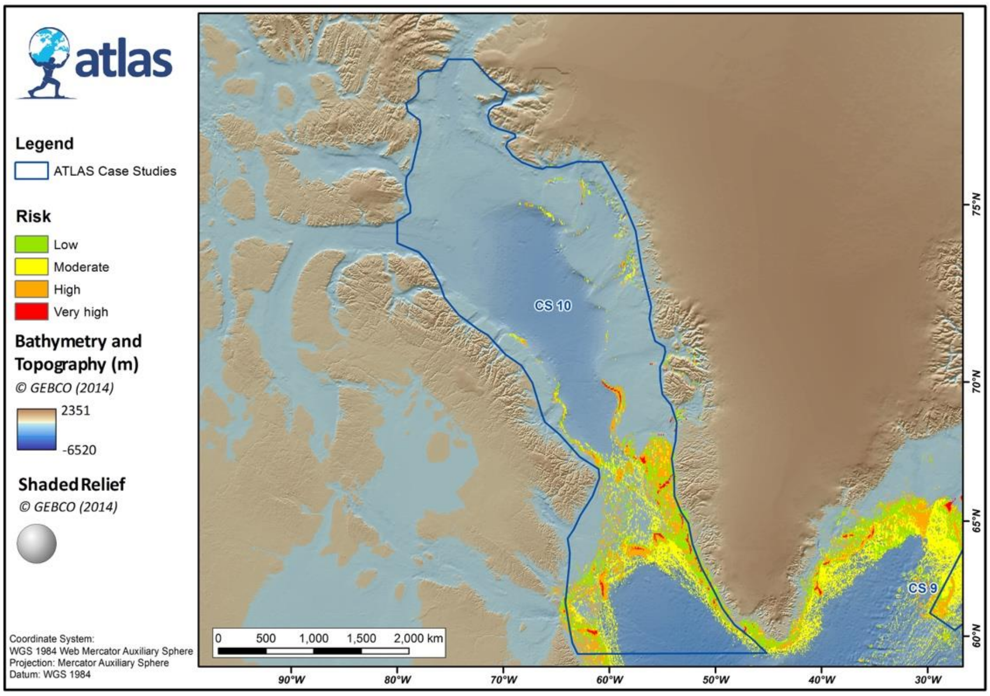


Figure 53. Assessment of risk posed to VME and fish habitat (using the predicted distribution of 6 VME indicator species (A) and 6 deep-sea fish (B) as proxies) from pressures due to fishing activity across the Reykjanes Ridge

2.3.1.10. Davis Strait and Baffin Bay VME Fishing Impact Risk Assessment



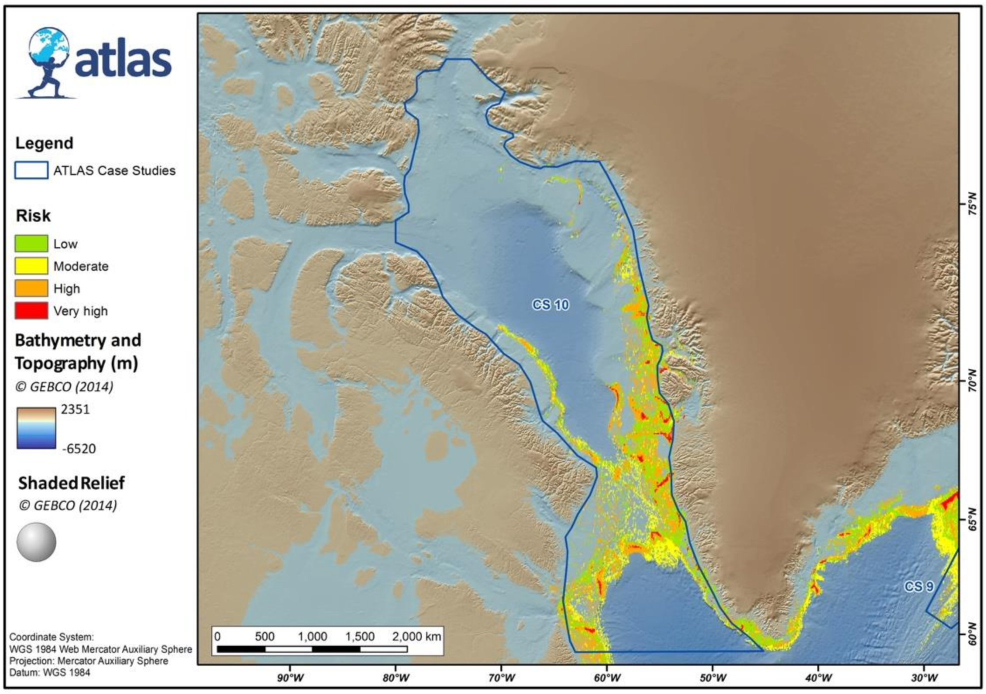
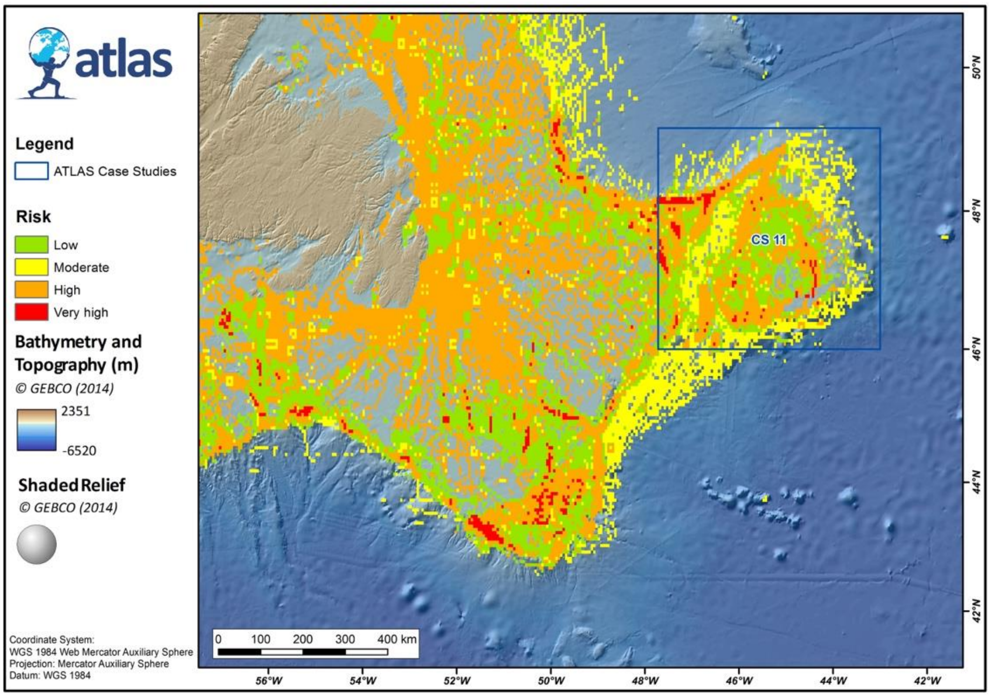


Figure 54. Assessment of risk posed to VME and fish habitat (using the predicted distribution of 6 VME indicator species (A) and 6 deep-sea fish (B) as proxies) from pressures due to fishing activity across the Davis Strait and Baffin Bay

2.3.1.11. Flemish Cap VME Fishing Impact Risk Assessment



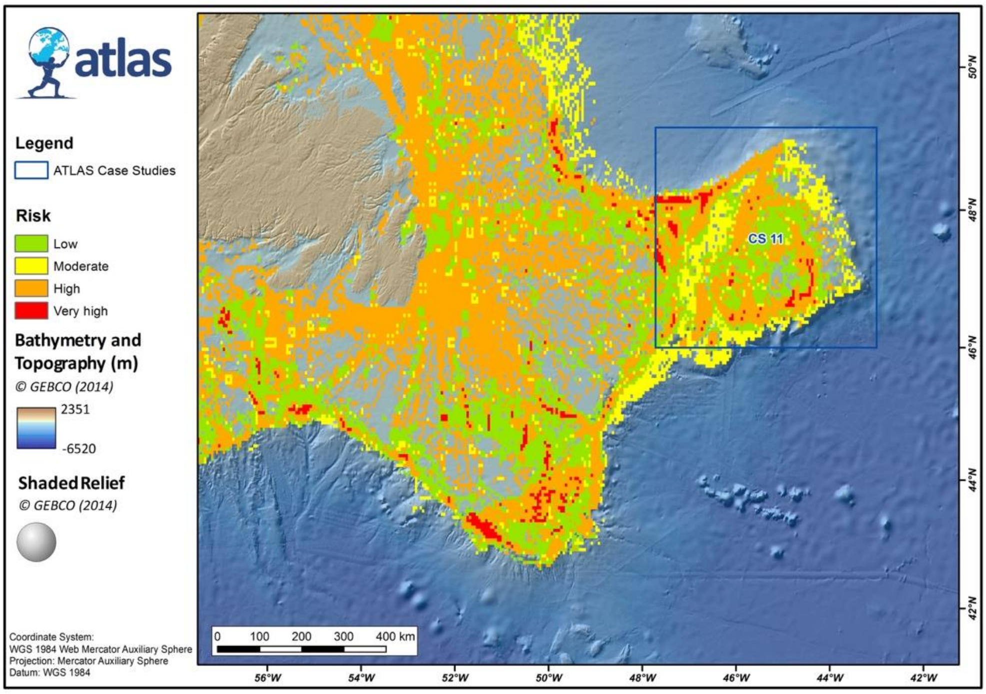
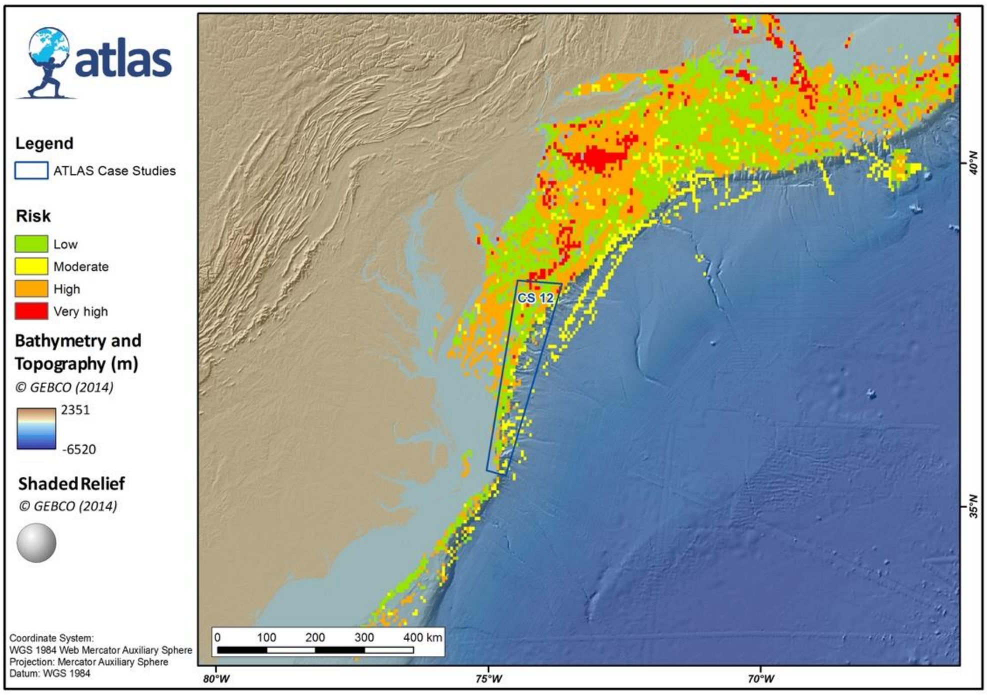


Figure 55. Assessment of risk posed to VME and fish habitat (using the predicted distribution of 6 VME indicator species (A) and 6 deep-sea fish (B) as proxies) from pressures due to fishing activity across the Flemish Cap

2.3.1.12. Mid-Atlantic Canyons, South-Eastern U.S.



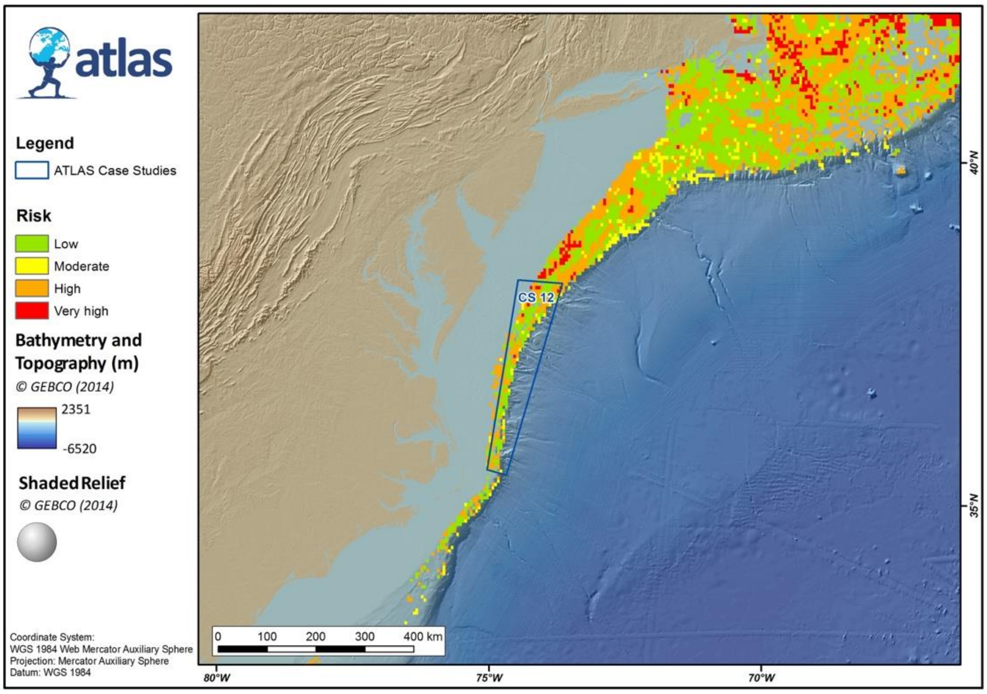


Figure 56. Assessment of risk posed to VME and fish habitat (using the predicted distribution of 6 VME indicator species (A) and 6 deep-sea fish (B) as proxies) from pressures due to fishing activity across the Mid-Atlantic Canyons, South-Eastern U.S.

3. Concluding Remarks

The EU Biodiversity Strategy (Target 2, Action 5) called for the mapping and assessment of ecosystems and their services (MAES project) by all Member States. This also included the assessment of the economic value of such services where possible by 2020. A common system of typologies of ecosystems and services for mapping and inclusion in natural capital accounting was developed to be applied by the EU and its Member States in order to ensure consistent approaches (Bouwma et al. 2018). However, the mapping of marine ecosystems services and associated benefits stills lags behind the terrestrial counterparts and this is even more so for deep-water ecosystem services. Indeed, in the list of recommended indicators for ecosystem services delivered by marine ecosystems the least amount are given for the category 'open ocean' and 'shelf waters' with the majority of indicators listed under 'Marine inlets and transitional waters' followed by 'coastal waters'. See https://biodiversity.europa.eu/maes/mapping-ecosystems/indicators-for-ecosystem-services-marine for the list of indicators. In the EEA (2016) progress report on mapping and assessing the condition of Europe's ecosystems it states "For marine ecosystem areas, the information base generated by the implementation of relevant EU legislation is poor and fragmented, so that assessment at the European level remains challenging". Furthermore it notes that within Member States reporting "There was some lack of clarity in the ecosystem typology, in particular with regards to marine ecosystems". This still remains an issue to be resolved before better integration of ecosystem goods and service valuation can be achieved.

Recent changes to the MSFD (2008/56/EC) through Commission Directive (EU) 2017/845 and Commission Decision (EU) 2017/848 have also made the reporting requirements by Member States more explicit in terms of including information on the human pressures on marine ecosystem and taking into account recent scientific progress (Cavallo et al., 2019). The amendments have also introduced a risk based approach to the reporting requirements for the MSFD through the use of threshold values based on the precautionary principle. The risk assessment and ecosystem services atlas is a useful tool in helping Member States to assess areas at risk that may need further action in achieving Good Environmental Status as required by the MSFD. Member States are also currently developing their own National Marine Spatial Plans as is required under the EU Maritime Spatial Planning Directive. The availability of information on ecosystem service delivery at alternative spatial scales is even more important for the requirements of this Directive to ensure that developments offshore are carried out in a manner that does not jeopardise the long-term capacity of our oceans to continue to deliver ecosystem services.

With regard to risk assessment of activities that are likely to cause abrasion/removal of seafloor sediments, these now fall under the assessment framework of the Marine Strategy Framework Directive particularly in terms of the status of D1 and D6 GES descriptors. Developing suitable indicators is a work in progress in the deep-sea (cf. Atlas Deliverable 3.3 – Good Environmental Status and Biodiversity Assessments) and is an active topic in the ICES Working Group on Deep-sea Ecosystems (ICES WGDEC 2019) which is accessing the merits of an assessment framework developed in shallower waters for application in the deep-sea (ICES WGFBIT 2018). The assessment of risks to Atlantic basin deep-sea habitats from fishing activity in this study will feed into deliberations at next year's ICES WGDEC meeting.

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6. Appendices

Appendix 1. The 41 species used to measure the Food Ecosystem Service

Scientific name	English name	FAO 3A CODE	STECF Records	Estimated Price[2]	Tonnes landed	Estimated Value
Reinhardtius hippoglossoides	Greenland halibut	GHL	240	€6,300.00	6,014	€37,885,877
Lophiidae	Anglerfishes	ANF	549	€3,358.75	57,270	€192,355,758
Merluccius merluccius	European hake	HKE	542	€2,416.62	107,747	€260,384,800
Rajidae	Rays and skates	RAJ	322	€1,624.00	8,384	€13,616,001
Raja spp	Raja rays	SKA	140	€1,624.00	26	€42,281
Raja hyperborea	Arctic skate	RJG	12	€1,624.00	18	€28,819
Coryphaenoides rupestris	Roundnose grenadier	RNG	112	€843.88	1,750	€1,476,569
Macrourus spp	Grenadiers	GRV	45	€843.88	69	€58,479
Macrourus berglax	Roughhead grenadier	RHG	68	€843.88	6	€5,286
Helicolenus dactylopterus	Blackbelly rosefish	BRF	220	€771.60	1,191	€918,739
Molva dypterygia	Blue ling	BLI	216	€751.88	1,689	€1,269,732
Aphanopus carbo	Black scabbardfish	BSF	143	€692.04	5,199	€3,597,828
Argentina silus	Greater argentine	ARU	47	€100.00	5,394	€539,366
Alepocephalus bairdii	Baird's slickhead	ALC	29		400	
Pagellus bogaraveo	Blackspot(=red) seabream	SBR	180		390	
Lepidopus caudatus	Silver scabbardfish	SFS	52		349	
Chaceon affinis	Deep-sea red crab	KEF	51		243	
Chimaera monstrosa	Rabbit fish	CMO	136		218	
Mora moro	Common mora	RIB	112		161	
Galeus melastomus	Blackmouth catshark	SHO	33		139	
Beryx spp	Alfonsinos nei	ALF	126		119	
Polyprion americanus	Wreckfish	WRF	143		104	
Beryx splendens	Splendid alfonsino	BYS	21		41	
Epigonus telescopus	Black cardinal fish	EPI	83		33	
Centrophorus squamosus	Leafscale gulper shark	GUQ	5		14	
Beryx decadactylus	Alfonsino	BXD	18		12	
Scymnodon ringens	Knifetooth dogfish	SYR	3		6	
Centroscymnus coelolepis	Portuguese dogfish	CYO	7		4	
Galeus murinus	Mouse catshark	GAM	5		3	

[2] Price is based on 2016 Irish Stock Book (2017) prices and the 2012 prices Atlas of Commercial Fisheries (2013) where prices were not available for certain species

Hoplostethus mediterraneus	Mediterranean slimehead	HPR	11	2	
Trachyscorpia cristulata	Atlantic thornyhead	TJX	37	1	
Hoplostethus atlanticus	Orange roughy	ORY	5	1	
Sebastes viviparus	Norway redfish	SFV	3	1	
Antimora rostrata	Blue antimora	ANT	2	0	
Etmopterus spinax	Velvet belly	ETX	4	0	
Dalatias licha	Kitefin shark	SCK	4	0	
Hexanchus griseus	Bluntnose sixgill shark	SBL	6	0	
Centroscyllium fabricii	Black dogfish	CFB	5	0	
Somniosus microcephalus	Greenland shark	GSK	1	0	
Talismania bifurcata	Threadfin slickhead	TAB	1	0	
Centroscymnus crepidater	Longnose velvet dogfish	CYP	1	0	
Totals				196,997	€512,179,535

Appendix 2. Predicted cover of VME and Fish Habitat in each Case Study Area.

Case Study	CS 01	CS 02	CS 03	CS 04	CS 05	CS 06	CS 07	CS 08	CS 09	CS 10	CS 11	CS 12
Case Study area (km2)	2175	5278	38862	115	595278	53047	38302	958033	99581	1127011	124817	16523
Areal extent of VME (km2)												
Lophelia pertusa	-	5212	38861	84	212654	35861	16012	20871	77298	9	-	11215
Madrepora oculata	-	-	37070	-	207261	30548	29845	73294	46266	63	-	14593
Desmophyllum dianthus	-	-	28007	-	240861	38042	22898	221712	58053	15966	2592	11758
Acanella arbuscula	1828	29	7042	-	214283	39572	-	130291	66727	297011	95462	7408
Acanthogorgia armata	1155	749	7006	-	73795	30978	-	13635	21330	92497	81853	2266
Paragorgia arborea	1138	55	3791	-	22786	14642	-	-	4837	170263	30401	564
Areal Extent of Fish Habitat (km2)												
Coryphaenoides rupestris	234	5278	14346	-	116373	11101	-	24360	65337	187018	65886	-
Gadus morhua	71	513	8406	112	7341	61	-	-	17685	46021	30900	-
Helicolenus dactylopterus	-	1479	35568	115	122262	19100	6925	20019	20710	-	108	8403
Hippoglossoides platessoides	14	1516	16569	67	7703	-	-	-	19659	106203	36076	-
Reinhardtius hippoglossoides	40	1530	-	-	-	-	-	-	128	361214	72071	-
Sebastes mentella	106	8	-	-	-	-	-	-	14305	189162	57864	-
Percentage Cover - VME												
Lophelia pertusa	-	99%	100%	73%	36%	68%	42%	2%	78%	0%	-	68%
Madrepora oculata	-	-	95%	-	35%	58%	78%	8%	46%	0%	-	88%
Desmophyllum dianthus	-	-	72%	-	40%	72%	60%	23%	58%	1%	2%	71%
Acanella arbuscula	84%	1%	18%	-	36%	75%	-	14%	67%	26%	76%	45%
Acanthogorgia armata	53%	14%	18%	-	12%	58%	-	1%	21%	8%	66%	14%
Paragorgia arborea	52%	1%	10%	-	4%	28%	-	-	5%	15%	24%	3%
Percentage Cover - Fish Habitat												
Coryphaenoides rupestris	11%	100%	37%	-	20%	21%	-	3%	66%	17%	53%	-
Gadus morhua	3%	10%	22%	97%	1%	0%	-	-	18%	4%	25%	-
Helicolenus dactylopterus	-	28%	92%	100%	21%	36%	18%	2%	21%	-	0%	51%
Hippoglossoides platessoides	1%	29%	43%	58%	1%	-	-	-	20%	9%	29%	-
Reinhardtius hippoglossoides	2%	29%	-	-	-	-	-	-	0%	32%	58%	-
Sebastes mentella	5%	0%	-	-	-	-	-	-	14%	17%	46%	-

Case Studies: CS01 - LoVe Observatory , CS02 - Faroe Shetland Channel, CS03 - Rockall Bank, CS04 - Mingulay Reef, CS05 - Porcupine Seabight, CS06 - Bay of Biscay, CS07 - Strait of Gibraltar, CS08 - Azores, CS09 - Reykjanes Ridge, CS10 - Davis Strait, CS11 - Flemish Cap, CS12 - Mid-Atlantic Canyon

Appendix 3. Percentage of VME and Fish Habitat at Risk in Case Study Areas

Figure A3.1 – VME/Fish Habitat at Risk in LoVe Observatory Case Study (CS01)

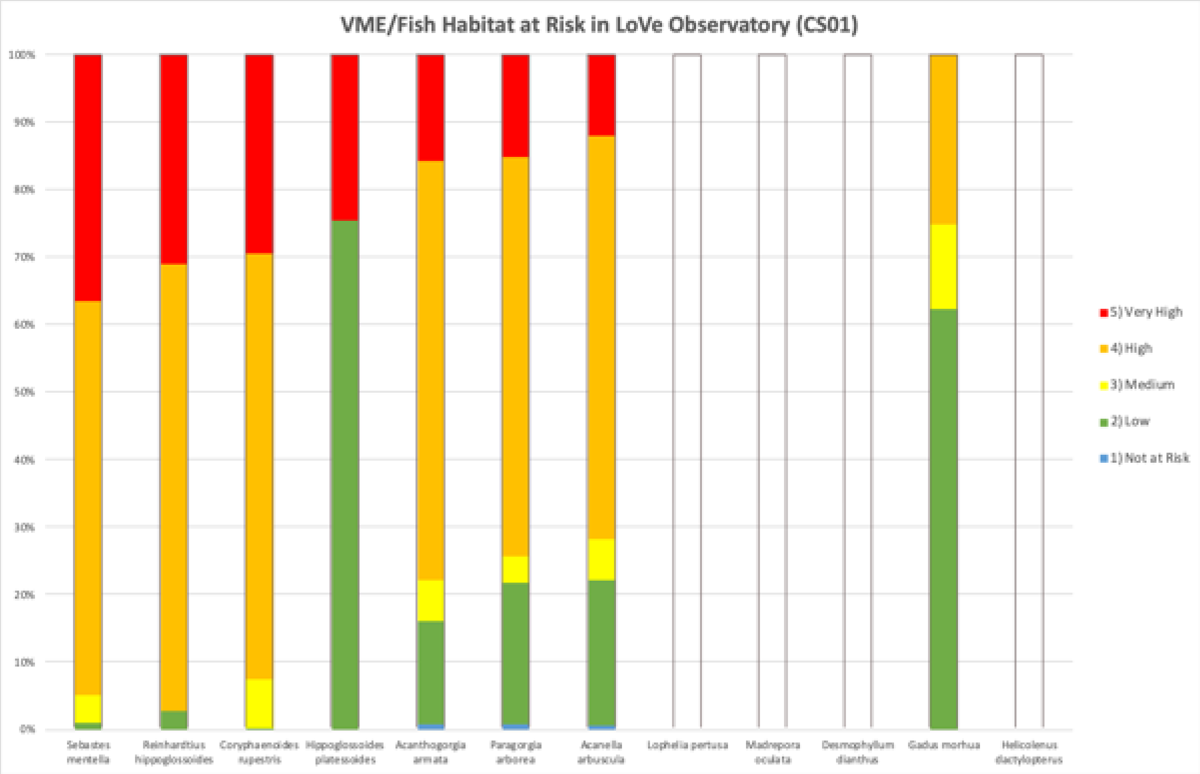


Figure A3.2 – VME/Fish Habitat at Risk in Faroe-Shetland Channel Case Study (CS02)

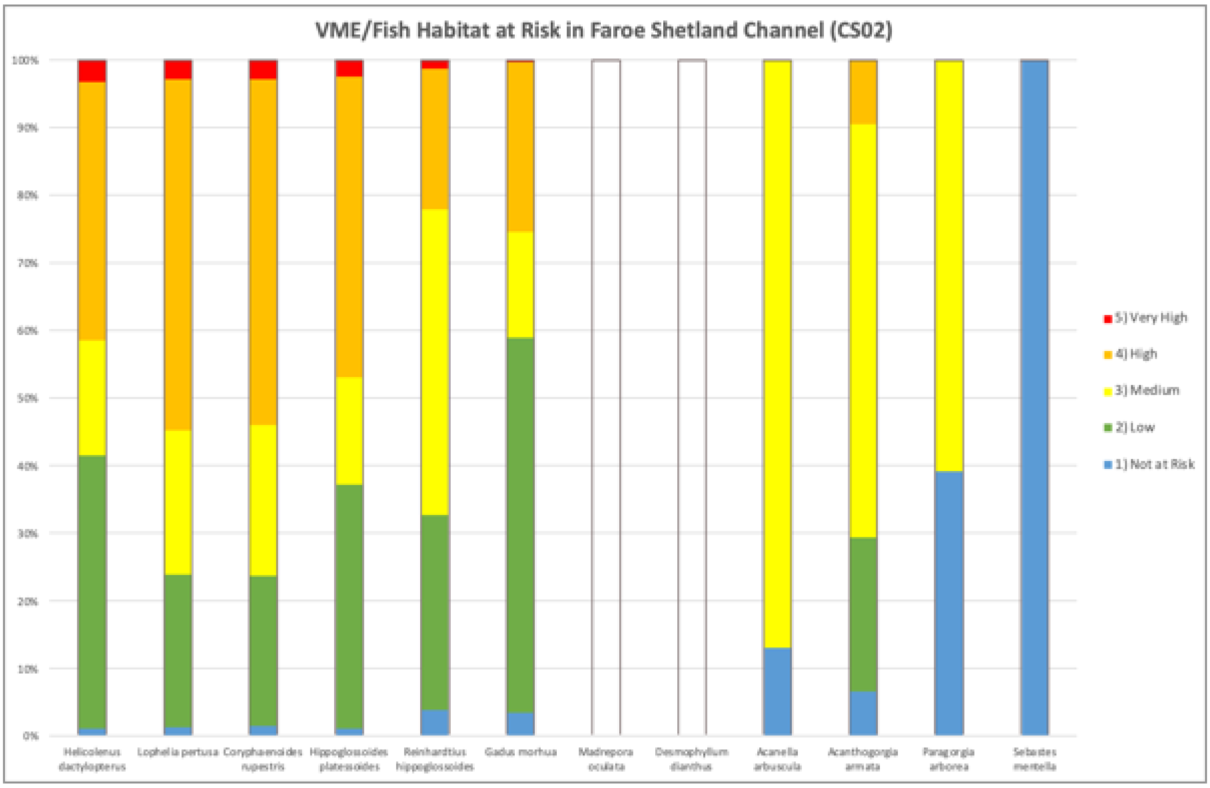


Figure A3.3 – VME/Fish Habitat at Risk in Rockall Bank Case Study (CS03)

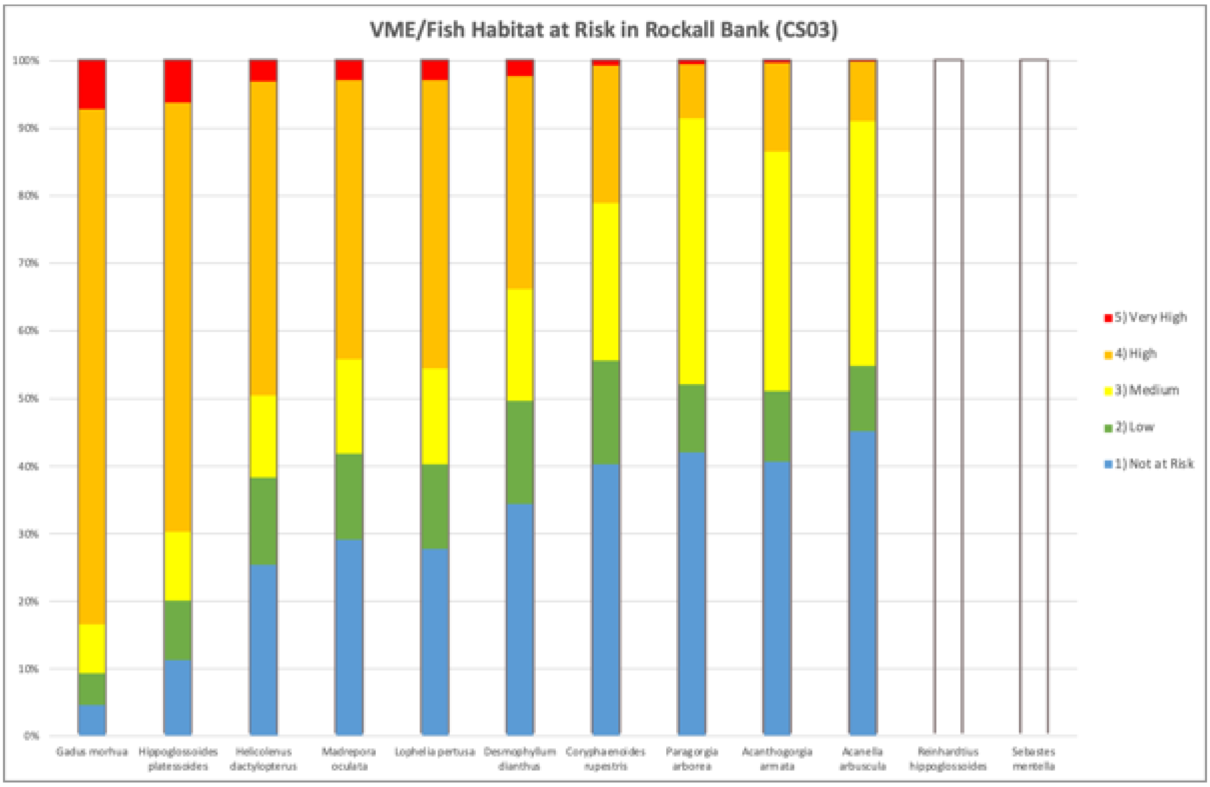


Figure A3.4 – VME/Fish Habitat at Risk in Mingulay Reef Case Study (CS04)

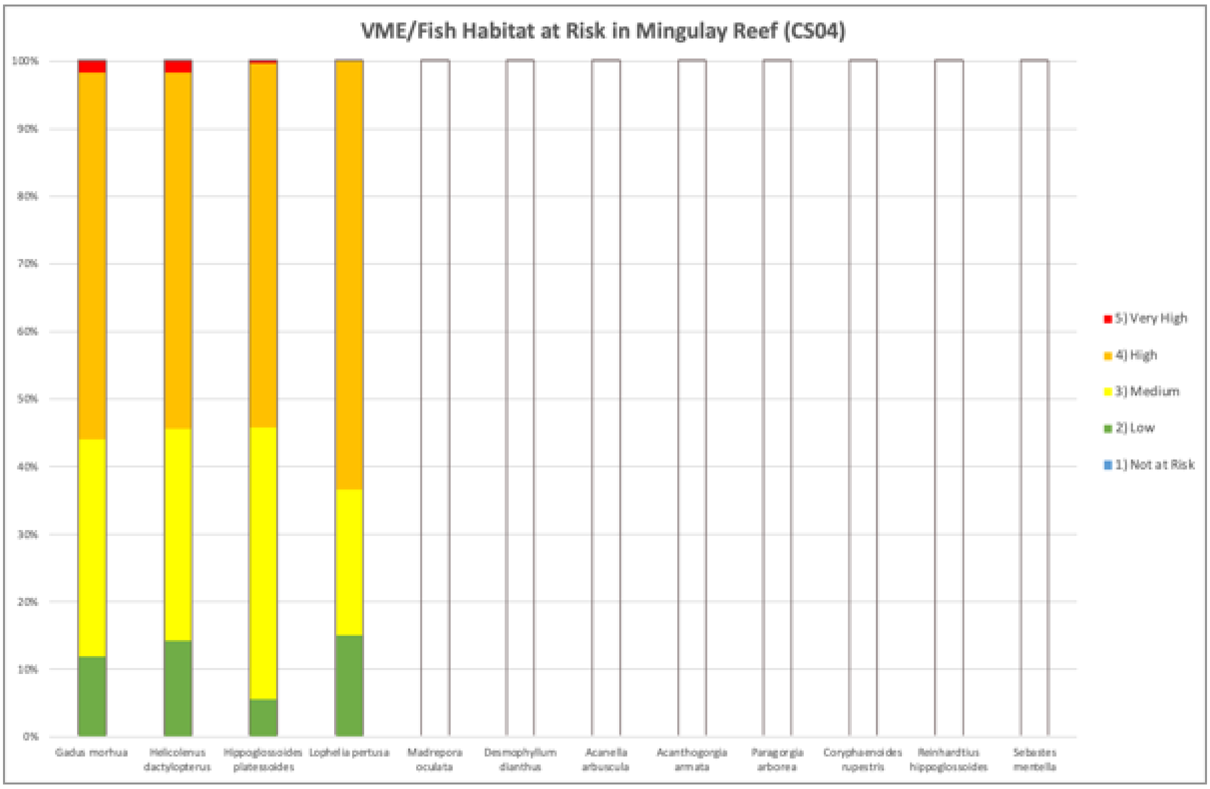


Figure A3.5 – VME/Fish Habitat at Risk in Porcupine Seabight Case Study (CS05)

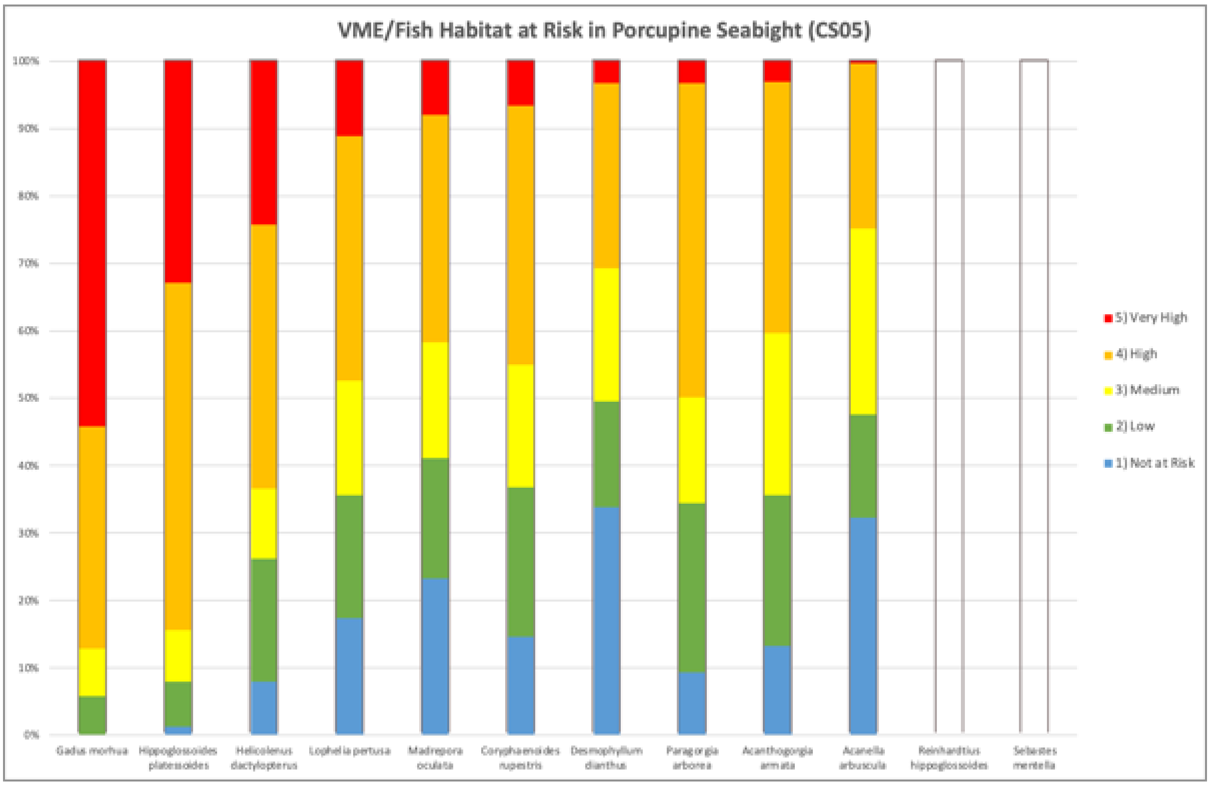


Figure A3.6 – VME/Fish Habitat at Risk in Bay of Biscay Case Study (CS06)

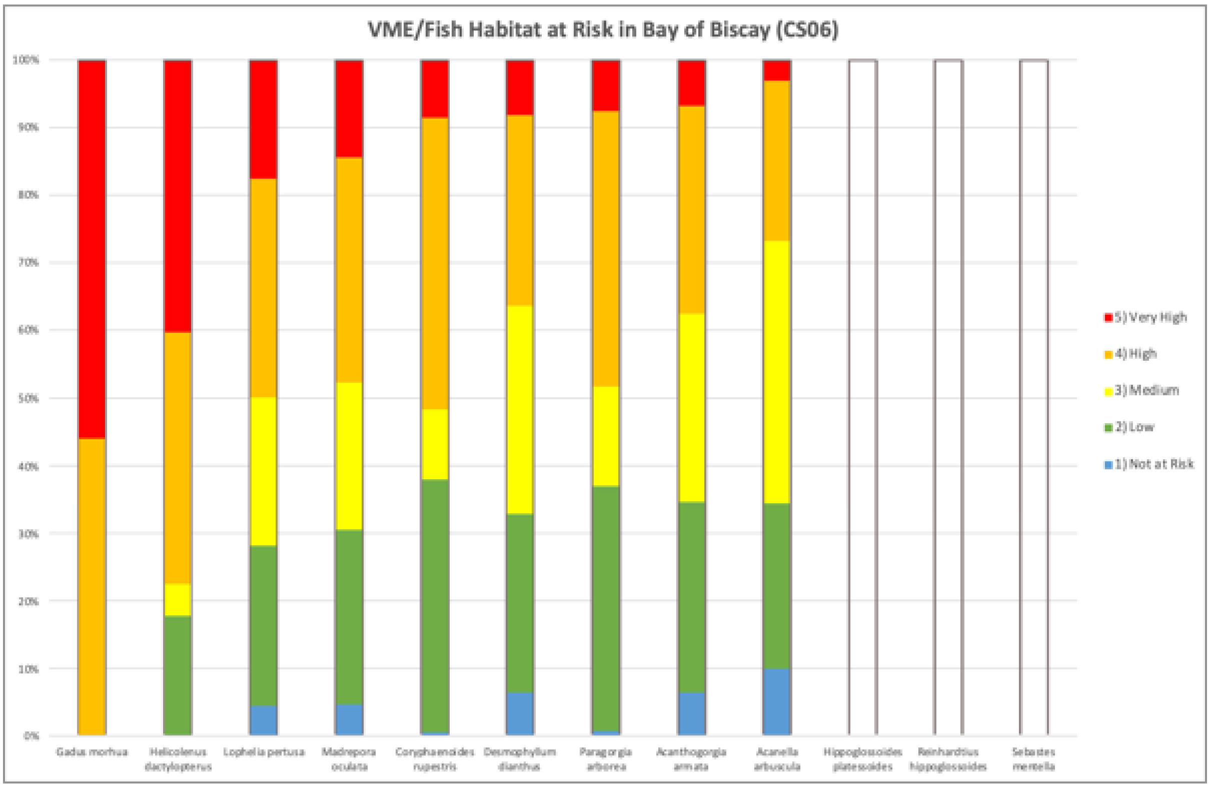


Figure A3.7 – VME/Fish Habitat at Risk in Strait of Gibraltar Case Study (CS07)

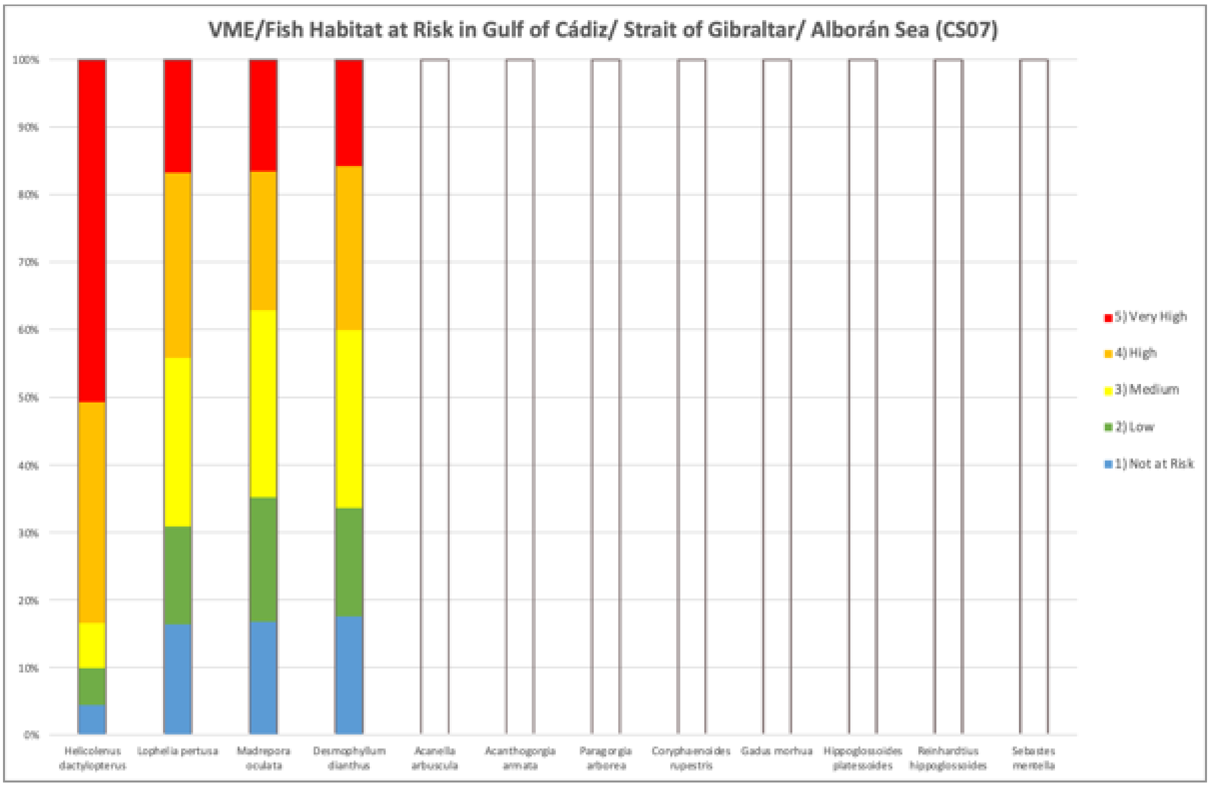


Figure A3.8 – VME/Fish Habitat at Risk in Azores Case Study (CS08)

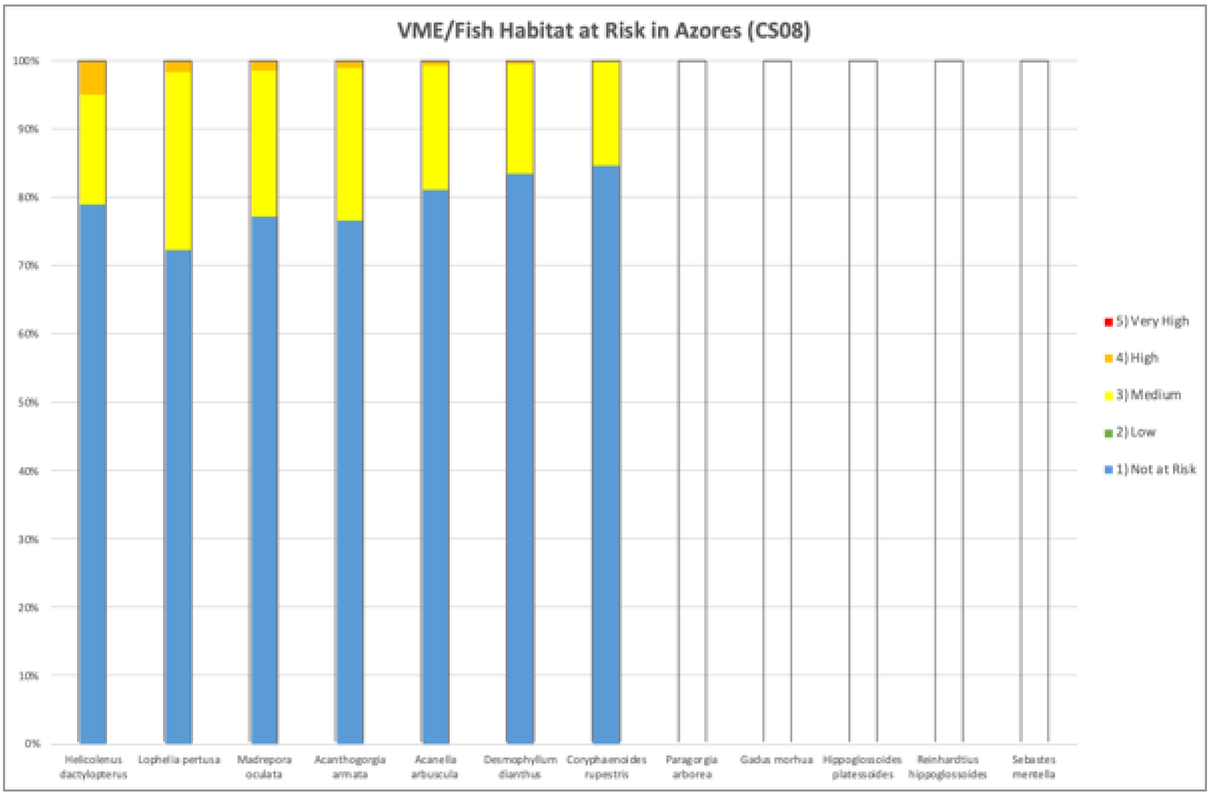


Figure A3.9 – VME/Fish Habitat at Risk in Reykjanes Ridge Case Study (CS09)

Figure A3.10 – VME/Fish Habitat at Risk in Davis Strait Case Study (CS10)

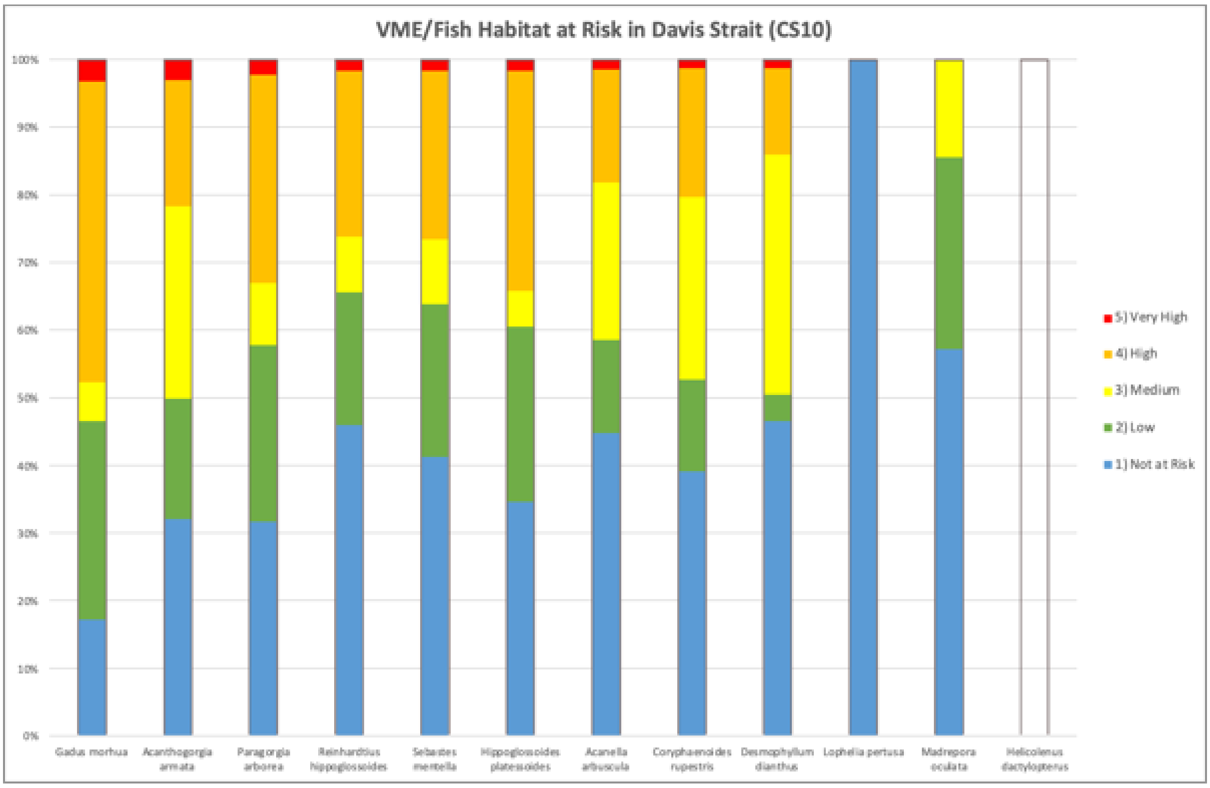


Figure A3.11 – VME/Fish Habitat at Risk in Flemish Cap Case Study (CS11)

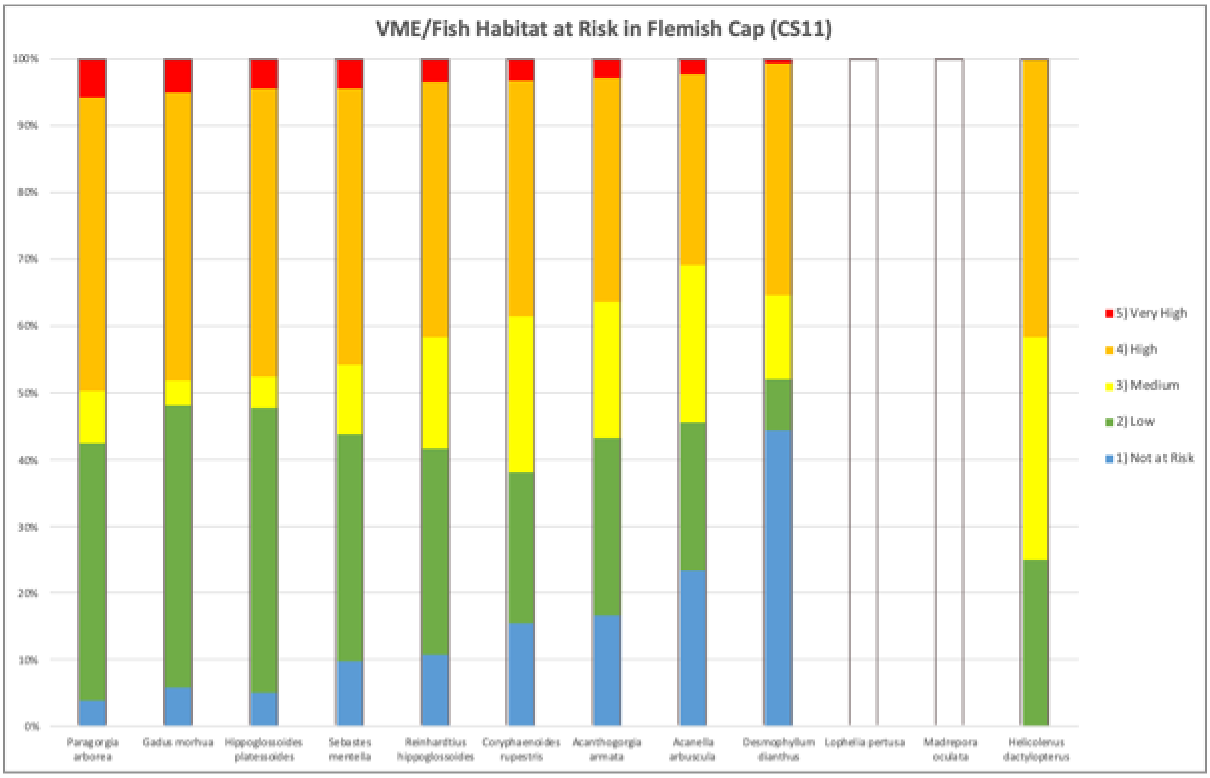
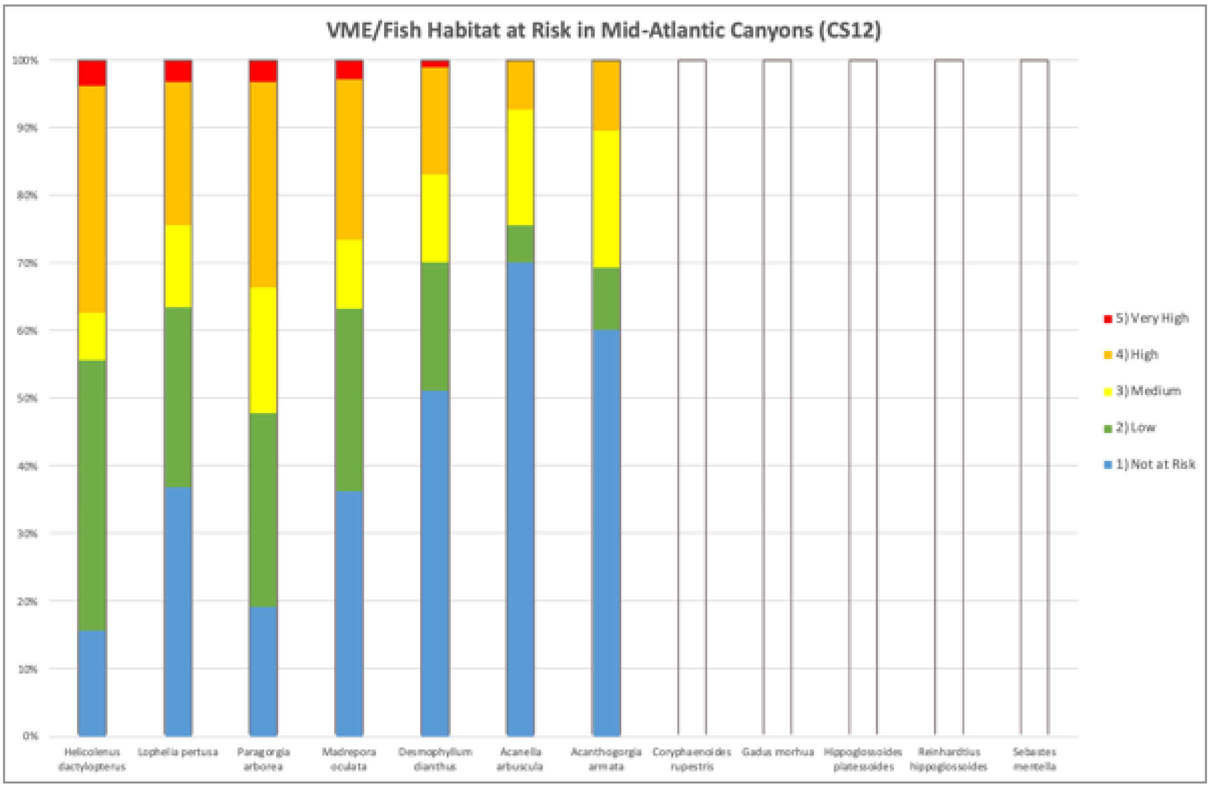


Figure A3.12 – VME/Fish Habitat at Risk in Mid-Atlantic Canyons Case Study (CS12)



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Authors (Partner)				
Responsible Authors	**Name**		**Email**	
	Anthony Grehan		anthony.grehan@nuigalway.ie	
	Stephen Hynes		stephen.hynes@nuigalway.ie	

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