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# Marine habitats ecosystem service potential: A vulnerability approach in the Normand-Breton (Saint Malo) Gulf, France

Cabral Pedro [1, 7, *], Levrel Harold [2], Schoenn Jennifer [3, 5], Thiébaut Eric [3, 4], Le Mao Patrick [5], Mongruel Remi [2], Rollet Claire [5], Dedieu K. [6], Carrier Sonia [6], Morisseau Francois [6], Daures Fabienne [2]

[1] Université de Brest, UMR AMURE – Centre de droit et d'économie de la mer, IUEM, 12 rue du Kergoat, CS 93837, 29238 Brest Cedex 3, France
[2] Ifremer, UMR AMURE, Unité d'Economie Maritime, BP 70, F-29280 Plouzané Cedex, France
[3] Sorbonne Universités, UPMC Univ. Paris 06, UMR 7144, Station Biologique de Roscoff, CS90074, 29688 Roscoff Cedex, France
[4] CNRS, UMR 7144, Adaptation et Diversité en Milieu Marin, Place Georges Teissier, 29680 Roscoff, France
[5] Ifremer, Laboratoire Environnement & Ressources de Bretagne Nord, Station Ifremer de Dinard, CRESCO, 38 rue du Port Blanc, BP 70134, 35801 Dinard Cedex, France
[6] Agence des Aires Marines Protégées, 16 quai de la douane, CS 42932, 29229 Brest Cedex 2, France
[7] Instituto Superior de Estatística e Gestão de Informação, ISEGI, Universidade Nova de Lisboa, 1070-312 Lisboa, Portugal

* Corresponding author : Pedro Cabral, email address : pcabral@ifremer.fr

**Abstract :**

In this paper is assessed the vulnerability of the benthic habitats potential to deliver ES caused by physical, chemical and biological pressures identified by the Marine Strategy Framework Directive (MSFD) in the Normand-Breton (Saint Malo) Gulf (GNB), in France. The InVEST Habitat Risk Assessment (HRA) model provides useful information for identifying the regions on the seascape where the impacts of human activities are the highest. Additionally, and because the HRA does not address any ES in particular but the whole set of services offered by marine and coastal ecosystems, we analyze the habitats potential to deliver different types of ES (provisioning, regulating and maintenance, and cultural) using habitats vulnerability as a proxy. Concept-driven scenarios are presented to enable the understanding of existing trade-offs as a consequence of different management options. Results provide relevant ES-based information for managers to communicate with stakeholders and prioritize actions for risk mitigation.

**Keywords** : Marine spatial planning, Marine governance, Habitat vulnerability, Habitat risk assessment, Ecosystem services, MSFD

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## 1. Introduction

Marine and coastal systems are subject to increasing multiple human uses and pressures including atmospheric and climate change impacts, pollution, resources exploitation or urbanization (Harley et al., 2006; Halpern et al., 2007; Lester et al., 2010; Parravicini et al., 2012). These impacts may compromise the ability of these ecosystems to provide benefits known as ecosystem services (ES) to support mankind (Millennium Ecosystem Assessment, 2005): (i) provisioning (or production) services, such as food and raw materials; (ii) regulating services, such as gas and climate regulation, protection from flood and storms and waste bioremediation; (iii) cultural services such as cultural heritage and identity, cognitive benefits, leisure and recreation and non-use benefits; and (iv) supporting services such as the provision of biologically mediated habitats and nutrient cycling. Regulating and supporting services have also been treated as a single category in marine ES, i.e., regulating and maintenance services (Liquete et al., 2013).

The marine socio-ecosystem delivers multiple ES and is connected with multiple systems of values and with multiple sustainability criteria. This source of complexity explains why governing these socio-ecosystems is a global challenge (European Commission, 2013; UNEP, 2006). One way of dealing with this complexity is by using an ecosystem-based management (EBM) approach. EBM is about maintaining the long-term ability of ecosystems for providing multiple ES (McLeod and Leslie, 2009). It includes local political aspects and considers different management actions at diverse spatial scales of application (Lester et al., 2010). In this context, a core challenge is to be able to consider simultaneously variables and values characterized by limited comparability. The only way to do it is by adopting an approach that considers a multi-criteria analysis (Martinez-Alier et al., 1998). However, knowledge gaps regarding the availability of data and indicators that measure the capacity, flow or benefit derived from each ES have been highlighted in previous research (Liquete et al., 2013; Townsend et al., 2014).

EBM can be combined with Marine Spatial Planning (MSP) and an ES framework (Lester et al., 2010) to support multi-criteria analysis using a geographical information systems (GIS) (Malczewski, 1999). MSP represents decision-making approaches that use geospatial information to mitigate human uses in the ocean while maintaining or improving ES. The ES framework enables an explicit assessment of the trade-offs in services providing a quantitative approach for assessing the value of MSP versus random planning (Guerry et al., 2012). An ES framework approach requires the knowledge of the status and the changes of the ES in response to different management options (Leh et al., 2013). A reasonable number of studies have mapped and quantified multiple ES for terrestrial (Bai et al., 2012; Bhagabati et al., 2012; Chan et al., 2006; Egoh et al., 2008; Gulickx et al., 2013; Maes et al., 2012; Nelson et al., 2009; Swetnam et al., 2011) and more seldom in marine environments due to difficulties in obtaining data (Guerry et al., 2012; Townsend et al., 2014). Furthermore, for marine ecosystems, ES valuation is generally performed for large habitats (e.g. coral reefs, coastal wetlands, estuaries) while there is a need for a spatially explicit ecosystem service analysis that includes the local scale (Hutchison et al., 2013).

The MSFD (Directive 2008/56/EC) is the pillar of Europe's maritime policy which aims to protect the European marine environment. It was adopted in 2008 and it was due to be transposed into national legislation by 2010. This Directive outlines a legislative framework at the EU level, at all scales, to reach a "Good Environmental Status (GEnS)" by 2020 and to ensure the sustainable use of marine resources (EC, 2008). This approach clearly promotes an EBM approach for managing the human activities in marine environments.

The supply of multiple ES needs to be traded off because it is impossible to simultaneously maximize its delivery (Barbier et al., 2008; Halpern et al., 2007; Tallis and Kareiva, 2006). The ability of the habitats to deliver ES may be approached using the vulnerability concept which is a function of exposure (i.e., the nature and degree to which ecosystems are exposed to environmental change), sensitivity (i.e., the degree to which a human-environment system is affected by environmental change) and adaptive capacity (i.e.; adjustment in natural or human systems to a new or changing environment (Metzger et al., 2006). An increase in the habitats vulnerability is likely to decrease the supply of ecosystems (Schroter, 2005).

The ES trade-offs that arise from different management options provide relevant information for decision-making by revealing the benefits of an EBM approach (Lester et al., 2010). One alternative way to the use of monetary or biophysical valuation as indicators of marine ES where data scarcity is very present, is to estimate the changes in the vulnerability of marine habitat's as a proxy of the habitat's ability, or potential, to deliver ES. Mapping these changes in the study area will enable a good understanding of the components that can be managed using an EBM approach.

The understanding of the trade-offs of an EBM approach can be achieved using scenarios of future possible states of the ecosystem. The use of consistent scenarios for potential future states that represent policy-induced changes to services are more informative than the ones solely based on gross estimates (Peterson et al., 2003; Swetnam et al., 2011). The scenarios should be based on coherent narratives incorporating likely future changes in important drivers (Raskin, 2005). These can be built using a participatory approach with the stakeholders or concept-driven (Castella, 2005; Guerry et al., 2012; Walz et al., 2007). The former is harder to implement due to problems in obtaining information from dispersed stakeholders, institutional barriers to sustained participation and parameterization of ideas generated in scenario building process (Swetnam et al., 2011). The latter, which is applied in the present study, is a preliminary approach aimed to engage initial discussion with the stakeholders in the framework of marine governance.

The main objectives of this paper are: (1) to describe spatially the major sources of physical, chemical and biological pressures according to the MSFD in the GNB; and, (2) to propose an integrated estimate of marine habitat vulnerability as a proxy of their potential to deliver ES, according to different management scenarios. This approach will provide relevant information for the study mission led by the French Marine Protected Areas Agency (AAMP) for establishing the management guidelines of a new Marine Protected Area (AAMP, 2013).

## 2. Material and methods

### 2.1 Study area

The GNB is a profound coastal indentation located in the western part of the English Channel, from the island of Bréhat (west) to the north of the Cotentin Peninsula (Figure 1). It is characterized by a large variety of habitats in relation to complex currents and the presence of islands, archipelagos and rock plates, from vast tidal flats in the Mont Saint-Michel and rocky shores to diverse subtidal environments at depth reaching 80 m (Le Mao, 2011). Both Normandy and Brittany coasts are heterogeneous areas more developed and densely populated around the main urban centers of Ille-et-Vilaine and Côtes d'Armor, but less than other coastal areas in France such as the Mediterranean coasts (VALMER, 2014). There are 267 municipalities within a distance of 3 km from the coastline of the study area with a population of approximately 600,340 inhabitants in 2011 (INSEE, 2014). The economic activities are mainly related with shellfish farming, commercial fishing, agriculture, tourism and leisure, nuclear power and fuel reprocessing industries, aggregates extraction and, in the future, offshore renewable energy farms (VALMER, 2014).

This area benefits from several conventions signed by France on the protection and sustainable management of species and marine habitats. These include, besides the previously mentioned MSFD, other European Directives on the protection of the marine environment such as: (i) the Birds and Habitats Directives aiming to preserve species and habitats which are of European importance, including marine ones (European Commission, 2007, 2000, 1992); and, (ii) the Water Framework Directive aiming to achieve a good quality of water and a good ecological status of aquatic environments (European Commission, 2000).

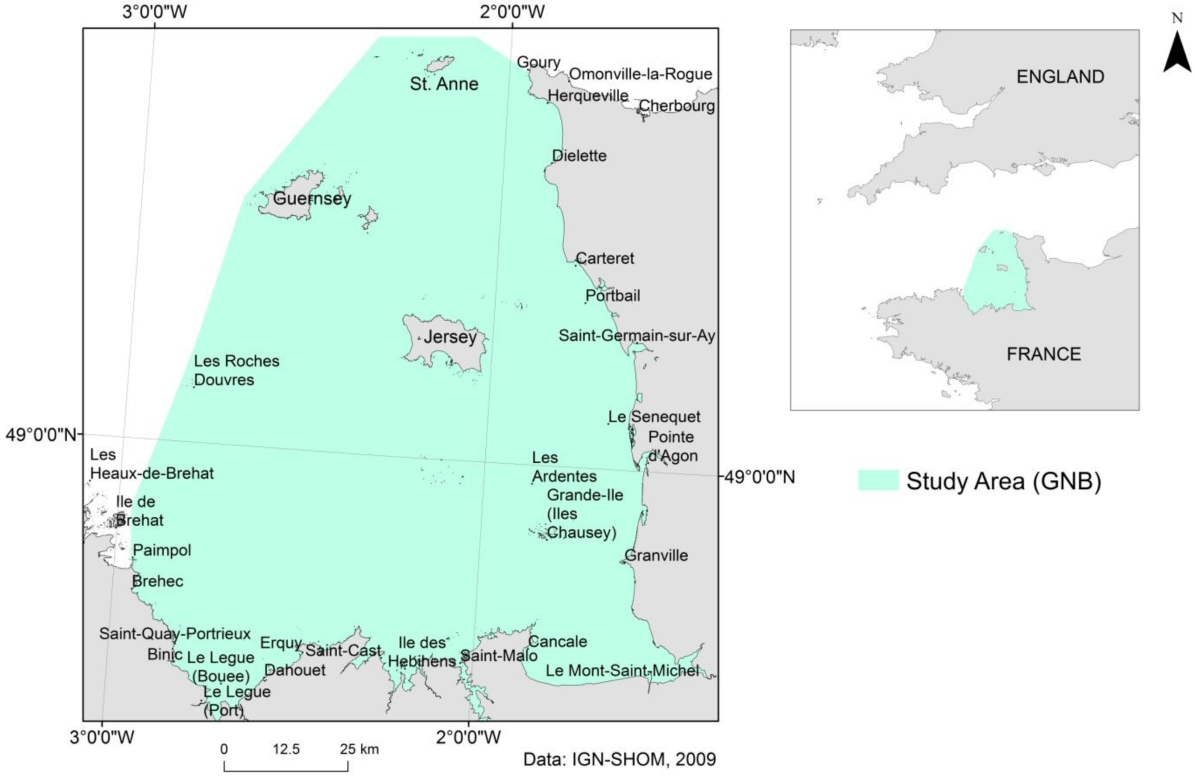


**Figure 1 The Normand-Breton (Saint Malo) Gulf**

## 2.2 Data

An habitat vector map was produced for the purpose of this study using several historical datasets (Augris, 2008, 2006; Bonnot-Courtois et al, 1986; Bouvier, 1993; Cabioch and Retière, 1968; Godet et al, 2007; Guillaumont et al, 1987; Ifremer-CNRS-CEVA, 2007; Ifremer-EPHE/CNRS-MNHN-RNBSB, 2006; Jackson, 2003; Le Mao, 2013; Thouzeau and Hamon, 1992). This map is based on the habitat types classification of the European Nature Information System (EUNIS) habitat (EEA, n.d.) at level 4 for soft-sediment habitats and, at level 2, for hard substrata habitats (Figure 2; Table 1). A total area of 9970.6 km$^2$ has been analyzed including two hard substrata habitats and 15 soft-sediment habitats.

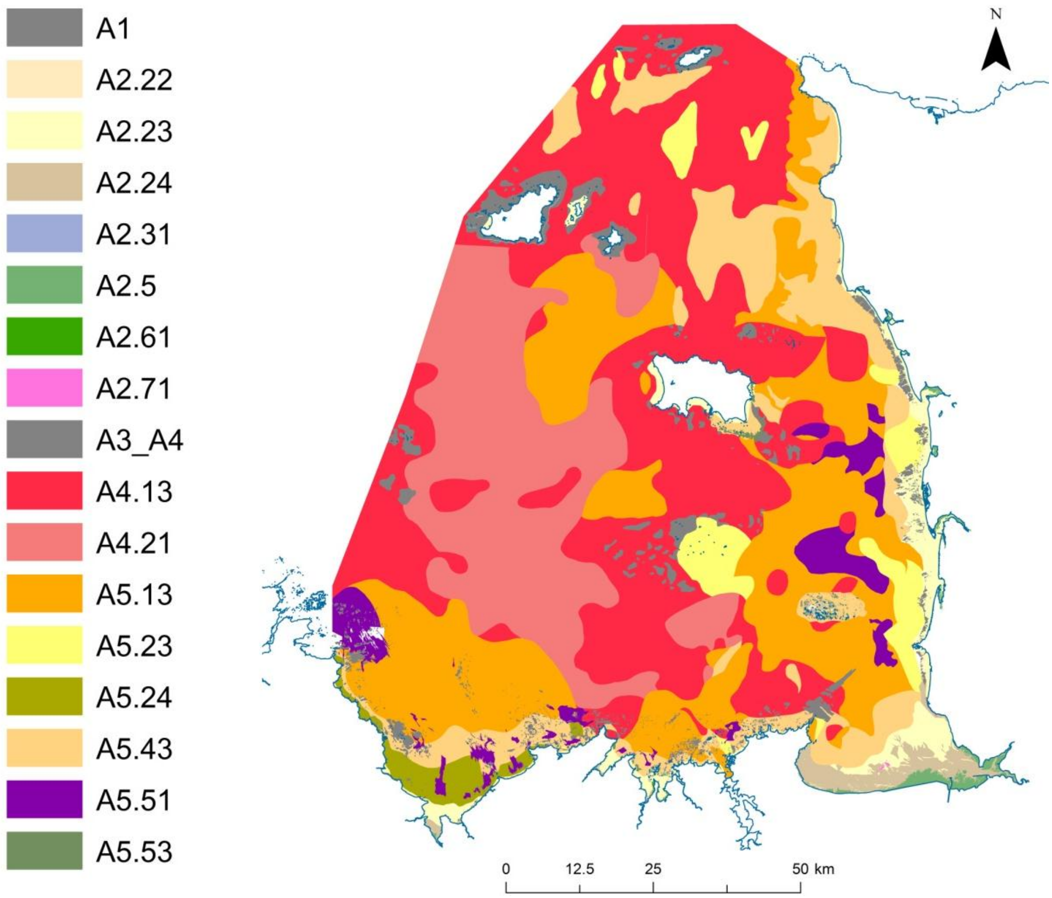


**Figure 2 Benthic habitat compilation using EUNIS 2004 classification in the GNB**

| Eunis code | Description | Area (km$^2$) | % of total area |
|---|---|---|---|
| A1 | Littoral rock and other hard substrata | 80.4 | 0.81 |
| A2.22 | Barren or amphipod-dominated mobile sand shores | 3.1 | 0.03 |
| A2.23 | Polychaete/amphipod-dominated fine sand shores | 311.2 | 3.12 |
| A2.24 | Polychaete/bivalve-dominated muddy sand shores | 141.6 | 1.42 |
| A2.31 | Polychaete/bivalve-dominated mid estuarine mud shores | 1.4 | 0.01 |
| A2.5 | Coastal saltmarshes and saline reedbeds | 58.4 | 0.59 |
| A2.61 | Seagrass beds on littoral sediments | 0.5 | 0.01 |
| A2.71 | Littoral [Sabellaria] reefs | 1.4 | 0.01 |
| A3.A4 | Infralittoral rock and other hard substrata / Circalittoral | 355.6 | 3.57 |
| A4.13 | Mixed faunal turf communities on circalittoral rock | 3157.6 | 31.67 |
| A4.21 | Echinoderms and crustose communities on circalittoral rock | 1732.7 | 17.38 |
| A5.13 | Circalittoral coarse sediment | 2265.8 | 22.72 |
| A5.23 | Infralittoral fine sand | 370.6 | 3.72 |
| A5.24 | Infralittoral muddy sand | 124.1 | 1.24 |
| A5.43 | Infralittoral mixed sediments | 1044.2 | 10.47 |
| A5.51 | Maerl beds | 305.3 | 3.06 |
| A5.53 | Sublittoral seagrass beds | 16.7 | 0.17 |

**Table 1 EUNIS 4 habitat classes used in this study**

The datasets used to build the pressure layers according to the main human drivers identified by the MSFD are given in Table 2. The geographical information system (GIS) data used in the modeling process was provided by the French Agency of Marine Protected Areas (AAMP), the French Research Institute for Exploitation of the Sea (Ifremer) and the National Center for Ecological Analysis and Synthesis of the University of California Santa Barbara (NCEAS). All the input datasets are, or were, converted into common a NTF France II (Degrees) projection.

| GIS layers | Source | Associated MSFD pressure/impact |
|---|---|---|
| Recreational on-foot fishing | AAMP | Physical loss - Abrasion<br>Other physical disturbance - Marine liter<br>Biological disturbance - Selective extraction of species |
| Recreational boat fishing | AAMP | Other physical disturbance - Marine liter<br>Biological disturbance - Selective extraction of species |
| Professional fishing | Ifremer, SIH (Activity data, 2012) | Physical loss - Abrasion<br>Other physical disturbance - Marine liter<br>Biological disturbance - Selective extraction of species |
| Dredge spoil disposal sites | AAMP | Physical loss - Smothering and sealing<br>Physical loss - Abrasion<br>Physical damage - Changes in siltation |
| Off-shore energy | AAMP | Physical loss - Smothering and sealing<br>Interference with hydrological processes-changes in the currents |
| Harbors | AAMP | Physical loss - Smothering and sealing<br>Physical loss - Abrasion<br>Contamination by hazardous substances |
| Marinas | AAMP | Physical loss - Smothering and sealing<br>Physical loss - Abrasion<br>Contamination by hazardous substances |
| Marine traffic | AAMP | Other physical disturbance - Marine liter<br>Contamination by hazardous substances |
| Shipwrecks | AAMP | Physical loss - Smothering and sealing<br>Other physical disturbance - Marine liter<br>Contamination by hazardous substances |
| Submarine cables | AAMP | Physical loss - Smothering and sealing<br>Physical loss – Abrasion |
| Shellfish farms | AAMP | Physical loss - Smothering and sealing<br>Other physical disturbance - Marine liter<br>Interference with hydrological processes-changes in the currents |
| Granulate extraction | AAMP | Physical loss - Abrasion<br>Physical damage - Selective extraction |
| Anchorages | AAMP | Physical loss - Abrasion |
| Ammunition | AAMP | Other physical disturbance - Marine liter |
| *Crepidula fornicata* | Ifremer | Biological disturbance - Non-indigenous species |
| Nutrients | NCEAS | Nutrient and organic matter enrichment-Inputs of organic matter |
| Organic pollutants | NCEAS | Nutrient and organic matter enrichment- Input of fertilizers and other nitrogen |

**Table 2 GIS layers used to build the MSFD pressures**

The MSFD pressures were represented using GIS layers that were preprocessed using several spatial operations (Figure 3). The preprocessing procedure is described in the supplementary material (Table A.1).

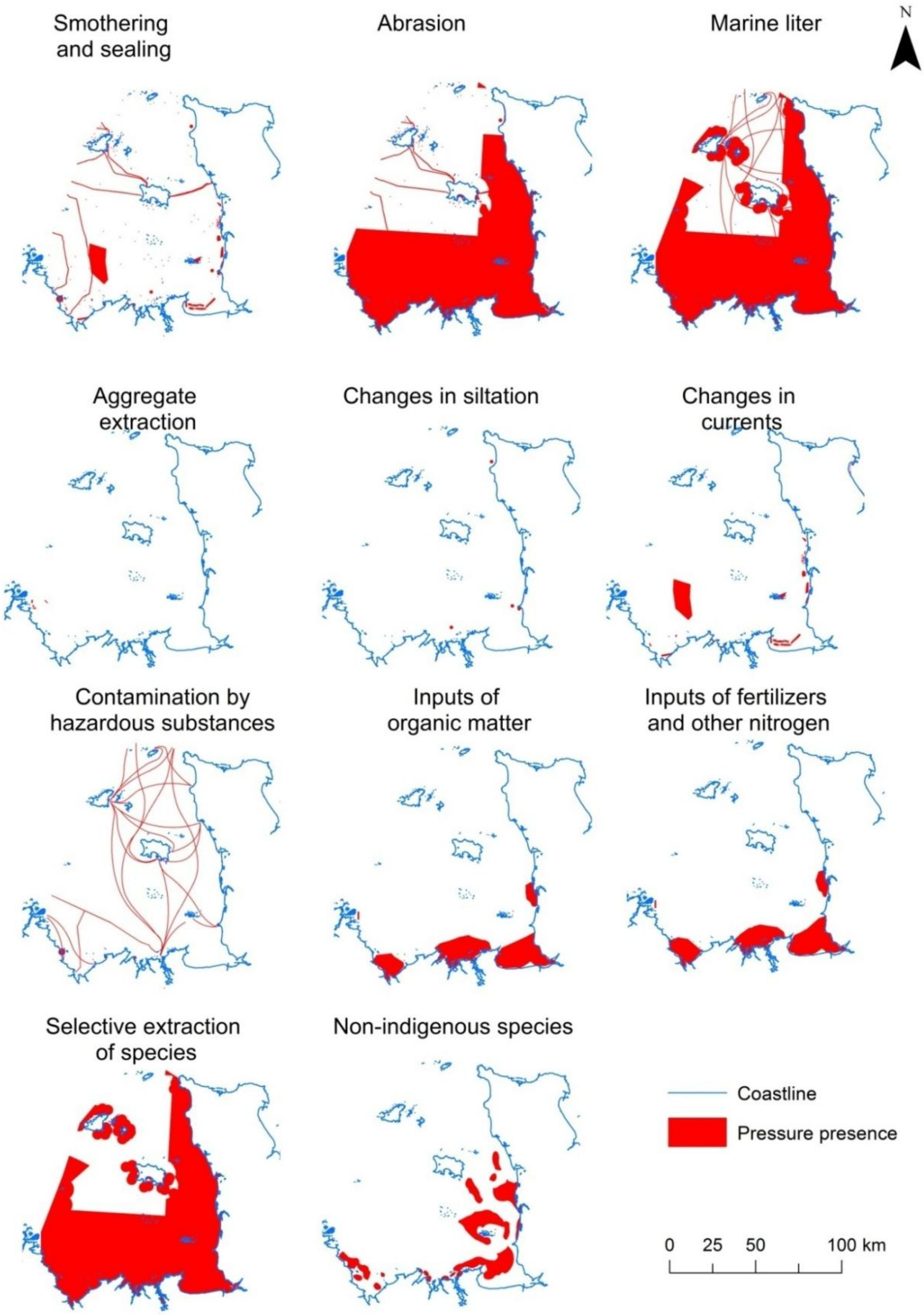


**Figure 3 Physical, chemical and biological pressures in the GNB according to the MSFD**

The physical pressures and impacts for marine habitats include smothering and sealing, interference in the hydrological process, physical disturbance and damage (AAMP et IFREMER, 2012; EC, 2008; OSPAR, 2010).

Smothering can be caused by man-made structures such as sites for disposal of dredge spoil, shipwrecks, submarine cables, or land reclamation for harbors and marinas building (Airoldi and Beckland, 2007; Bolam, 2012). Permanent constructions such as shellfish farms and offshore energy infrastructures can cause a sealing effect and alter locally the sediment structure (Crawford et al., 2003). Constructions impeding water movements such as offshore energy farms and shellfish farms may change currents with consequences on the hydrological processes (Defne et al., 2011; Karsten et al., 2008; Plew, 2011; Plew et al., 2005). Several human activities contribute to the creation of marine liter such as recreational fishing activities, professional fishing, marine traffic, shipwrecks and shellfish farming (Eastwood et al., 2007). Abrasion may have an important erosion impact on the seabed and can be caused by commercial fishing such as scallop dredging (Hall-Spencer, 2000), trawling (Kaiser et al., 2002), on-foot fishing (trampling) (Davenport and Davenport, 2006), aggregate extraction (de Groot, 1996; Desprez, 2000; ICES, 2009, pp. 1998–2004), submarine cables (OSPAR, 2009) and dredging activities (Guijarrogarcia et al., 2006). Most physical impacts on marine habitats alter the sediment grain size and chemistry, and may cause diverse changes on benthic communities and their functioning depending on the sensitivity of habitats (Bolam et al., 2006; Guarin, 1991; Hartstein and Rowden, 2004; Kaiser et al., 2006).

Analyzed chemical pressures to marine habitats include the contamination by hazardous substances, inputs of organic matter and inputs of fertilizers and other nitrogen compounds (Fabry et al., 2008; Halpern et al., 2007). Contamination by hazardous substances may result from the pollution from ships, harbor and marina activities and from inorganic pollutants (e.g., impervious surfaces) (Halpern et al., 2008). Inputs of fertilizers and phosphorus-rich substances (e.g. from point and diffuse sources including agriculture, aquaculture, atmospheric deposition), and inputs of organic matter (e.g. sewers, mariculture, riverine inputs) contribute for nutrient and organic matter enrichment, and is a major cause of eutrophication of coastal areas potentially leading to hypoxia and major changes in the ecosystem dynamics (Diaz and Rosenberg, 2008; Halpern et al., 2008).

The biological pressures in the GNB were evaluated through the impact of a non-indigenous species and fishing activities. The American slipper-limpet (*Crepidula fornicata*, L. 1758) expansion has had negative impacts on different ecosystem properties, such as the modification of the sediment, changes in the biogeochemical cycles and nutrient cycling, changes in primary production and long-term biodiversity loss, and the emergence of a new benthic community (Blanchard, 2009; Chauvaud et al., 2000; Cugier et al., 2010; de Montaudouin and Sauriau, 1999; Kostecki et al., 2011; Le Pape et al., 2004). The selective extraction of species through commercial and recreational fishing is also considered a biological pressure (AAMP et IFREMER, 2012; OSPAR, 2010).

The overall methodological workflow for assessing the habitat's vulnerability to deliver ES is depicted in figure 4 and explained subsequently.

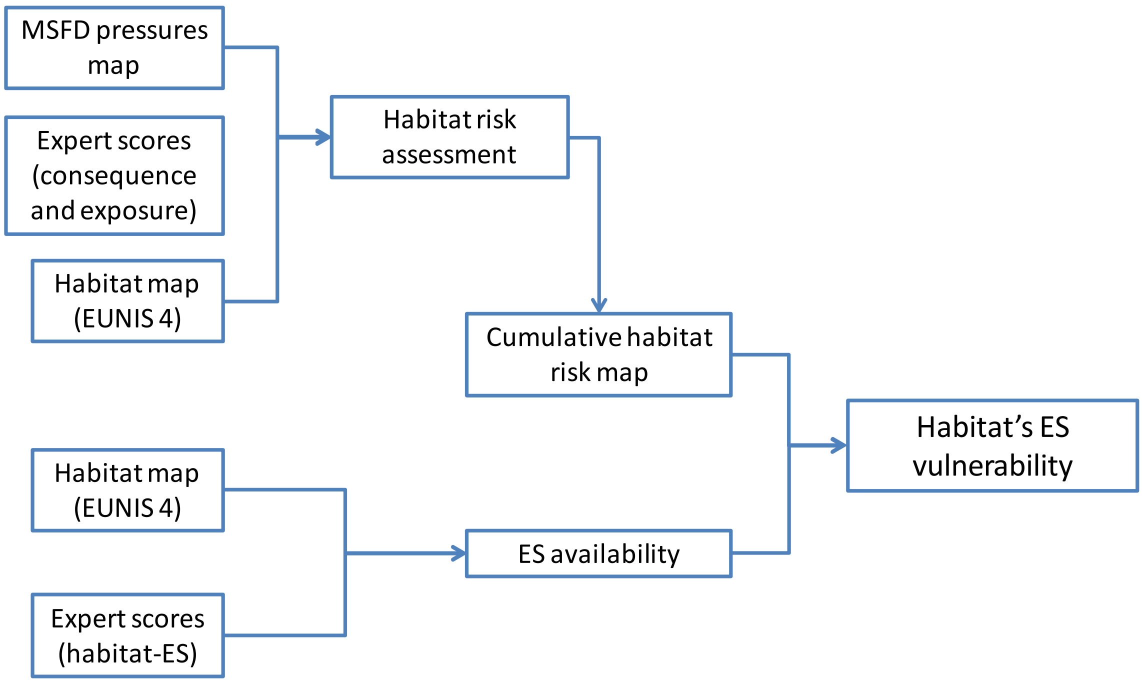


**Figure 4 Methodological workflow of this study**

### 2.3 Habitat Risk Assessment

The InVEST habitat risk assessment (HRA) model allows users to assess the risk posed to coastal and marine habitats by human activities and the potential consequences of exposure for the delivery of environmental services and biodiversity (Tallis et al., 2013). The likelihood of exposure of the habitat to the stressor and the consequence of this exposure was done using expert knowledge by assigning a rating to a set of criteria for each attribute (Table 3).

| | | **Score** | | | |
|---|---|---|---|---|---|
| **Criteria** | | 0 | 1 | 2 | 3 |
| Exposure | Data quality (DQ) | - | Limited | Adequate | Best |
| | Intensity | No score | Low | Medium | High |
| | Management | No score | Very effective | Somewhat effective | Not effective |
| | Buffer | Distance in m | | | |
| Consequence Resilience | Change in area | No score | Low loss (0-20%) | Medium loss (20-50%) | High loss (50-100%) |
| | Change in structure | No score | Low loss (0-20%) | Medium loss (20-50%) | High loss (50-100%) |
| | Natural disturbance | No score | Daily to weekly | Several times per year | Annually or less often |
| | Temporal overlap | No score | 0-4 mois | 4-8 mois | 8-12 mois |
| Consequence Recovery | Mortality | No score | High mortality (>=80%) | Moderate mortality (20-50%) | Low mortality (0-20%) |
| | Recrutement | No score | Annual or more often | Every 1-2 years | Every 2+ years |
| | Connectivity | No score | High dispersal (+ 100 km) | Medium dispersion (10-100km) | Low dispersion (<10km) |
| | Regeneration | No score | Less than 1 year | 1-10 years | 10+ years |

**Table 3 Exposure and consequence scoring criteria (Tallis et al., 2013)**

If the stressor *j* does not spatially overlap an habitat *i*, both the exposure value $e_i$ and the consequence value $c_i$ are set to 0 as well as the risk value. The model also enables to score the quality of the data and the weighted importance of the criteria. In this case, an equal importance for all criteria was used. Exposure *E* (1) and consequence *C* (2) scores are calculated as weighted averages of the exposure values $e_i$ and consequence values $c_i$ for each criterion *i* as follows (InVEST, 2013):

$$E = \frac{\sum_{i=1}^{N} \frac{e_i}{d_i w_i}}{\sum_{i=1}^{N} \frac{1}{d_i w_i}} \tag{1}$$

$$C = \frac{\sum_{i=1}^{N} \frac{c_i}{d_i w_i}}{\sum_{i=1}^{N} \frac{1}{d_i w_i}} \tag{2}$$

where $d_i$ is the data quality rating for criterion *i*, $w_i$ is the importance weighing for criterion *i* and *N* is the number of criteria evaluated for each habitat.

The risk to habitat *i* caused by stressor *j* ($R_{ij}$) is calculated as (3):

$$R_{ij} = \sqrt{(E-1)^2 + (C-1)^2} \tag{3}$$

Finally, the cumulative risk for habitat *i* is the sum of all risk scores for each habitat (4).

$$R_i = \sum_{j=1}^{J} R_{ij} \tag{4}$$

The values for each criterion in the model were previously scored using the individual input layers (Table 2). These values were then averaged and, for the spatial influence criteria, the maximum value was used. The data quality criterion is a scale ranging from 1, indicating a limited knowledge of the data quality, to 3, indicating increasingly reliable data.

The scoring of the exposure to the different MSFD pressures was done according to intensity, for example, activities that occur the whole year have higher intensity than the ones that occur only for 1 or 2 months in the year, and management effectiveness, which are strategies that reduce or enhance exposure (Table 3). The buffer distance represents the spatial influence of each stressor.

The scoring of the resilience attributes was done according to (Tallis et al., 2013): changes in area (measured as the percent change in areal extent of a habitat when exposed to a stressor), changes in structure (for biotic habitats, is the percentage change in structural density of the habitat when exposed to a stressor; for abiotic habitats, is the amount of structural damage sustained by the habitat), natural disturbance (naturally frequently habitats perturbed in a way similar to the anthropogenic stressor are more resistant to additional anthropogenic stress) and temporal overlap (the duration of time that the habitat and the stressor experience spatial overlap) (Table 3).

The scoring of the recovery attributes was done according to (Tallis et al., 2013): mortality (habitats with high natural mortality rates are usually more productive and more capable of recovery), recruitment (frequent recruitment increases recovery potential), connectivity (for biotic habitats only, dispersal and close spacing of habitat patches increases the recovery potential of a habitat), and regeneration (biotic habitats that reach maturity earlier are likely to be able to recover faster from disturbance; for abiotic habitats, shorter recovery times for habitats decrease the consequences of exposure to human activities (Table 3).

In tables 4 and 5 are presented, respectively, the values used for exposure and consequence (recovery) attributes. The values used for the resilience attributes are presented as supplementary material (Table B.1).

| Pressure # | MSFD pressure | Intensity | DQ | Management | DQ | Buffer (m) |
|---|---|---|---|---|---|---|
| **1** | Smothering and sealing | 2 | 2 | 2 | 2 | 4000 |
| **2** | Abrasion | 2 | 2 | 2 | 2 | 4000 |
| **3** | Selective extraction | 3 | 3 | 2 | 2 | 1000 |
| **4** | Marine liter | 2 | 2 | 3 | 2 | 10000 |
| **5** | Change in currents | 3 | 3 | 2 | 2 | 4000 |
| **6** | Contamination by hazardous substances | 2 | 3 | 2 | 2 | 10000 |
| **7** | Changes in siltation | 2 | 3 | 3 | 2 | 4000 |
| **8** | Input of fertilizers and other nitrogen | 3 | 2 | 3 | 2 | 30000 |
| **9** | Inputs of organic matter | 3 | 2 | 3 | 2 | 30000 |
| **10** | Non-indigenous species | 3 | 2 | 3 | 2 | 4000 |
| **11** | Selective extraction of species | 2 | 2 | 3 | 1 | 3000 |

**Table 4 Exposure of habitats to MSFD pressures (DQ = data quality)**

| Habitat | Mortality | DQ | Recruitment | DQ | Connectivity | DQ | Regeneration | DQ |
|---|---|---|---|---|---|---|---|---|
| A1 | 2 | 2 | 1 | 3 | 2 | 3 | 3 | 2 |
| A2.22 | 2 | 3 | 1 | 3 | 3 | 3 | 0 | 1 |
| A2.23 | 2 | 3 | 1 | 3 | 2 | 3 | 2 | 2 |
| A2.24 | 2 | 3 | 1 | 3 | 2 | 3 | 2 | 2 |
| A2.31 | 2 | 3 | 1 | 3 | 2 | 3 | 2 | 2 |
| A2.5 | 2 | 2 | 1 | 2 | 3 | 2 | 2 | 2 |
| A2.61 | 2 | 2 | 2 | 3 | 3 | 2 | 2 | 2 |
| A2.71 | 2 | 3 | 3 | 3 | 2 | 3 | 2 | 3 |
| A3.A4 | 2 | 2 | 1 | 3 | 2 | 2 | 3 | 2 |
| A4.13 | 3 | 2 | 1 | 3 | 2 | 2 | 3 | 1 |
| A4.21 | 3 | 2 | 1 | 3 | 2 | 3 | 3 | 1 |
| A5.13 | 3 | 3 | 1 | 3 | 2 | 3 | 3 | 1 |
| A5.23 | 3 | 3 | 1 | 3 | 2 | 2 | 2 | 2 |
| A5.24 | 2 | 3 | 1 | 3 | 2 | 3 | 2 | 2 |
| A5.43 | 2 | 3 | 1 | 3 | 2 | 3 | 2 | 2 |
| A5.51 | 2 | 2 | 0 | 1 | 0 | 1 | 3 | 3 |
| A5.53 | 3 | 1 | 0 | 1 | 0 | 1 | 0 | 1 |

**Table 5 Consequences of exposure scores (recovery attributes) (DQ= Data quality).**

## 2.4 ES availability mapping

Although there are more ES provided by the GNB habitats, the one's listed in table 6 were selected as the most relevant for this study. The support and regulation services were grouped into a single category designated "regulating and maintenance" (Liquete et al., 2013). Biodiversity is treated as a cultural service and it concerns only the remarkable species of the GNB.

| Type of ES | Ecosystem Service |
|---|---|
| Provisioning | Food provision |
| | Raw material |
| Regulating and maintenance | Climate regulation and composition of the atmosphere (carbon sequestration and greenhouse gas emissions) |
| | Prevention/protection against disturbance |
| | Water quality regulation /buffering effect on waste and pollutants |
| | Shoreline stabilization |
| | Resistance and resilience |
| Cultural | Cultural heritage and identity |
| | Cognitive benefits |
| | Recreation |
| | Remarkable biodiversity |

**Table 6 Relevant ES identified for the GNB habitats**

A matrix that links the 17 EUNIS habitats to the availability of 11 ES was created using expert knowledge (Table 7). The scores reflected the availability of ES provided by the habitats ($A_i$) for each type of service and could have the values of 0 (absent), 1 (weak), 2 (medium) or 3 (strong).

Food provision benefits included the analysis of 20 species that are usually fished in the GNB. The provision of raw materials included the analysis of aggregate and crepidula extraction activities. The cultural services included the analysis of 10 recreational activities such as bird watching, recreational fishing and several recreation sports. The cognitive benefits included nature recreation and research activities. The regulating and maintenance services did not include any sub-category and were evaluated as a whole. The ES availability scores for each ES are presented as supplementary material (Table C.1).

To enable a common comparison among the 3 three types of ES, all values were transformed into an interval between 0 and 1, by subtracting the minimum value and dividing by the difference between the maximum and minimum value (Parravicini et al., 2012). The information of table 7 was used to build maps of ES availability in the GNB on a grid of 5x5 km.

| Habitat | Provisioning ($a_{Pi}$) | Range [0-1] | Regulating and maintenance ($a_{RMi}$) | Range [0-1] | Cultural ($a_{Ci}$) | Range [0-1] |
|---|---|---|---|---|---|---|
| A1 | 0 | 0.00 | 4 | 0.30 | 15 | 0.67 |
| A2.22 | 0 | 0.00 | 1 | 0.00 | 4 | 0.14 |
| A2.23 | 15 | 0.63 | 4 | 0.30 | 21 | 0.95 |
| A2.24 | 12 | 0.50 | 4 | 0.30 | 22 | 1.00 |
| A2.31 | 9 | 0.38 | 6 | 0.50 | 9 | 0.38 |
| A2.5 | 7 | 0.29 | 11 | 1.00 | 21 | 0.95 |
| A2.61 | 0 | 0.00 | 7 | 0.60 | 5 | 0.19 |
| A2.71 | 0 | 0.00 | 3 | 0.20 | 17 | 0.76 |
| A3.A4 | 7 | 0.29 | 3 | 0.20 | 19 | 0.86 |
| A4.13 | 13 | 0.54 | 2 | 0.10 | 4 | 0.14 |
| A4.21 | 8 | 0.33 | 2 | 0.10 | 4 | 0.14 |
| A5.13 | 24 | 1.00 | 2 | 0.10 | 12 | 0.52 |
| A5.23 | 2 | 0.08 | 5 | 0.40 | 1 | 0.00 |
| A5.24 | 13 | 0.54 | 3 | 0.20 | 12 | 0.52 |
| A5.43 | 19 | 0.79 | 3 | 0.20 | 12 | 0.52 |
| A5.51 | 10 | 0.42 | 2 | 0.10 | 5 | 0.19 |
| A5.53 | 7 | 0.29 | 5 | 0.40 | 11 | 0.48 |

**Table 7 ES availability by habitat**

A5.13 and A5.43 are the habitats that provide the highest availability of provisioning services ($a_{Pi}$). Regulating and maintenance services ($a_{RMi}$) are mostly provided by habitat A2.5. Cultural services ($a_{Ci}$) are mostly provided by the habitats A2.23, A2.24 and A.25.

### 2.5 Marine habitats ES vulnerability and scenarios of change

In this study, we assess the habitats potential to deliver ES using habitat's vulnerability as a proxy. The habitat's vulnerability is an increasing function of exposure and impact (Metzger et al., 2006). We consider the adaptive capacity of the habitat's proportional to the existing level of ES availability ($A_i$). The habitats ES potential is less vulnerable where the habitats already provide more ES. Thus, the habitat's vulnerability (*Vi*) is obtained by dividing the cumulative risk for habitat ($R_i$) by the ES availability level ($A_i$) (5).

$$V_i = R_i / A_i \qquad (5)$$

Two hypothetical scenarios were created to show the stakeholders how changes in management options may influence habitat's ability to deliver ES. The first scenario promotes the development of human activities by increasing the intensity of pressures to the maximum possible value (3, high) and decreasing the management effectiveness to the minimum (3, not effective). The second scenario strengthens the conservation measures by decreasing the intensity of pressures to the minimum possible value (1, low) and increasing the management effectiveness to the maximum (1, very effective). Regarding the spatial influence of the pressures, these are increased in 100% in the first scenario whereas, in the second scenario, they are decreased by 50%.

The change of the habitats vulnerability in a given scenario relative to the baseline can be calculated as (6):

$$VCI_x = \left[\frac{V_{SCExj} - V_{BASxi}}{V_{BASxi}}\right] * 100 \qquad (6)$$

where $VCI_x$ is the vulnerability change index for delivering ES of type x, $V_{BASxi}$ is the baseline habitat's vulnerability for delivering ES of type x at time i and $V_{SCExj}$ is the habitat's vulnerability scenario for delivering ES of type x at time j.

## 3. Results

### 3.1 Habitat Risk Assessment

The map of figure 5 depicts, using a 5x5 km cell, the sum of all cumulative risk scores for all habitats. As expected, the near shore areas exhibit higher risk values. This means that these habitats are more exposed to MSFD pressures unlike the habitats in the offshore areas of the GNB.

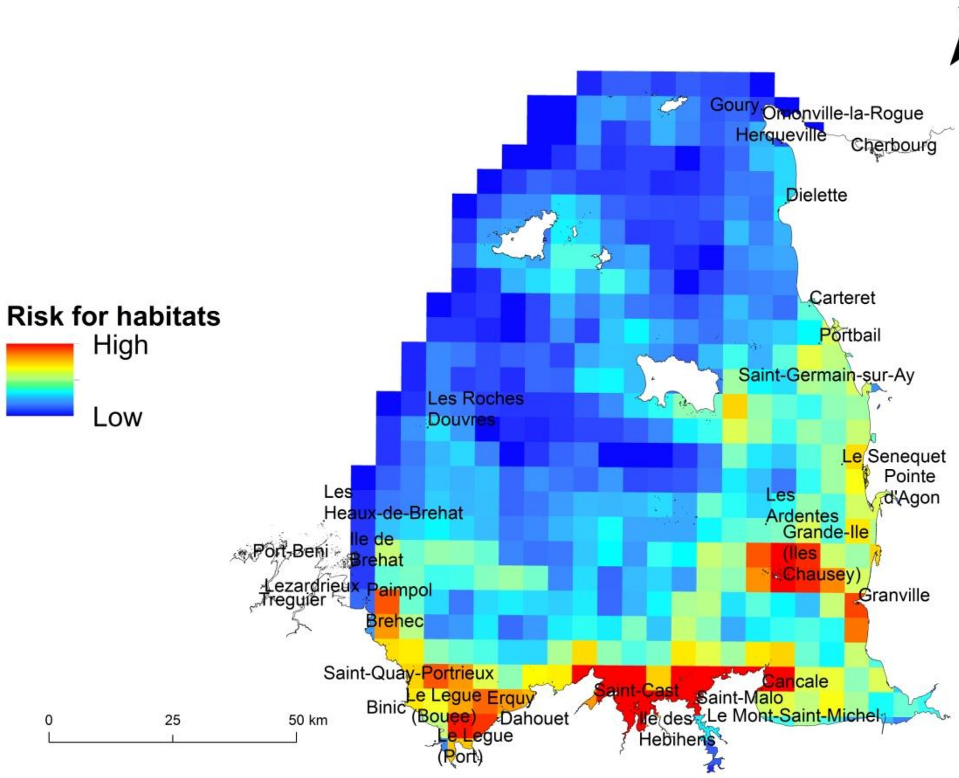


**Figure 5 Cumulative habitat risk for the GNB**

### 3.2 ES availability maps

The maps of figure 6 depict, using a 5x5 km cell, the ES availability for each type of ES. These maps were created using the information of table 7.

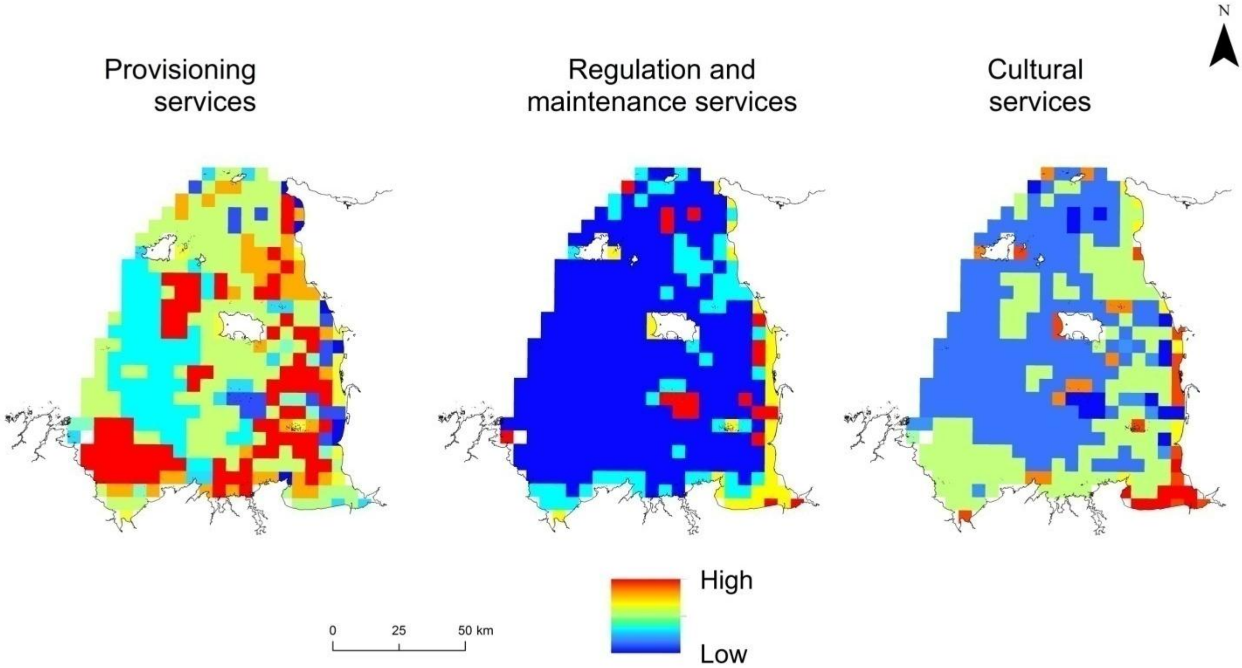


**Figure 6 ES availability by type of service**

### 3.3 Marine habitat's potential to deliver ES and scenarios of change

The maps of figure 7 depict, using a 5x5 km cell, the habitat's vulnerability to deliver each type of service for the baseline and the alternative scenarios. The resulting maps show the areas sensitive to the management actions.

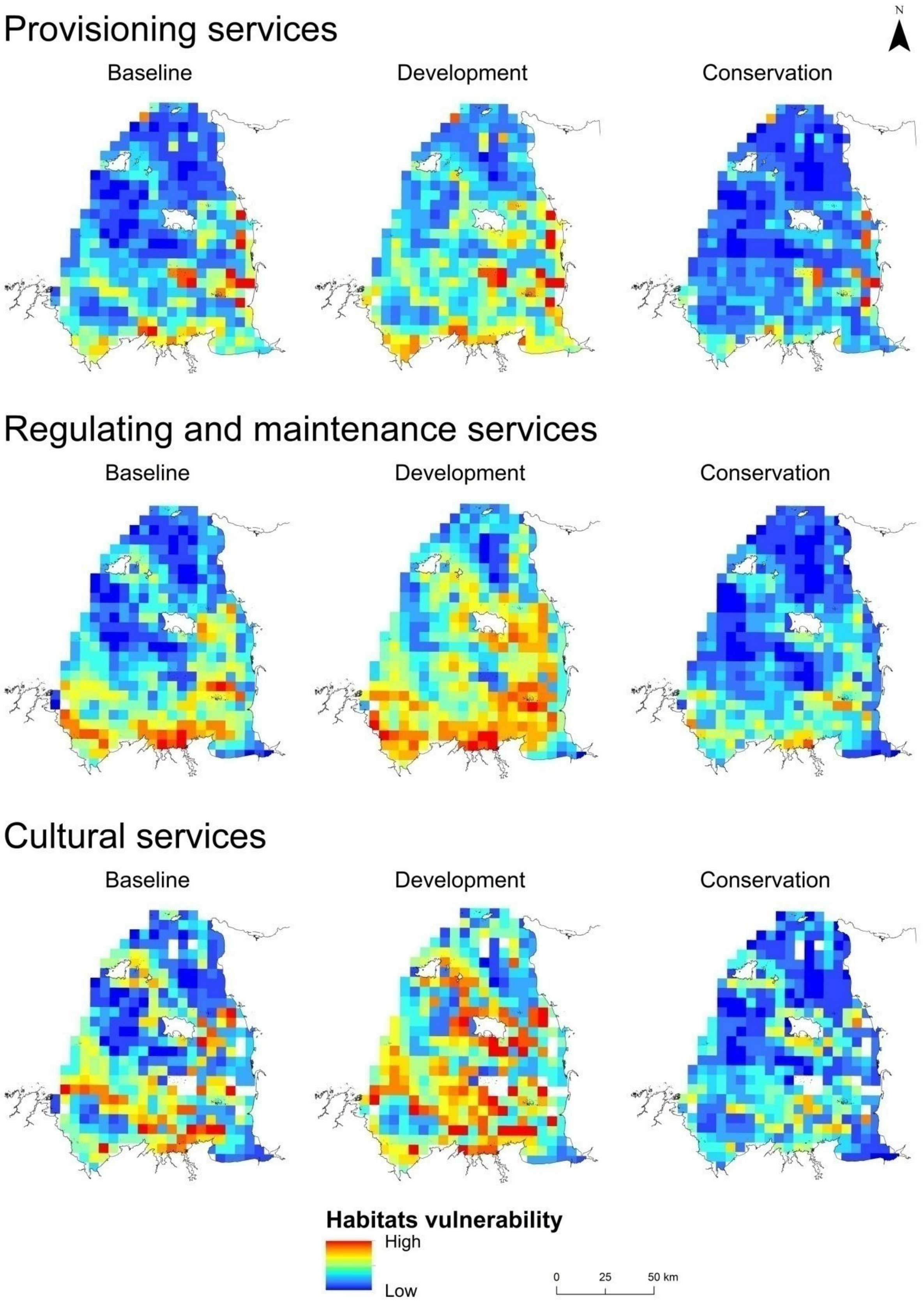


**Figure 7 Habitat's ES vulnerability and scenario changes**

Table 8 shows the changes on the habitat's vulnerability index ($VCI_x$) to deliver ES for each scenario using the baseline as reference.

| | | Provisioning | | Regulating and maintenance | | Cultural | |
|---|---|---|---|---|---|---|---|
| Habitat | Description | $VCI_{Development}$ (%) | $VCI_{Conservation}$ (%) | $VCI_{Development}$ (%) | $VCI_{Conservation}$ (%) | $VCI_{Development}$ (%) | $VCI_{Conservation}$ (%) |
| A1 | Littoral rock and other hard substrata | 49.6 | -32.3 | 32.3 | -39.2 | 31.7 | -38.9 |
| A2.22 | Barren or amphipod-dominated mobile sand shores | 26.8 | -42.4 | 0.0 | 0.0 | 26.8 | -42.5 |
| A2.23 | Polychaete/amphipod-dominated fine sand shores | 47.6 | -34.8 | 36.4 | -41.7 | 35.5 | -42.1 |
| A2.24 | Polychaete/bivalve-dominated muddy sand shores | 59.1 | -35.1 | 58.1 | -35.3 | 58.5 | -35.0 |
| A2.31 | Polychaete/bivalve-dominated mid estuarine mud shores | 5.0 | -56.0 | 0.0 | 0.0 | 5.0 | -56.0 |
| A2.5 | Coastal saltmarshes and saline reedbeds | 67.9 | -38.7 | 56.7 | -42.6 | 62.2 | -40.4 |
| A2.61 | Seagrass beds on littoral sediments | - | - | - | - | - | - |
| A2.71 | Littoral [Sabellaria] reefs | 26.7 | -44.8 | 23.5 | -47.0 | 23.2 | -47.2 |
| A3_A4 | Infralittoral rock and other hard substrata / Circalittoral | 27.8 | -41.4 | 25.1 | -41.7 | 26.2 | -41.3 |
| A4.13 | Mixed faunal turf communities on circalittoral rock | 38.9 | -38.4 | 43.7 | -36.7 | 44.5 | -36.4 |
| A4.21 | Echinoderms and crustose communities on circalittoral rock | 46.8 | -39.8 | 0.0 | 0.0 | 46.9 | -39.7 |
| A5.13 | Circalittoral coarse sediment | 36.6 | -35.6 | 39.7 | -32.7 | 41.6 | -33.0 |
| A5.23 | Infralittoral fine sand | 42.1 | -38.8 | 34.0 | -40.2 | 43.0 | -34.4 |
| A5.24 | Infralittoral muddy sand | 37.1 | -39.5 | 0.0 | -39.1 | 35.0 | -40.0 |
| A5.43 | Infralittoral mixed sediments | 46.5 | -35.3 | 42.8 | -39.5 | 44.6 | -39.7 |
| A5.51 | Maerl beds | 33.3 | -35.0 | 27.6 | -36.5 | 30.6 | -34.8 |
| A5.53 | Sublittoral seagrass beds | 54.9 | -30.3 | 61.9 | -29.3 | 71.1 | -27.1 |

**Table 8 Changes in the habitat's vulnerability index to deliver ES (the most important habitats for each type of ES are highlighted)**

If a development scenario is adopted, the habitat's vulnerability for delivering provisioning ES could increase between 36.6% and 46.5% in, respectively, the habitats A5.13 and A5.43. In the conservation scenario, this value is likely to decrease, respectively, 35.6% and 35.3% for these habitats. A development scenario would increase habitat's A2.5vulnerability for delivering regulating and maintenance services in 56.7%. A conservation scenario would decrease this value in about 42.6%. Finally, a development scenario could also increase habitats A2.23, A2.24 and A2.5 vulnerability in, respectively, 35.5%, 58.5% and 62.2%. A conservation scenario would decrease these values in, respectively, 42.1%, 35.0% and 40.4%. Values for habitat A2.61 are not presented due to the small area occupied by these habitats (<0.5 $km^2$).

### 3.4 Demand of human activities for habitats

After identifying the most important habitats for supplying the different type of ES, it is possible to know which human activities interact with these habitats in the various scenarios. This enables defining which activities should be more managed from an EBM point of view considering the habitat's vulnerability. Since we are using a GIS, one can easily retrieve this information through a spatial query (Table 9). Table 9 shows that the activities that demand more habitat space are the fishing activities (professional and recreation).

| Habitats | Dredging | Harbors | Marinas | Shipwrecks | Submarine cables | Offshore energy | Shellfish farms | On foot recreational fishing | Recreational boat fishing | Professional fishing | Marine traffic |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A2.23 | 0.3 | 2.0 | 0.3 | 0.5 | 0.6 | - | 12.6 | 74.7 | 60.6 | 85.1 | 0.2 |
| A2.24 | - | 0.4 | 0.1 | 0.0 | - | - | 8.1 | 90.7 | 48.5 | 85.0 | - |
| A2.5 | - | 0.8 | 0.2 | 0.3 | - | - | 0.1 | 86.5 | 21.6 | 53.5 | - |
| A4.13 | 0.0 | 0.0 | 0.0 | 0.3 | 1.4 | 0.4 | 0.1 | 0.1 | 16.7 | 40.9 | 6.8 |
| A5.13 | 0.1 | 0.0 | 0.0 | 0.2 | 2.6 | 2.2 | - | - | 16.2 | 77.7 | 5.3 |

**Table 9 Habitat area (%) occupied by each human activity**

## 4. Discussion

This study includes a modeling approach that incorporates the knowledge from scientists and managers of the GNB enabling an informed discussion with the stakeholders about risks for habitats and their impact on ES potential. However, several limitations were identified that should be carefully considered when using these results.

The data scarcity and quality are critical aspects difficult to overcome in this study. The results were not validated due to the lack of suitable empirical data. The geographical datasets needed for this modeling approach are hard to find due to a varied number of reasons which may include disparate collection dates, different scales and/or different data production purposes (e.g., as is the case of the habitat map of the GNB). The lack of data is particularly important in the NW section of the GNB. A considerable effort was made to integrate coherently dispersed geographical data and describe it with the adequate data quality score used in the HRA model. However, the quality of some datasets should be improved in future versions of the model.

Although there are some publications that describe the ecological state of the marine ecosystems (AAMP et IFREMER, 2012), these are context-dependent and there is a variable degree of knowledge of the impacts of the pressures.

Finally, the HRA model assumes additive effects of pressures which is highly questionable as some human pressures may have synergy and/or antagonism effects that are not considered (Crain et al., 2008; Halpern et al., 2008).

## 5. Conclusions

This study characterized the habitats vulnerability as a proxy of their ability to deliver different types of ES in the GNB. The modeling approach involved the use of expert knowledge and geographical data to describe the habitats (EUNIS classification at level 4) and their pressures defined according to the MSFD. The most important habitats for the supply of ES and the human activities that require more surface area of these habitats were also identified. The use of scenarios enabled the understanding of potential degradation or improvement as a consequence of alternative management options. These scenarios will be adapted to specific management options required by the stakeholders.

Despite the important above-mentioned limitations, this project constitutes an outstanding opportunity to integrate available expert knowledge and to use datasets that have been produced over the years by several institutions that work in the sea environment of the GNB. These results should be regarded as a first step in characterizing the GNB using an integrated EBM approach aiming to provide useful elements for discussion and information to better design the future marine protected area with the stakeholders. Future work will include the study of more services such as primary production, carbon storage and nutrient cycling. Data quality improvement and the description of the activities that are causing the highest pressure on the habitats and their services are also envisaged in a near future.

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**Supplementary Material to: "Marine habitat's ecosystem service potential: a vulnerability approach in the Normand-Breton (Saint Malo) Gulf, France" by Cabral et al.**

Table A.1. GIS layers preprocessing.

| GIS layers | Source | Type | Preprocessing |
|---|---|---|---|
| Recreational on-foot fishing | AAMP | Polygon | Selection of the foreshore area |
| Recreational boat fishing | AAMP | Polygon | Buffer of 3000m around points and inside the sailing areas |
| Professional fishing | Ifremer, SIH, 2012 | Polygon | Density of ships per month per statistical sub-rectangle. Selection of bottom trawl and dredging engines for abrasion. All engine types for the other pressures. Density >0.2 |
| Dredge spoil disposal sites | AAMP | Point | Buffer 1000m |
| Offshore energy | AAMP | Polygon | None |
| Harbours | AAMP | Point | Buffer according to number of ships: < 5 = 250m; >=5 and <25 = 500m; >=25 and <100=1000m; >=100=2000m |
| Marinas | AAMP | Point | Buffer of 250m |
| Marine traffic | AAMP | Polyline | None |
| Shipwrecks | AAMP | Point | Buffer of 250m |
| Submarine cables | AAMP | Polyline | Buffer of 250m |
| Shellfish farms | AAMP | Polygon | Convex hull |
| Aggregate extraction | AAMP | Polygon | None |
| Anchorages | AAMP | Point | Buffer according to the capacity: <10 = 250m; > =10 and <100 = 500m; >=100 = 2000m |
| Ammunition | AAMP | Point and polygon | Buffer of 500m for the points |
| *Crepidula fornicata* | (Noël et al, 1995) | Polygon | Selection of densities > 50g |
| Nutrients | NCEAS | Raster | Reclassification in 2 classes using natural breaks, conversion to vector |
| Organic pollutants | NCEAS | Raster | Reclassification in 2 classes using natural breaks, conversion to vector |

Table B.1. Consequences of exposure scores (resilience attributes). (DQ=Data quality)

| Habitat | Pressure # | Change in area | DQ | Change in structure | DQ | Natural disturbance | DQ | Temporal overlap |
|---|---|---|---|---|---|---|---|---|
| A1 | 1 | 0 | 1 | 1 | 2 | 1 | 3 | 2 |
| | 2 | 0 | 1 | 1 | 2 | 1 | 3 | 2 |
| | 3 | 0 | 1 | 2 | 3 | 1 | 3 | 3 |
| | 4 | 0 | 1 | 0 | 1 | 1 | 3 | 1 |
| | 5 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 6 | 0 | 1 | 1 | 1 | 1 | 3 | 1 |
| | 7 | 0 | 1 | 1 | 3 | 1 | 3 | 3 |
| | 8 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 9 | 0 | 1 | 1 | 1 | 1 | 3 | 3 |
| | 10 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 11 | 0 | 1 | 1 | 2 | 1 | 3 | 2 |
| A2.22 | 1 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 2 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 3 | 0 | 1 | 3 | 1 | 1 | 3 | 2 |
| | 4 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 5 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 6 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 7 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 8 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 9 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 10 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 11 | 0 | 1 | 0 | 1 | 1 | 3 | 1 |
| A2.23 | 1 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 2 | 0 | 1 | 0 | 1 | 1 | 3 | 1 |
| | 3 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 4 | 0 | 1 | 0 | 1 | 1 | 3 | 1 |
| | 5 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 6 | 1 | 1 | 1 | 1 | 1 | 3 | 2 |
| | 7 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 8 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 9 | 0 | 1 | 1 | 1 | 1 | 3 | 2 |
| | 10 | 0 | 1 | 1 | 2 | 1 | 3 | 2 |
| | 11 | 0 | 1 | 0 | 1 | 1 | 3 | 1 |
| A2.24 | 1 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 2 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 3 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 4 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 5 | 0 | 1 | 1 | 1 | 1 | 3 | 1 |
| | 6 | 0 | 1 | 1 | 1 | 1 | 3 | 1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 7 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 8 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 9 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 10 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 11 | 0 | 1 | 1 | 1 | 1 | 3 | 1 |
| A2.31 | 1 | 0 | 1 | 0 | 1 | 1 | 3 | 1 |
| | 2 | 0 | 1 | 0 | 1 | 1 | 3 | 1 |
| | 3 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 4 | 0 | 1 | 1 | 1 | 1 | 3 | 1 |
| | 5 | 1 | 1 | 1 | 1 | 1 | 3 | 2 |
| | 6 | 0 | 1 | 1 | 1 | 1 | 3 | 1 |
| | 7 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 8 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 9 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 10 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 11 | 0 | 1 | 0 | 1 | 1 | 3 | 2 |
| A2.5 | 1 | 0 | 1 | 0 | 1 | 3 | 2 | 1 |
| | 2 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 3 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 4 | 0 | 1 | 1 | 1 | 2 | 2 | 1 |
| | 5 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 6 | 0 | 1 | 0 | 1 | 3 | 2 | 1 |
| | 7 | 1 | 3 | 1 | 2 | 3 | 2 | 3 |
| | 8 | 1 | 2 | 1 | 2 | 3 | 1 | 2 |
| | 9 | 0 | 1 | 0 | 1 | 3 | 1 | 0 |
| | 10 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 11 | 1 | 2 | 1 | 2 | 3 | 2 | 2 |
| A2.61 | 1 | 0 | 2 | 0 | 1 | 3 | 2 | 1 |
| | 2 | 0 | 1 | 1 | 2 | 3 | 2 | 1 |
| | 3 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 4 | 0 | 2 | 1 | 2 | 3 | 2 | 1 |
| | 5 | 0 | 1 | 2 | 2 | 3 | 2 | 1 |
| | 6 | 0 | 2 | 0 | 2 | 3 | 2 | 0 |
| | 7 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 8 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 9 | 2 | 3 | 2 | 3 | 3 | 2 | 2 |
| | 10 | 1 | 2 | 1 | 2 | 3 | 2 | 1 |
| | 11 | 0 | 1 | 0 | 1 | 2 | 2 | 1 |
| A2.71 | 1 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 2 | 1 | 1 | 1 | 2 | 3 | 2 | 1 |
| | 3 | 2 | 2 | 2 | 2 | 3 | 2 | 2 |
| | 4 | 1 | 1 | 1 | 2 | 3 | 2 | 2 |
| | 5 | 1 | 1 | 2 | 1 | 3 | 2 | 3 |
| | 6 | 0 | 1 | 1 | 2 | 2 | 2 | 1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 7 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 8 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 9 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 10 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 11 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| A3.A4 | 1 | 0 | 1 | 0 | 1 | 3 | 2 | 1 |
| | 2 | 0 | 1 | 1 | 1 | 3 | 2 | 1 |
| | 3 | 2 | 1 | 2 | 1 | 3 | 2 | 3 |
| | 4 | 0 | 1 | 0 | 1 | 3 | 2 | 1 |
| | 5 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 6 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 7 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 8 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 9 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 10 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 11 | 0 | 1 | 1 | 1 | 3 | 2 | 1 |
| A4.13 | 1 | 0 | 1 | 0 | 1 | 3 | 2 | 1 |
| | 2 | 0 | 1 | 0 | 1 | 3 | 2 | 1 |
| | 3 | 0 | 1 | 0 | 1 | 3 | 2 | 3 |
| | 4 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 5 | 0 | 1 | 1 | 1 | 3 | 2 | 2 |
| | 6 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 7 | 0 | 1 | 1 | 1 | 3 | 2 | 2 |
| | 8 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 9 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 10 | 1 | 1 | 1 | 1 | 3 | 2 | 3 |
| | 11 | 0 | 1 | 1 | 1 | 3 | 2 | 1 |
| A4.21 | 1 | 0 | 1 | 0 | 1 | 3 | 2 | 1 |
| | 2 | 0 | 1 | 0 | 1 | 3 | 2 | 1 |
| | 3 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 4 | 0 | 1 | 0 | 1 | 3 | 2 | 1 |
| | 5 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 6 | 0 | 1 | 1 | 1 | 3 | 2 | 1 |
| | 7 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 8 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 9 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 10 | 1 | 2 | 1 | 2 | 3 | 2 | 3 |
| | 11 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| A5.13 | 1 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 2 | 0 | 1 | 0 | 1 | 3 | 2 | 1 |
| | 3 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 4 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 5 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 6 | 1 | 1 | 1 | 1 | 3 | 2 | 2 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 7 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 8 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 9 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 10 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 11 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| A5.23 | 1 | 0 | 1 | 1 | 1 | 2 | 2 | 1 |
| | 2 | 0 | 1 | 0 | 1 | 2 | 2 | 1 |
| | 3 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 4 | 0 | 1 | 1 | 1 | 2 | 2 | 1 |
| | 5 | 0 | 1 | 1 | 1 | 3 | 2 | 2 |
| | 6 | 0 | 1 | 1 | 1 | 3 | 2 | 1 |
| | 7 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 8 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 9 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 10 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 11 | 0 | 1 | 0 | 1 | 2 | 3 | 1 |
| A5.24 | 1 | 0 | 1 | 1 | 1 | 1 | 3 | 1 |
| | 2 | 0 | 1 | 1 | 1 | 1 | 3 | 1 |
| | 3 | 0 | 1 | 1 | 1 | 1 | 3 | 2 |
| | 4 | 0 | 1 | 0 | 1 | 1 | 3 | 1 |
| | 5 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 6 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 7 | 1 | 1 | 1 | 1 | 1 | 3 | 3 |
| | 8 | 0 | 1 | 0 | 1 | 2 | 2 | 0 |
| | 9 | 0 | 1 | 0 | 1 | 2 | 2 | 0 |
| | 10 | 0 | 1 | 0 | 1 | 1 | 3 | 0 |
| | 11 | 1 | 1 | 1 | 1 | 2 | 3 | 2 |
| A5.43 | 1 | 0 | 1 | 0 | 1 | 2 | 2 | 0 |
| | 2 | 0 | 1 | 0 | 1 | 2 | 2 | 1 |
| | 3 | 0 | 1 | 0 | 1 | 2 | 2 | 0 |
| | 4 | 1 | 1 | 1 | 1 | 2 | 2 | 1 |
| | 5 | 0 | 1 | 0 | 1 | 2 | 2 | 0 |
| | 6 | 0 | 1 | 0 | 1 | 2 | 2 | 0 |
| | 7 | 1 | 2 | 2 | 2 | 2 | 2 | 3 |
| | 8 | 0 | 1 | 0 | 1 | 2 | 2 | 0 |
| | 9 | 0 | 1 | 0 | 1 | 2 | 2 | 0 |
| | 10 | 0 | 1 | 2 | 1 | 2 | 2 | 2 |
| | 11 | 1 | 2 | 1 | 2 | 2 | 2 | 2 |
| A5.51 | 1 | 0 | 1 | 1 | 1 | 2 | 2 | 1 |
| | 2 | 0 | 1 | 1 | 1 | 2 | 2 | 1 |
| | 3 | 0 | 1 | 1 | 1 | 2 | 2 | 1 |
| | 4 | 0 | 1 | 1 | 1 | 2 | 2 | 1 |
| | 5 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | 6 | 0 | 1 | 0 | 1 | 2 | 2 | 1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 7 | 0 | 1 | 0 | 1 | 2 | 2 | 0 |
| | 8 | 0 | 1 | 1 | 1 | 2 | 2 | 2 |
| | 9 | 0 | 1 | 0 | 1 | 2 | 2 | 0 |
| | 10 | 0 | 1 | 0 | 1 | 2 | 2 | 0 |
| | 11 | 1 | 2 | 1 | 1 | 3 | 2 | 2 |
| A5.53 | 1 | 1 | 1 | 1 | 2 | 3 | 2 | 1 |
| | 2 | 0 | 1 | 1 | 2 | 3 | 2 | 1 |
| | 3 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 4 | 1 | 1 | 1 | 1 | 3 | 2 | 1 |
| | 5 | 1 | 2 | 1 | 1 | 3 | 2 | 2 |
| | 6 | 1 | 2 | 2 | 2 | 3 | 2 | 2 |
| | 7 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 8 | 2 | 1 | 2 | 1 | 3 | 2 | 3 |
| | 9 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 10 | 0 | 1 | 0 | 1 | 3 | 2 | 0 |
| | 11 | 1 | 2 | 1 | 1 | 3 | 2 | 1 |

Table C.1. ES availability levels

| Habitat | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 | S11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A1 | 0 | 0 | 0 | 1 | 1 | 1 | 4 | 1 | 3 | 6 | 2 |
| A2.22 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 1 |
| A2.23 | 15 | 0 | 1 | 0 | 0 | 1 | 3 | 2 | 3 | 13 | 2 |
| A2.24 | 12 | 0 | 2 | 0 | 0 | 0 | 6 | 2 | 3 | 11 | 2 |
| A2.31 | 9 | 0 | 2 | 0 | 2 | 0 | 1 | 2 | 0 | 7 | 1 |
| A2.5 | 7 | 0 | 3 | 3 | 0 | 3 | 4 | 2 | 3 | 12 | 2 |
| A2.61 | 0 | 0 | 3 | 0 | 1 | 1 | 0 | 2 | 0 | 3 | 2 |
| A2.71 | 0 | 0 | 0 | 0 | 0 | 1 | 5 | 2 | 3 | 6 | 3 |
| A3.A4 | 7 | 0 | 0 | 1 | 1 | 0 | 3 | 1 | 0 | 13 | 3 |
| A4.13 | 13 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 2 |
| A4.21 | 8 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 2 |
| A5.13 | 23 | 1 | 1 | 0 | 0 | 0 | 2 | 1 | 3 | 5 | 2 |
| A5.23 | 2 | 0 | 1 | 1 | 0 | 1 | 0 | 2 | 0 | 0 | 1 |
| A5.24 | 13 | 0 | 1 | 0 | 0 | 0 | 3 | 2 | 0 | 7 | 2 |
| A5.43 | 18 | 1 | 1 | 0 | 0 | 0 | 3 | 2 | 0 | 7 | 2 |
| A5.51 | 10 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 3 |
| A5.53 | 7 | 0 | 3 | 0 | 1 | 1 | 2 | 0 | 0 | 6 | 3 |

(S1 Provisioning; S2 Raw material; S3 Climate regulation and composition of the atmosphere (carbon sequestration and greenhouse gas emissions); S4 Prevention/protection against disturbance; S5 Water quality regulation/buffering effect on waste and pollutants; S6 Shoreline stabilization; S7 Cognitive benefits; S8 Resistance and resilience; S9 Cultural heritage and identity; S10 Recreation; S11 Biodiversity)