Methodology for analysing the risk of marine protected areas of the Natura 2000 Network in the face of climate change

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LIFE IP INTEMARES

Integrated, innovative and participatory management for the marine Natura 2000 Network in Spain

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The LIFE IP INTEMARES project, which is coordinated by Biodiversity Foundation under the auspices of the Ministry for the Ecological Transition and the Demographic Challenge, has the aim of achieving efficient management of the Natura 2000 Network marine spaces, with science and active participation of the sectors involved.

Participating as partners are the Ministry itself, through the Directorate General of Biodiversity, Forests and Desertification, the Regional Government of Andalusia, through the Regional Ministry of Agriculture, Livestock, Fisheries and Sustainable Development, and the Environment and Water Agency; the Spanish Institute of Oceanography; AZTI; Universitat Politècnica de València, the Spanish Fisheries Confederation, SEO/BirdLife and WWF-España. The project has the financial support of the European Union LIFE programme.

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1. BACKGROUND

In June 2020, the Biodiversity Foundation commissioned the Institute of Environmental Hydraulics of the University of Cantabria to draft a methodology for the climate change risk analysis of the Marine Protected Areas (MPAs) of the Natura 2000 Network.

This document describes the methodology ultimately proposed, the process of drafting which encompassed the following tasks:

- **Task 1. Review of existing methodology**

  The first task consisted of the review and diagnosis of different methodologies currently used at national and international level, to analyse and assess the vulnerability and risk facing marine protected areas in relation to climate change.

- **Task 2. Proposed methodology for analysis of MPAs climate change risk**

  The second task was to propose a methodology for climate change risk analysis in Marine Protected Areas of the Natura 2000 marine network. For the development of this methodology, an initial proposal was drafted, which was revised and agreed with Biodiversity Foundation and subsequently incorporated into the contributions of different experts and managers. The final result of this process is the method set forth in this document.

- **Task 3. Consultation to experts and managers**

  Task 3 consisted on a consultation to experts and managers to i) validate the method developed; ii) establish criteria to choose pilot areas on which this method can be applied; and iii) propose a series of pilot areas for its application and, when it is the case, subsequent design and implementation of measures for promoting adjustment to climate change in such areas.

2. THEORETICAL FRAMEWORK

The method used has the general goal of guiding managers as they implement risk assessment procedures for the risk associated to climate change in marine protected spaces, that may be adapted to the requirements and characteristics of each protected area. With the goal of including all the different figures that apply to protected marine spaces in Spain without limiting the scope of application of this methodology to those areas designed as protected marine areas, the term Protected Marine Space (PMS) shall be used to designate the areas which are the subject of this assessment.

The future application of this method would enable the design and proposal of climate change adjustment measures for their inclusion in planning and/or management plans for protected marine species. For this reason, and although outlining such measures falls outside of the scope of the risk assessment which is the goal of this study, it has been deemed appropriate to list potential PMS management measures, which can be used as a starting point to address the subsequent phases in the adjustment process to climate change.

Besides, the outcomes of the study may be considered when preparing the Strategies for Marine Subdivisions as established by Act 41/2010 on Protection of the Marine Environment. Specifically, an enhanced knowledge on the impact of climate change on the studied areas may be useful in the revision of the criteria that define Good Environmental Conditions that has to be regularly carried out, as well as proposing specific measures or establishing environmental goal aligned with the previsions resulting from the corresponding risk analysis.

As commented above, before the methodology was developed, a review and diagnosis of some of the methodology currently used was carried out (IHCantabria – Biodiversity Foundation, 2020), after which it was verified that only a few methodologies have as their main goal to estimate the consequences of the variations in environmental conditions caused by the climate change on marine or coastal habitats or species. Finally, in order to develop the methodology described in this document, the approaches set out in the following works were considered as our main sources:

- "*Guidelines for Assessing Species' Vulnerability to Climate Change* (IUCN, 2016)";
- "*North American Marine Protected Area Rapid Vulnerability Assessment Tool* (RVA-North America) (CEC, 2017)";
- "*Análisis de riesgos de los ecosistemas litorales y marinos frente al cambio climático* (IHCantabria, not published)".

Besides, it is worth noting that there is much confusion regarding the definition of the different terms used throughout the vulnerability analysis and the assessment of the risk posed by climate change to natural systems. For example, in some cases vulnerability is equivalent to risk, and in other cases it is only one of its components. As a reference, the guidelines prepared by IUCN (2016) can be used as a reference, since it acknowledges the existing confusion and review the different definitions. For this reason, and in order to avoid confusion, in this document it has been deemed appropriate to adopt the methodological procedure and the nomenclature proposed by the Panel on Climate Change (IPCC, 2014a) (Figure 1), considering that, on the first place, it is the reference document to conduct climate change risk analyses, and besides, is the approach adopted in the preparation on the Environmental Promotion Plans (EPP), specifically in the one titled Adapta-Costas, whose goal is to contribute to the development of the National Plan for Adjustment to Climate Change in coastal areas and to implement the provisions regarding climate change enacted by Act 2/2013, of 29 May, on protection and sustainable use of coastal areas.

In consequence, pursuant to the IPCC (2014a) approach, the aforementioned methodology includes the following elements:

- Threats, understood as the potential occurrence of an event (that is, a change in environmental conditions) that may cause damages or losses of an species, habitat or ecosystem (e.g. increase of water surface temperature, rise of sea level, etc.). In order to provide an appropriate definition, it is essential to establish which variables and parameters determine the distribution of species or habitats that are the object of this study. The type and significance of such threats shall depend on the GEI emission targets and the changes in land use, which, in turn, shall depends on the mitigation measures that are applied globally.
- Exposition, which references species, habitats and ecosystems services of each PMS that may be negatively affected by the corresponding threats. That is, to the elements of the natural environment present in the protected marine space or are of interest which is the object of the risk analysis.
- Vulnerability or predisposition of species or habitat or be negatively impacted by changes in climatic conditions. This concept is a characteristic typical of each potentially impacted element, which integrates its sensibility and resilience. However, such intrinsic vulnerability bay be modified by anthropogenic pressures, which may work to increase or decrease such vulnerability depending on the management measures that apply to each specific case.
- Consequences or impacts, arising from the interplay of threats, exposition and vulnerability in the natural environment, that is, hat constitutes the specific impact of climate change on PMS (for example, species regression, habitat alteration, proliferation of invasive species, reduction of stocks, etc.) Implementation of specific mitigating or adapting measures that can reduce the magnitude of these consequences.
- Risk, which results from the integration of the consequences of the environmental elements arising from modification in environmental conditions, considering their probability of recurrence as well.

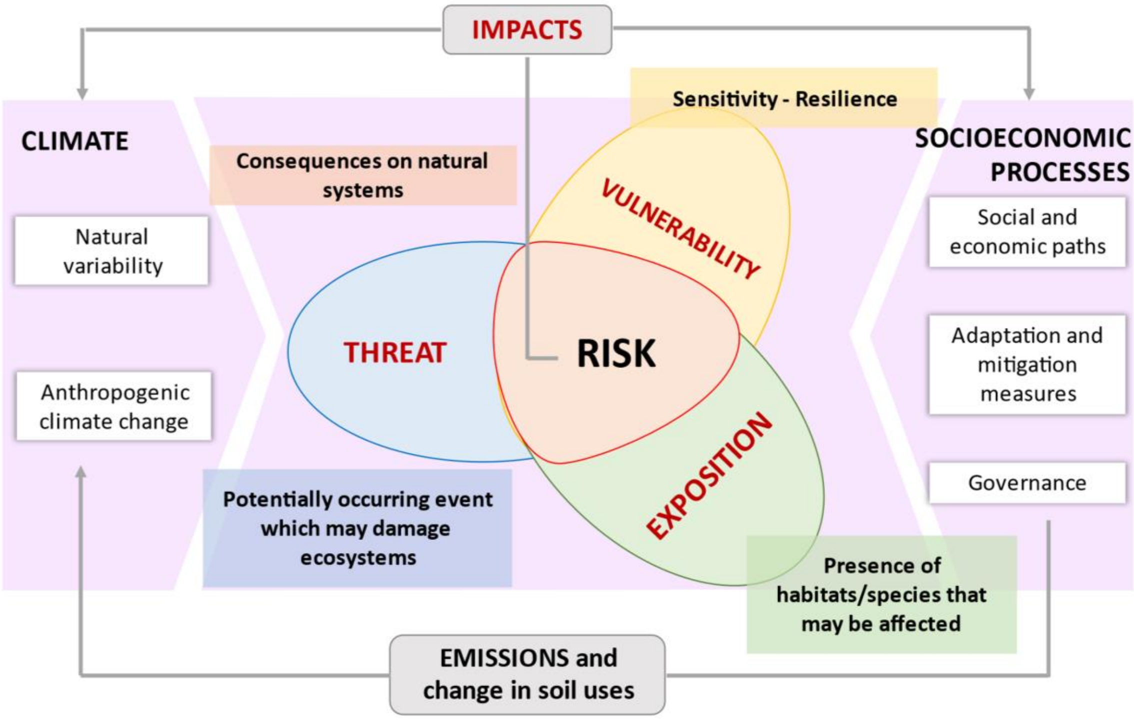


Figure 1. Risk assessment methodology proposed by IPCC (2014a), adapted to the risk analysis applied to natural systems.

3. METHODOLOGICAL PROCEDURE

As stated above, the proposed methodology proposed to carry out the risk analysis assessment in PMS is appropriate for the methodological procedure proposed by the IPCC (2014a).

The consequences or impacts on each SPM shall depend on the magnitude of changes occurring on environmental variables (threats) and these species, habitat or ecosystem services (environmental units) that may be impacted by the aforementioned threats (exposition). These environmental units, in turn, shall react in different ways to the changes in environmental conditions, depending on their sensitivity and resilience (vulnerability). Finally, the risk arising from adding consequences to the equation of different environmental factors taken into account, and from the likelihood of such consequences really occurring, which is determined, basically, by the likelihood of threat occurrence. As stated before, the risk on PMS is also conditioned by any mitigation and adaptation measures that are to be implemented, as well as by the management policies that apply to each specific case.

The proposed methodological procedure is structured in seven phases (Figure 2), which are detailed over the following sections:

I. Definition of specific goals and scope of the assessment that is intended to be made, which must be defined together with the characterisation of the exposition and threat analysis. The goals resulting form this processes shall determine the methodology and the tools to be applied in each case.

II. Characterization of the exposition of selection of environmental units of interest (species, habitats, ecosystem services), as well as the space and time scopes to be considered.

III. Threat analysis, which includes i) choosing the change variable that is to be analysed, considering, among other factors, which are the main climate threats on the different environmental units; ii) choosing the climate change scenarios considering those established by the IPCC or specifically defined for the area which is to be studied, and the time horizon for which the analysis needs to be made (short-term, medium-term or long-term); and iii) an estimation of the magnitude of change brought about by the relevant threat and an estimation of its probability of occurrence.

IV. Assessment of the vulnerability of the different environmental units faced with changes in climatic conditions, considering their sensitivity or the degree in which they may be affected by these changes, and their resilience, or their capacity to recover after its balance has been disrupted.

V. Identification and quantification of the consequences that expected changes in climate variables may have on the environmental units under study, on the different scenarios and time horizons chosen.

VI. Risk assessment, integrating said consequences and their probability of occurring.

VII. Definition of environmental adjustment and monitoring measures, once the main risk areas or elements have been identified.

For the analysis and assessment of each of these element, different approaches, methods or calculation tools are proposed according to the documents mentioned above and the expertise of the preparing teams, since these approaches, methods or tools present different levels of complexity and require different existing information in order to be applied. **Choosing the method to be applied in each specific case shall be closely related to the intended goal, the pre-existing information and the human and financial resources available** (see section 4).

In the following sections, the different phases of the proposed procedure and the tools and methods considered for each case are described in detail.

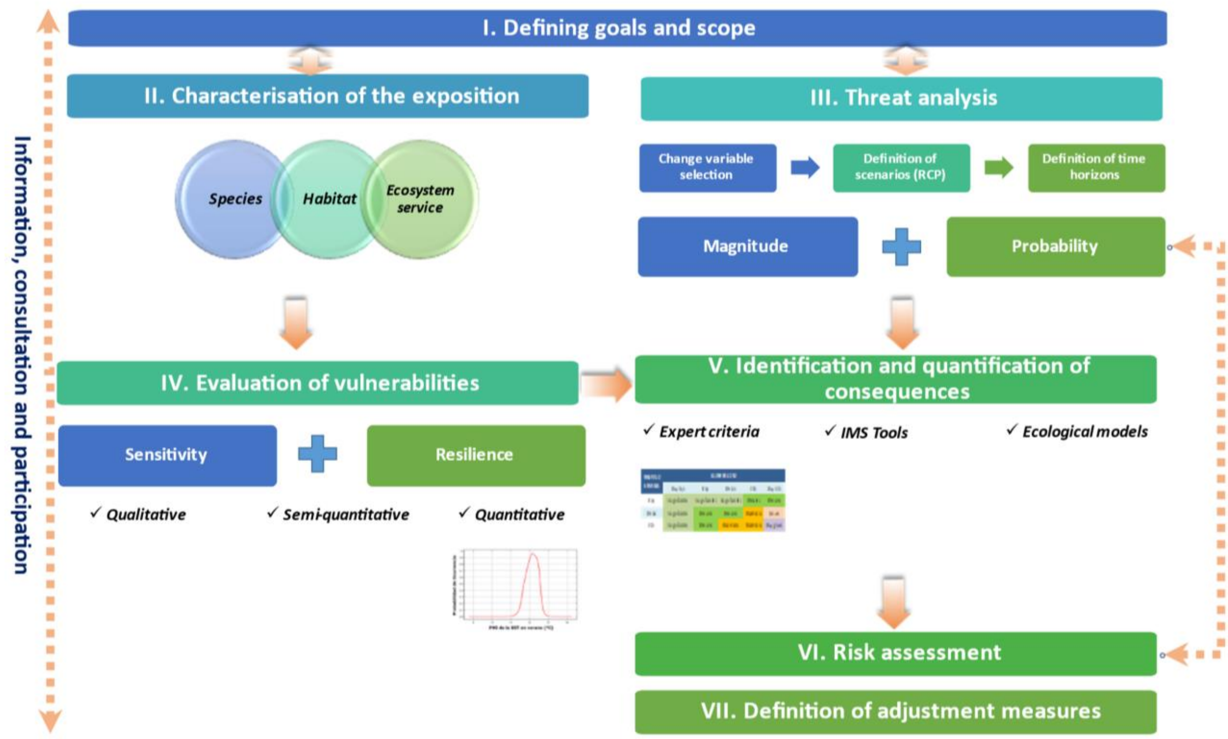


Figure 2. Outline of the proposed methodological procedure.

4. DEFINITION OF THE ASSESSMENT GOAL AND SCOPE

A key aspect in any risk procedure analysis is establishing specific goals which are to determined the scope of the analysis and the methods to be applied on each case (Figure 3). In all logic, the definition of the specific goals must be made at the same time that the relevant environmental units are chosen or the exposition is determined (Phase II) and the threat analysis is carried out (Phase III), that is, identification of climate variables for each specific case and the scenario and time horizon that intends to be analysed.

The initial wording of goals will depend, among other aspects, on the level of development and implementation of management plan in each space. Thus, according to Atauri *et al*. (2012), a preventive management can be applied, establishing general goals such as assessing the risk of an specific PMS against climate change. In those places in which the management measures and tools are well-structured, an active, space-specific management could be performed, that would require setting more specific and ambitious goals, such as identifying the most-threatened environmental unit or assess the impact of changes in climate variables in the progression or regression or native or invasive species.

Besides, when defining the goals and thus the scope of the risk analysis, it should be considered whether the available information is enough to answer those questions, or the time required and the available human and financial resources allows to perform specific studies to carry it out. When this is not the case, the relevant goals must be redefined to make them less ambitious. This information may arise from documents of a general nature that analyse the impact of climate change of marine ecosystems, of studies carried out in the study are with other ends, or of assessment carried out in other geographical areas which can be translated to the relevant PMS. As a guideline, and without intending to draw up an exhaustive list, Annex I includes a list of reports and projects that may be useful in this respect.

Finally, the chosen goals shall determine the methods and tools chosen as the most appropriate to carry out a risk analysis in each case. As stated above, in the proposed methodological procedure, different approaches, with different scopes, degrees of technical complexity and required available information, have been established.

In summary, the different methodological outlines are included in any of the following approaches:

I) **QUALITATIVE ASSESSMENT,** which can be performed through different techniques, including:

a. Expert criteria, carried out by the person or team that is performing a risk assessment, and which requires an in-depth knowledge of ecological processes and their response against climate threats.

b. Consultation to a panel of experts in this aspect, not necessarily involved in risk assessment. It is advisable to address such consultations to multi-disciplinary teams, and approaches such as the Delphi Method can be used to increase result reliability.

c. Consultation to the key managers and stakeholders of the relevant space, including other public entities, socio-economic agents, non-governmental organizations and simple users of this space. This approach allows to integrate the social and economic dimensions in risk analysis by means of public participation, and it is especially appropriate when the environmental unit under assessment is an ecosystem service. In order to be truly useful, this technique requires to design an information, consultation and, if appropriate, active participation process specific for each case study.

This is the **most straightforward assessment method that can be applied**, and its main advantage is that **it does not require an exact definition of threats**, which can conversely be established from the general trends identified in the study area. **Application of this technique does not require a high specialization level**, although it is **not space-specific**, and obtaining robust, reliable results **is conditioned by the knowledge that experts, managers and users** have of the PMS. For this reason, designing and implementing the appropriate tools for enabling and promoting such participation is key. This approach **may be applied throughout the entire process.**

II) **SEMI-QUANTITATIVE ASSESSMENT,** based on pre-defined indicators, indexes and assessment systems (already existing or specifically defined for the intended assessment).

This method is **more labour-intensive**, although it is also **less subjective**, since it is less dependent on the specific knowledge that experts participating on the process have on the area, and allows to have **space-specific results**. Usually, it requires to have cartographic information of the threats and/or environmental units at the appropriate scale, which require using Geographic Information Systems (GIS). The level of accuracy required to analyse the relevant threats will vary depending on the level of detail that needs to be achieved, and, in some cases, mathematical models must be used to define such threats.

III) **QUANTITATIVE ASSESSMENT**, that involves the application of more or less complex mathematical models (climatic, hydrodynamic, ecological) which in general require a **medium - high degree of specialization**. Usually, it is required to define the threats in deeper details (historic series and future projections) and have sufficient data available on the distribution of environmental units at the appropriate space scale. This procedure is **space-specific** and enables to obtain results that are more objective, more trustworthy and with a higher level of detail.

Over the following sections, the qualitative, semi-quantitative and quantitative assessment procedures set forth to characterize the exposition (section 5), threat analysis (section 6), vulnerability assessment (section 7), identification and quantification of consequences (section 8) and risk assessment (section 9) are described.

Besides, at the end of the document, a series of case studies have been included as an example of the different approach proposals, in order to help interpreting them. A specific manual has been prepared to streamline the application of qualitative methods.

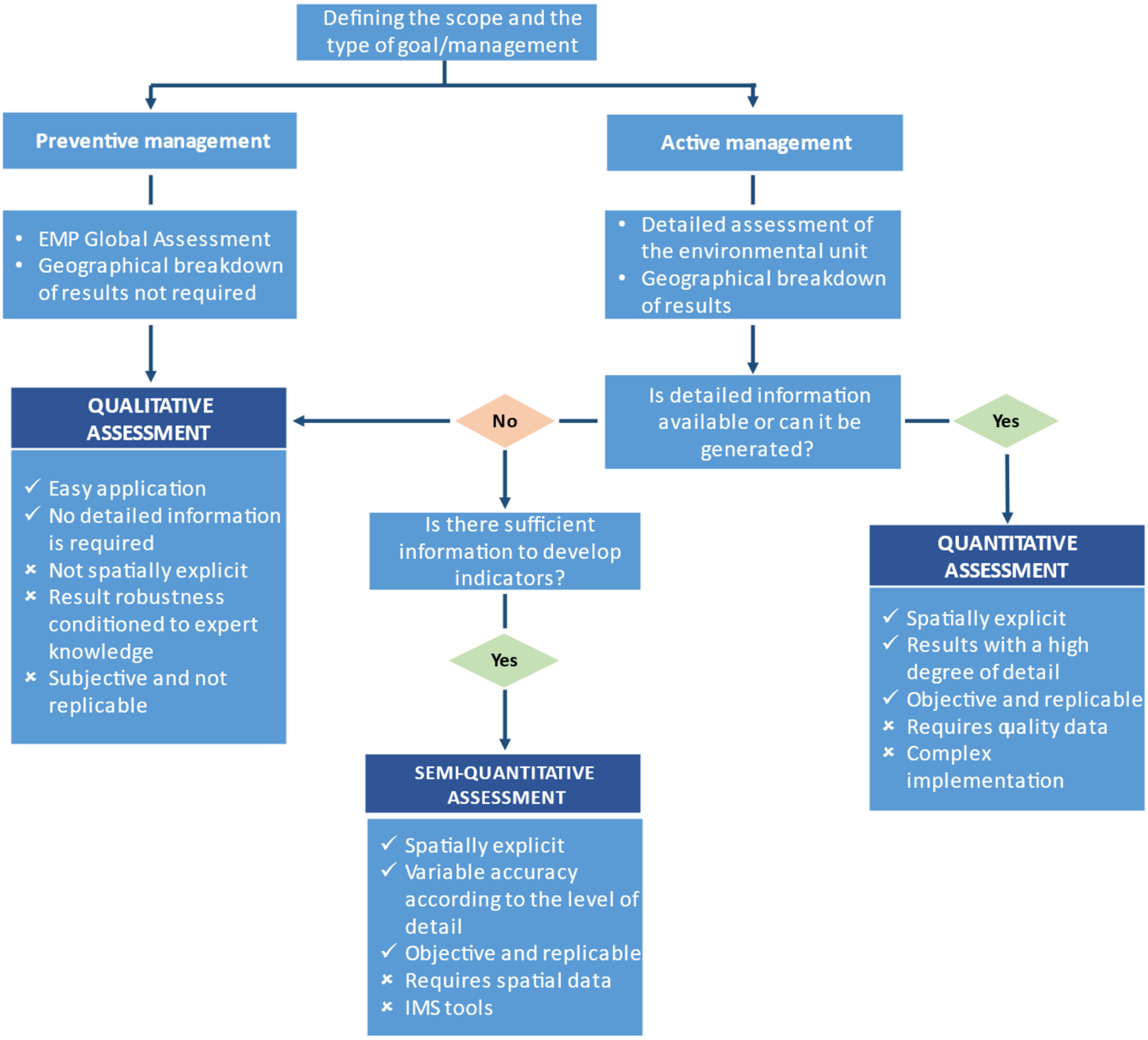


Figure 3. Decision tree to select a methodology. Next to each methodology, a chart of its main pros and cos is shown.

5. CHARACTERISATION OF THE EXPOSITION

A key point of the entire process is choosing the item of the natural medium or environmental unit that are under assessment (species, habitat, ecosystem service) must be clearly limited, as well as the territorial scope of intervention (be it the entire PMS, specific geographical areas, etc.) The environmental unit must follow the accepted nomenclature and general application, so that information may be collected and processed in an uniform way, and is comparable with the results obtained for different spaces, environmental units or geographical areas. As a guideline, Tables 1 to 3 reference different sources for the definition and classification of environmental units, as well as examples of possible lists of habitats and ecosystem services.

For species, it is advisable to use their scientific name, considering the Master List of Marine Species defined by the Ministry for Ecological Transition and the Demographic Challenge (MITECO), updated or completed according to the nomenclature induced in databases such as "World Register of Marine Species (WoRMS)" or "Integrated Taxonomic Information System (ITIS)" (Table 1).

For habitats, it is also advisable to use the Master List of Marine Species prepared by MITECO, so as to remedy the existing divergences in nomenclature and denominations, and be easier to understand by manager and experts. In lack thereof, the (*European Nature Information System*) (European Commission, 2007) classification could be used, which is generally based on the physical environment to describe habitats in the first levels of classification and, subsequently, adds biological information to characterize habitats with a higher level of detail; or the classification established for habitats of European interest, in the sense established by the 92/43/EEC Habitats Directive, which is mainly based on phytosociological associations to define habitats with a high degree of detail and, in a complementary manner, combines it with the physical characteristics of the specific habitat (Tables 1 y 2).

IN case of ecosystem services, one of the most widely used classification is the one proposed by the European Environmental Agency (EEA), called CICES (*Common International Classification of Ecosystem Services*) (Tables 1 and 3). This classification system has been adopted by the MAES (Mapping and Assessment of Ecosystems and their Services) task group to generate maps and assess such services at European scale. There are different approaches and tools (such as InVEST "Integrated Valuation of Ecosystem Services and Tradeoffs" developed by the Natural Capital Project), both qualitative and quantitative, to characterize the exposition of ecosystem services.

Whenever possible, mapping information regarding the assessed environmental units shall be collected. For this purpose, you can use the information included in the PMS Management Plans, the Marine Strategies, the existing inventories or mapping (for example, eco-mapping carried out by MITECO), free-access global databases (such as GIBIF, IOBIS, EMODNET,) or the performance of specific field campaigns (Table 4). This information shall refer, at least, to the presence of environmental units, but it is recommended to collect also data corresponding to absences, when available, or additional information such as coverage, abundance or biomass.

All collected mapping information should comply with the minimum standards established by the INSPIRE European Directive (Directive 2007/2/CE), transposed into the Spanish legal framework by means of Act 14/2010, of 5 July, on the infrastructures and services of geographical information in

Spain. As a reference, it is recommended to follow the instruction of the IMS Protocol of the IP INTEMARES project (https://intemares.es/sites/default/files/protocolo-sig_intemares.pdf). Besides, this information must be compatible with the Nature Data Bank (https://www.miteco.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/) and the InfoMAR platform (http://infomar.cedex.es/). In this manner, the harmonization and interoperability of mappings is guaranteed.

Pursuant to the goal of this assessment, the environmental unit and the scope of intervention, the spatial and time scales of interest must also be established. These scales must guarantee an assessment sufficiently detailed to respond to the established goal, and shall be a main conditioning factor to select the table that is to be applied.

Table 1 Possible sources for defining and classifying the environmental unit.

ENVIRONMENTAL UNIT	DATA	LINK
Species	Master List of Marine Species (Ministry for Ecological Transition and the Demographic Challenge)	https://www.miteco.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/informacion-disponible/BDN_listas_patron.aspx
	WoRMS (World Register of Marine Species).	https://www.marinespecies.org/
	ITIS (Integrated Taxonomic Information System)	https://www.itis.gov/
	List of Wild Species under Special Protection Regimes and Spanish Catalogue of Threatened Species. (Ministry for Ecological Transition and the Demographic Challenge)	https://www.miteco.gob.es/es/biodiversidad/temas/conservacion-de-especies/especies-proteccion-especial/ce-proteccion-listado.aspx
Habitats	Master List of Marine Habitats (Ministry for Ecological Transition and the Demographic Challenge)	https://www.miteco.gob.es/es/costas/temas/proteccion-medio-marino/biodiversidad-marina/habitats-especies-marinos/inventario-espanol-habitats-especies-marinos/fichas-inventario-habitats-marinos.aspx
	List of Habitats of Community Interest in Spain (Ministry for Ecological Transition and the Demographic Challenge)	https://www.miteco.gob.es/es/biodiversidad/temas/espacios-protegidos/red-natura-2000/rn_tip_hab_esp_espana.aspx
Ecosystem services	Common International Classification of Ecosystem Services (CICES). European Environment Agency (EEA)	https://cices.eu/

Table 2 List of types of habitats

ENVIRONMENTAL UNIT	POSSIBLE CLASSIFICATION
	030402: Infralittoral and circalittoral sands and muddy sands
	040303: Deep water coral reefs
	040201: Structures caused by gas leaks
	040202 - Bathyal muds
	030405 - Infralittoral and circalittoral biogenic detrictic seabeds
	030513 - Meadows of phanerogams and rhizome green algae
	030512 - Meadows of Neptune grass (*Posidonia oceanica)*
	030508 - Macaronesic meadows of *Cymodocea nodosa*
	030504 - Mediterranean meadows of dwarf eelgrass (*Zostera noltii)*
	030202 - Circalittoral rock dominated by invertebrae
	030103 - Protected infralittoral rock
	030301 - Semi-dark infralittoral and circalittoral tunnels and caves
Marine, coastal and estuarine habitats of community interest	1110: Sandbanks which are slightly covered by sea water all the time
	1120*: Posidonia beds (*Posidonion oceanicae*)
	1130: Estuaries
	1140: Mudflats and sandflats not covered by seawater at low tide
	1160: Large shallow inlets and bays
	1170: Reefs
	1180: Submarine structures made by leaking gases
	1210: Annual vegetation of drift lines
	1230: Vegetated sea cliffs of the Atlantic and Baltic coasts.
	1310: Salicornia and other annuals colonizing mud and sand
	1320: Spartina swards
	1330: Atlantic salt meadows
	1420: Mediterranean and thermo-Atlantic halophilous scrubs
	2110: Embryonic shifting dunes
	2120: Shifting dunes along the shoreline with *Ammophila arenaria*
	2130*: Fixed coastal dunes with herbaceous vegetation
	2180: Wooded dunes
	2190: Humid dune slacks
	8330: Submerged or partially submerged sea caves
EUNIS Classification	A1 – Littoral rock and other hard substrata
	A2 – Littoral sediment
	A3 – Infralittoral rock and other hard substrata
	A4 - Circalittoral rock and other hard substrata
	A5 – Sublittoral sediment
	A6 – Deep-sea bed
	A7 – Pelagic water column
	X1 - Estuaries
	X2_3 – Coastal lagoons
	B1 – Coastal dunes and sandy shores
	B2 – Coastal shingle
	B3 - Rock cliffs, ledges and shores, including the supralittoral

Table 3 Example list of ecosystem services (according to the CICES classification).

ENVIRONMENTAL UNIT	POSSIBLE CLASSIFICATION
Provision services	Food
	Raw material of biological origin
	Raw material of non-biological origin
	Fresh water
	Renewable energy
Regulatory services	Decontamination
	Reduction of visual or noise impact
	Erosion control
	Regulation or natural disturbances
	Genetic pool
	Soil fertility
	Regulation of water quality
	Climatic regulation
Cultural services	Recreational activities and eco-tourism
	Scientific knowledge
	Local ecological knowledge
	Cultural identity and sense of belonging
	Aesthetic enjoyment of landscape
	Spiritual and religious enjoyment
	Existential value

Table 4 Data sources to obtain information and characterize each environmental unit.

ENVIRONMENTAL UNIT	DATA	LINK
Species	Global Biodiversity Information Facility (GBIF).	https://www.gbif.org/es/
	Ocean Biodiversity Information System (OBIS)	https://obis.org/
	EMODNET-Biology	https://www.emodnet-biology.eu/
Habitats	Habitats of Community Interest Distribution Map (Ministry for Ecological Transition and the Demographic Challenge)	https://www.miteco.gob.es/es/cartografia-y-sig/ide/descargas/biodiversidad/habitat-art17-2007_2012.aspx
	Eco-mapping (Ministry for Ecological Transition and the Demographic Challenge)	https://www.miteco.gob.es/es/costas/temas/proteccion-costa/ecocartografias/default.aspx
Ecosystem services	Valuation of Natural Assets in Spain (VANE)	https://www.miteco.gob.es/es/biodiversidad/temas/conservacion-de-la-biodiversidad/valoracion-y-aspectos-economicos-de-la-biodiversidad/cb_vae_valoracion_activos_naturales.aspx

6. THREAT ANALYSIS

Once the exposure has been characterised, the following steps is to identify and analyse climatic and, if appropriate, anthropogenic threats that may compromise their status of conservation and geographical distribution. Such threats have to be characterized in the appropriate level of detail, that is, with the spatial resolution established in the previous stages. This analysis involves i) selecting the most significant change variables or climate stressors for the environmental unit under study, ii) selecting the relevant climate change scenarios and time horizon; and iii) estimation of magnitude of change in the threat and its occurrence likelihood.

6.1. Climate stressors

6.1.1. Selection of climate stressors

Table 5 includes the main climate stressors, which will be more or less relevant depending on the area under study and the corresponding environmental area. With regard to stressors, it is important to consider both changes in average temperatures (e.g. temperature increase, sea level rise) and extreme events (e.g. heatwaves, floods),since both can limit the possibilities of colonization and development of biological communities.

Table 5 List of examples of types of climate stressors

TYPES OF CLIMATE STRESSORS
Increase of water temperature
Increase of air temperature
Modification of precipitation regimes patterns
Rise of sea level
Decrease of dissolved oxygen
Modification of currents
Modification of upwelling patterns
Changes in the salinity regimes
Acidification
Changes in wave strength

The type of data required and the information sources of such data shall depend on the risk analysis method applied in each case. Thus, in some cases it may be directly obtained from the trends established by the IPCC, while in other cases, it may be required to collect historic series and projections from climate databases or even apply specific models to perform projection of the relevant variables, at the required space and time scale (e.g. statistical or dynamic downscaling).

Besides the information collected by the IPCC reports, currently there are different databases that provide information on climate variables, both considering historic data and different climate change scenarios (Table 6). Some of those databases are specific for the marine environment, at an European scale (e.g. OCLE) or a global scale (e.g. Bio-Oracle), while others are more focused in the terrestrial environment (e.g. WorldClim).

Table 6 Potential information sources on climate stressors and projections to characterize the threat.

DATABASES	VARIABLES (historic and future)	LINK
OCLE	Water temperature Air temperature Salinity Waves pH Rise of sea level Wind speed	https://ocle.ihcantabria.com/
BIO-ORACLE	Water temperature Salinity Sea current speed Ice layer thickness	https://bio-oracle.org/
MARSPEC	Water temperature Salinity Distance to the coastline	http://www.marspec.org/.
MERRAclim	Temperature Relative humidity	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5477563/
WORLDCLIM	Temperature Precipitations	https://worldclim.com/
AdapteCCA	Temperature Precipitations Evapotranspiration	http://escenarios.adaptecca.es/#&model=eqm-multimodel&variable=tasmax&scenario=rcp85&temporalFilter=YEAR&layers=AREAS&period=MEDIUM_FUTURE&anomaly=RAW_VALUE

6.1.2. Selecting scenarios and time horizons

In the IPCC report (IPCC, 2014a) different emission scenarios have been created (RCP, as per its English acronym) that contemplate the greenhouse gases and soil uses for the year 2100, considering the effects of the international policies or covenants used to mitigate them, representing potential socio-economic scenarios (Table 7). In each of the considered scenarios, mitigation efforts lead to a very low level of forcing (RCP2.6), two stabilization scenarios (RCP4.5 and RCP6.0) and a scenario with a very high level of emissions of greenhouse gases (RCP8.5). Such scenarios determine the projections of variables, and, therefore, the scenario chosen shall determine the magnitude of the threat. For example, in case of ocean temperature or frequency of heatwaves (Figure 4), differences between the increases estimated in RCP 2.6 and in RCP 8.5 (IPCC, 2019) are significant.

With regard to time scales, as a reference, the IPCC considers that predictions up to 20150 are short-term and predictions up to 2010 are long-term predictions.

Scenarios and temporal scales established by the IPCC are accepted by the international scientific community, although other specific scenarios could be established for the PMS under assessment.

Table 7 Scenarios established in the IPCC reports (2014a, 2019) and associated values by 2100 for the concentration of carbon dioxide (CO_2) and the average increase of ocean temperature relative to 1850-1900.

SCENARIO	TREND	CO_2 CONCENTRATION	OCEAN TEMPERATURE INCREASE
RCP2.6	Decreasing	421 ppm	1.6ºC
RCP4.5	Stable	538 ppm	2.5ºC
RCP6	Increasing	670 ppm	2.9ºC
RCP8.5	Increasing	936 ppm	4.3ºC

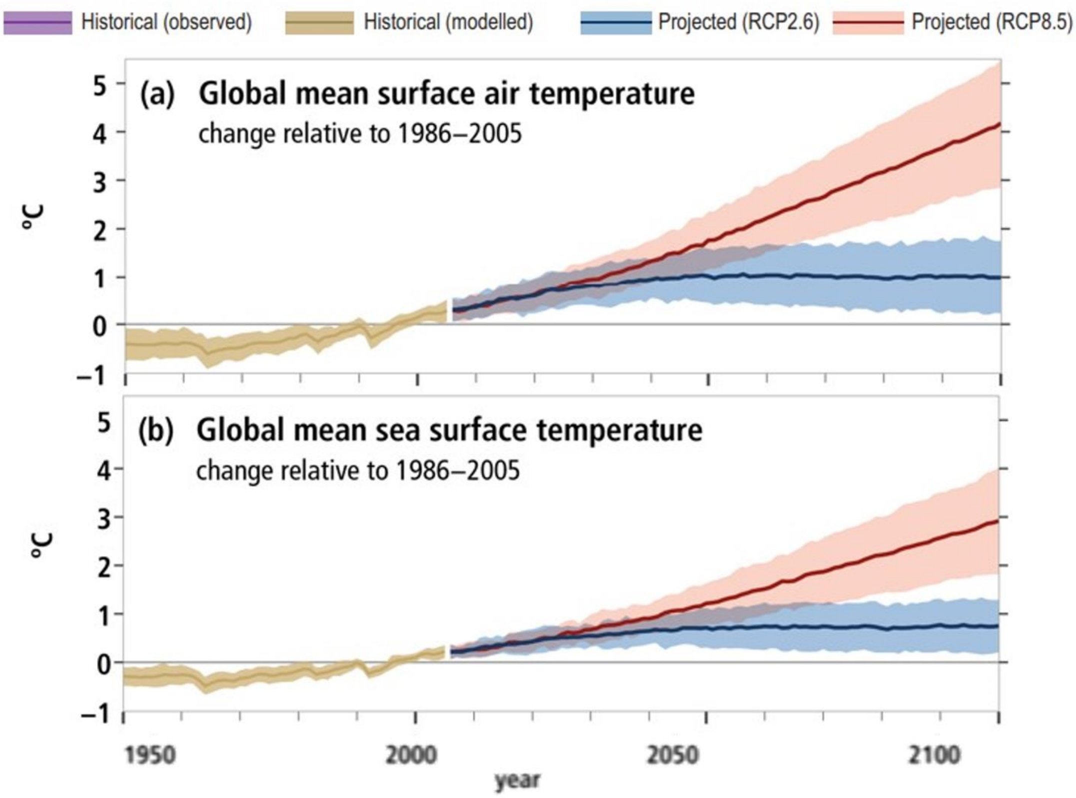


Figure 4. Historical evolution (purple: observed evolution; brown; modelled evolution) and projections in RCP 2.6 (blue) and 8.5 (red) of the relative change in global average temperature of sea surface (upper panel) and the change factor on the sea during heatwave days. The lighter lines represent the uncertainty of each indicator. Source: extracted by IPCC (2019).

6.1.3. Estimation of magnitude and occurrence probability

Once the threat on the environmental unit, first its magnitude and its probability of occurrence need to be defined.

The above mentioned databases include a numeric value given to the magnitude of the threat, which can also be obtained using geographical information systems when it is space specific, or simply applying the expert criteria and/or public participation, based on the trends described in scientific literature and existing technical reports (e.g., the IPCC report, 2014a).

In the simplest scenario, the categorization of the threat magnitude could be quantified pursuant the following scale:

- Low: the difference between the threat values at the baseline scenario and the scenario considered is practically zero.
- Average: threat projected values correspond to the maximum values of the baseline scenario.
- High: in the scenario considered, the threat reaches values not registered in the baseline situation.

Besides, it must be considered that, although scientific knowledge in this field has developed significantly, projections of climatic models such as those used by the IPPC include uncertainties associated to the considered scenarios, internal climate variability and the results provided by the different applied criteria, despite the fact that specific uncertainty-reducing techniques are applied, such as ensemble modelling. For this reason, it is advisable to include a estimation of occurrence likelihood and its associated uncertainty in threat analysis,

Thus, the trends and assessment included in the IPCC reports (2014a, 2019) refer to a level of confidence (very low, low, medium, high and very high) and, whenever possible, to the degree of likelihood of the relevant result or consequence (virtually likely, highly probable, as likely as unlikely, unlikely, very unlikely, exceptionally unlikely). For example, pursuant the most recent IPCC report regarding the marine environment (IPCC, 2019); the values of the sea temperature relative projection are very likely (probability of 90%-100%) which represents a low uncertainty and, therefore, a high degree of confidence.

In a manner similar to the qualitative estimation of the magnitude described above, the probability of a specific threat to actually occur, could be classified in the following levels:

- Rare: very low probability (<10 %).
- Unlikely: low probability (10% - 33%).
- Possible: but not unlikely, probability at 33% - 66%.
- Probable: probability between 66 % and 90%
- Very probable or virtually certain: probability higher than 90%.

6.2. Anthropogenic threats

Albeit the goal of this study is to carry out a risk analysis arising from changes in climate stressors, anthropogenic threats that may affect species vulnerability or habitat vulnerability for the assessed species or habitats, as well the potential ecosystem services associated to them.

6.2.1. Selection anthropogenic threats and stressors

With the ultimate goal of harmonizing the selection and categorization of these anthropogenic threats, it is proposed to refer to the reference list of threats and stressors (information for the reports on the application of the Habitats Directive and Birds Directive, in Spain), included in Annex 3 of the Guidelines for monitoring and assessment of the conservation status of threatened and special protection species (Table 8). Besides, it could be considered that the list of activities and uses defined in the Directive establishing a framework for maritime spatial planning (2014/89/UE)) (Table 9).

Information on the stressors existing in each study area (geo-referenced if possible) may be obtained from the characterization of activities and stressors carried out in the Special Preservation Areas (SPA, or ZEP as per its Spanish acronym), in compliance with the Habitat Directive (92/43/EEC); as with the specifications for Marine Strategies in line with the Framework Directive for an strategy for the marine environment (2008/56/EC), or the Marine Subdivision in which the PMS under study is included; or in the Plans for Organization of the Marine Space (POEM as per its Spanish acronym) as established in Directive 2014/89/EU. This information could be completed whenever possible, with the analysis of pressures and impacts set forth by the Hydrological Plans of the different basin subdivisions, in compliance with the Framework Directive on Water Policy (2000/60/EC).

Table 8 List of some of the anthropogenic stressors more related to PMS, listed in the Reference list of threats and stressors (information for the six-year reports on the application of the Habitats Directive and the Birds Directive, in Spain) (Annex 3of the Guidelines for monitoring and assessment of the conservation status of threatened and special protection species, 2012).

ANTHROPOGENIC STRESSORS	CODE	SUBCATEGORY
Farming	A01	Crops
	A07	Use of biocides, hormones and chemicals
	A08	Use of fertilizers
Mining and extractive activities and energy production	C01	Mines and quarries
	C02	Prospection and extraction of oil or natural gas
	C03	Use of abiotic renewable energy sources
Transportation and communication networks	D01	Roads, dirt roads and rail roads.
	D02	Public service line infrastructures
	D03	Sailing routes, ports, marine constructions
Urban, residential and commercial development	E01	Urban areas, human settings
	E02	Industrial or commercial areas
	E03	Waste
	E04	Impact of buildings and other constructions on the landscape
	E05	Storage warehouses
	E06	Other urban, industrial or similar activities
Use different biological resources from farming and silviculture	F01	Sea and fresh water fish farming
	F02	Fishing and collection of water resources
	F05	Illegal capture or destruction of marine wildlife
	F06	Hunting, fishing or gathering activities other than the ones mentioned above
Human intrusion and disruption	G01	Outdoor sport practice and outdoor leisure, including organized leisure activities
	G02	Sport and leisure installations
	G03	Interpretation centres
Pollution	H01	Surface water pollution (fresh water, sea water and brackish water)
	H02	Underground water pollution (from point sources or from diffuse sources).
	H03	Pollution of sea water
	H04	Air pollution
	H05	Soil pollution and solid waste (excluding dumping)
	H06	Excess energy (released into the environment)
	H07	Other forms of pollution
Invasive species, problematic species and genetic modifications	I01	Invasive species and non-native species
	I02	Problematic native species
	I03	Introductions of genetic material, GMO
Alterations to the natural system	J01	Fires and fire extinction
	J02	Human-induced changes to hydraulic conditions
	J03	Other alterations to ecosystems

Table 9 List of activities and uses as specified by article 8 of Directive 2014/89/EU.

ACTIVITIES AND USES
Fish farming areas
Fishing areas
Installations and infrastructures for the prospection, exploitation and extraction of oil, gas, and other energy sources, ore or mineral aggregates, and production of energy from renewable sources.
Routes of maritime transportation and traffic flows
Areas of military training
Areas of preservation of species and natural environment and protected areas
Areas of extraction of raw materials
Scientific research
Layout of cables and underground tubes
Tourism
Submarine cultural heritage

6.2.2. Establishing management scenarios

Besides the aforementioned climatic scenarios, other management scenarios can be defined considering the environmental goals and programmes established in the different industry plans, especially regarding the Habitats Directive, the Water Policy Framework Directive, the Marine Strategy Framework Directive and the Marine Space Planning Directive. This consideration would enable to foresee to a certain degree the evolution of vulnerability in the different environmental units, and to reduce it on those cases for which environmental restoration and recovery activities are planned (e.g., elimination of invasive species) or increasing it when an increase in anthropogenic stressors in the PMS is expected (e.g., when fishing quotas are increased).

6.2.3. Estimation of magnitude or degree of impact

In order to be able to estimate a quantification of the magnitude or degree of impact of these stressors, the methodology proposed by CEDEX (1018) can be used to prepare documents on the uses and activities in the Special Preservation Areas (SPA) managed by the central government.

According to such methodology, the degree of impact of stressors is classified under one of three categories (high, medium, low) considering their intensity and their impacting potential (Table 10). Intensity is classified in one of five categories (very high, medium, low, very low, zero), pursuant to a series of previously established criteria or thresholds. The total impacting potential of each activity is established according to three categories (high, medium and low), considering the total cumulative impacts of each of them.

Table 10 Estimation of quantification of magnitude or degree of impact of anthropogenic stressors, classified by their intensity and their impacting potential (CEDEX, 2018).

INTENSITY	IMPACTING POTENTIAL		
	High	Medium	Low
Very high	High	High	Medium
High	High	Medium	Medium
Medium	Medium	Medium	Low
Low	Medium	Low	Low
Very low	Low	Low	Low

7. ASSESSMENT OF VULNERABILITY

Vulnerability in face of climate change results from integration of sensitivity and resilience of each environmental unit against threats.

In this context, sensitivity is understood as the degree in which an environmental unit may be positively or negatively affected by a change in the threat (IPCC, 2014b).

On the other hand, according to the IPCC (2014b), resilience is defined as the capacity of an ecological or socio-economic system to absorb disruption and re-organize, keeping essentially the same function, structure and identity despite the change.

In both cases, this analysis needs to be performed for each environmental unit and each threat that may have an impact on it. Depending on the data available and the required level of detail, the assessment approach for both factors can be more or less complex. As mentioned above, this proposal includes, by way of example, three different approaches (a qualitative approach, a semi-quantitative approach and a quantitative approach) that may be adapted to each specific case, depending on the specific goals established in the initial phase of the risk analysis.

7.1. Qualitative Assessment

I. Sensitivity

This is the simplest method to apply. Sensitivity can be categorized according to a qualitative scale defined according the propensity of an environmental unit to be affected in case that a threat actually occurs. A possible evaluation system, based on the RVA-North America (CEC, 2017) methodology, could be similar to the following scale:

- Zero sensitivity: the propensity of the environmental unit to be affected by any changes in the threat is very low.
- Low sensitivity: the propensity of the environmental unit to be affected by any changes in the threat is low.
- Moderate sensitivity: the propensity of the environmental unit to be affected by any changes in the threat is moderate.
- High sensitivity: the propensity of the environmental unit to be affected by any changes in the threat is high.
- Very high sensitivity: the propensity of the environmental unit to be affected by any changes in the threat is very high.

In order to perform this assessment, some of the techniques mentioned above can be used (see section 4): i) expert opinion; ii) consultation to an expert panel; and iii) consultation to the key manager and stakeholder of the relevant space, including other public entities, socio-economic agents, non-governmental organizations and simple users of this space.

II. Resilience

Resilience or the adaptive capacity of an environmental unit can be assessed by a means similar to the one to assess its sensitivity, establishing an stale that represents the capacity of an environmental unit to recover after an impact, and applying different existing techniques for estimation.

In this case, resilience could be assessed according to the following criteria:

- Zero resilience: the environmental unit is totally incapable of recovering.
- Poor resilience: after a disruption, the system keeps some of its functions, but is not capable of recovering most of them.
- Moderate resilience: the system is capable of partial recovery.
- Resilience: after a disruption, the system is capable of recovering most of its functions.
- High resilience: ideal scenario (the system is entirely capable to revert to its original status before the disruption).

III. Vulnerability

Vulnerability results from the integration of sensitivity and resilience of the environmental unit, so that less vulnerable systems shall be less sensitive and more resilient, while more vulnerable environmental units will be more sensitive and will have low or zero capacity to recover (Table 11).

Table 11 Examples of qualitative assessment of vulnerability.

SENSITIVITY	RESILIENCE				
	High resilience	Resilience	Moderate resilience	Poor resilience	Zero resilience
Zero sensitivity	Very low	Very low	Low	Low	Medium
Low sensitivity	Very low	Low	Low	Medium	High
Moderate sensitivity	Low	Low	Medium	High	High
Sensitivity	Low	Medium	High	High	Very high
Very sensitive	Medium	High	High	Very high	Very high

7.2. Semi-quantitative assessment

I. Sensitivity

With a somewhat higher degree of detail, the assessment of sensitivity may be carried out according to a series of indicators, which may or may not be quantified, established as approximations of the sensitivity of the environmental unit under study. Depending on the considered indicators and the valuation method used in each case, they shall be more applicable at SPA level, geographical area level, habitat level or species level.

For example, in the method developed by IHCantabria (not published) for application in risk assessment of coastal ecosystem, naturalness and singularity are used as indicators for assessing the vulnerability of a certain space, applying the following criteria:

- Indicator of naturalness: calculated as the proportion of the total surface covered by natural habitats (e.g., as per the EUNIS classification) as opposed to anthropogenic habitats.
- Indication of singularity: calculated as the number of priority habitats of community interest (according to Directive 92/43/CEE) present in the study area; and, for species, the number of vulnerable species, in danger of extinction or in critical danger of extinction.

In other cases, the sensitivity of an space could be calculated by integrating the sensitivity of the different species present in the same front than the threat that is being assessed; in much the same manner than the methodology applied for the BESITO index (González-Irusta et al., 2018), which classifies species in a 1-to-5 scale depending on their sensitivity to trawling. This method involves to assign a sensitivity value to each species, which may be different depending on the considered variable, which implies having a detailed knowledge of biology and of the physiological response of the targeted species.

II. Resilience

In an approach similar to the one described for sensitivity, resilience can be described based on ecological indicators corresponding to the environmental unit under study (intrinsic indicators), such as richness, diversity or connectivity, considering the baseline hypothesis that best structured ecosystem will be those with a higher capacity to recover (Table 12).

On the other hand, other indexes or indicators external to the environmental unit, but which could have an additional impact on its capacity for recovery may be considered.

For example, the presence of invasive species can jeopardize the successful migration of native species of birds, with whom they fight to colonize new habitats and environment (for example, terrestrial habitats that become flooded, a change in the climatic conditions that characterize certain bio-geographical regions, etc.)

Besides, when biota is displaced from its original habitat, the capacity to migrate or colonize new spaces may depend as well of the degree of naturalness of the habitats adjacent to the environmental unit. For example, intertidal, estuarine or coastal communities that are displaced by the rising sea level may colonize non-sealed terrestrial surface more easily than those terrestrial surfaces that are artificially sealed or waterproofed. In the same manner, terrestrial surfaces with a high socio-economic value (e.g., industrial areas or farming land) are more likely to be the object of protection measures against rising sea levels, which would prevent estuarine habitats from migrating.

Table 12 Examples of indicators to assess resilience.

INDICATOR	DESCRIPTION
Richness	No. of habitats, No. of species
Taxonomic diversity	Shannon Index Simpson Index
Functional redundancy	Relationship between taxonomic diversity and functional diversity
Connectivity	Neighbouring relationship with other cells within the same habitat
Presence of invasive species	Richness of invasive species Relative surface colonized by invasive species
Migration capacity	Presence or absence or barriers
Capacity for colonizing different habitats	Percentage of adjacent artificial or economically valuable habitats
Population structure	Number of individuals, age structure of population

The different sensitivity and resilience indicators could be analysed independently and be directly incorporated to the assessment of consequences, or else be standardized according to a previously defined scale, and to be integrated in a multimetric vulnerability index.

7.3. Quantitative assessment

I. Sensitivity

The sensitivity of each species with respect to any changes arising from climate change depends on its tolerance and preference limits. These thresholds can be obtained from scientific literature, experimentation or from response curves generated by species distribution models (Figure 5). As the name suggests, these curves represent the response of each species (in terms of probability of species development) to the gradient of each physical parameter considered.

In this sense, the most sensitive species would be those that occupy regions characterized by environmental conditions close to the most extreme values in their response curve, i.e., those that are close to the limits of the distribution range of the species considered. In these populations, small changes can result in significant losses in abundance or biomass, or even in the complete destruction of the community, if the taxon in question is a key or structuring species in such community. Conversely, species that are close to optimal conditions have a greater capacity to adapt to small changes in the medium or long term, although their adaptive capacity could be reduced if such changes are sudden and/or accelerated.

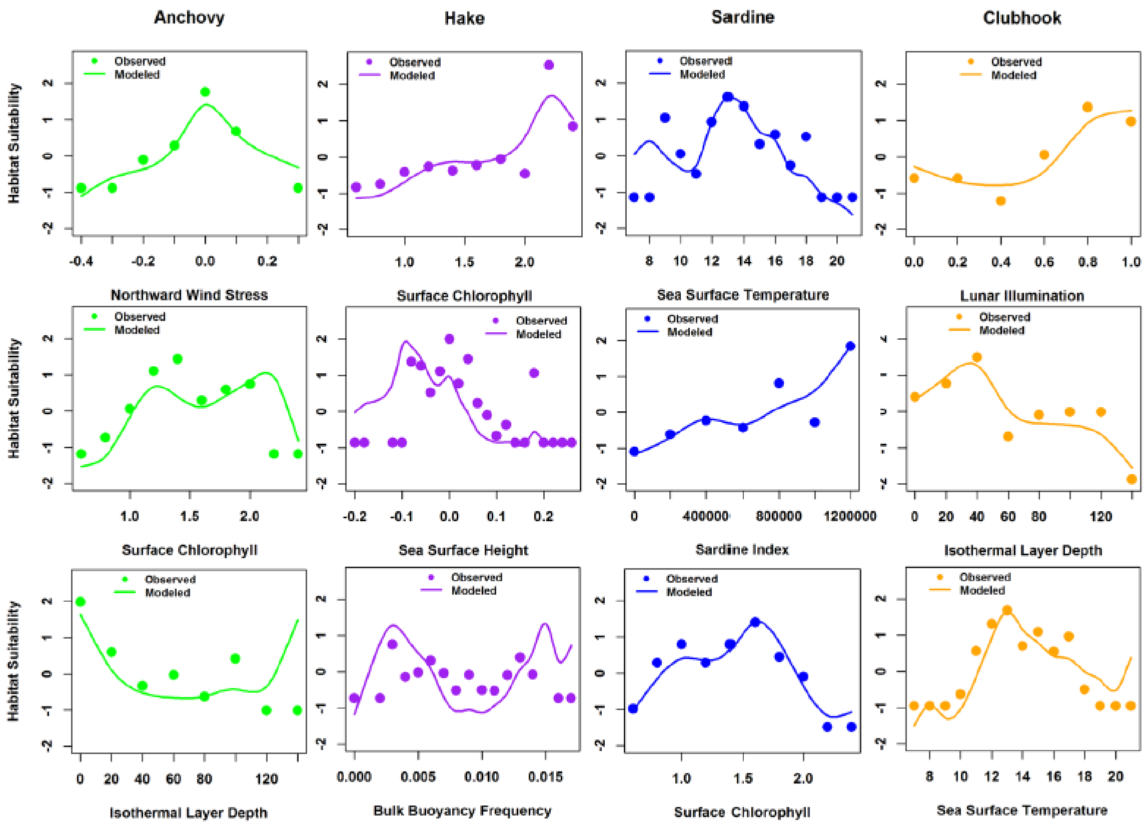


Figure 5. Response curves of (from left to right) anchovy, hake, sardine and squid, for different environmental variables. The y-axes show the occurrence probability of each species and the x-axes show the values for each variable. Source: Muhling et al. (2019)

II. Resilience

Explicit quantitative assessment of resilience is a complex task, as it requires specific experimentation for each environmental unit and threat under controlled conditions, which is resource and time consuming, and considerably limits the existing information on the subject.

Therefore, if the necessary information is not available at the required scale, the vulnerability analysis can be carried out exclusively based on the results obtained in the modelling (sensitivity), since the information related to the location of the environmental unit in its tolerance range (response curves) implicitly entails information related to its capacity for adaptation and recovery.

8. IDENTIFICATION AND QUANTIFICATION OF CONSEQUENCES

The quantification of consequences arises from integrating the previous sensitivity and resilience assessments (vulnerability) for each environmental unit (exposition) and for each threat. As it was the case in the vulnerability assessment, different approaches are used depending on the goal, the type of threat considered and the baseline data available.

8.1. Expert opinion and participation

In the most straightforward scenario, the consequences are defined qualitatively, by expert opinion or through public participation, based on previously made estimates of vulnerability and threat magnitude. In the same lines as the approach adopted for the vulnerability assessment, the assessment of the magnitude of consequences could be categorized into five levels, according to the following criteria:

- Negligible: when both vulnerability and threat are low or very low, it is considered that the main components will not have a visible or functional impact on the species, habitat or ecosystem service under consideration.
- Minor: under conditions of medium or high level vulnerability and threat, as well as when the threat level is very low but vulnerability is medium or high, or vice versa, it is expected that the environmental unit will be preserved and maintain its structure and functions, although some properties or processes may be affected.
- Moderate: the number of functions or elements may decrease, so that the environmental unit is considered as degraded, but not irreversibly so. This situation is generated under conditions of medium vulnerability and medium threat or high/low or very high/very low combinations of both parameters.
- Major: in situations where a very serious threat impacts an environmental unit of low or medium vulnerability, or a high threat acts on a unit of medium or high vulnerability, or vice versa, the environmental unit may regress and its main functions may be drastically altered, and its value significantly diminished.
- Extreme: in situations where a very serious threat acts on the environmental unit in such a way that such unit ceases to exist or its function is permanently altered, as the vulnerability and/or threat is very high.

In order to simplify and standardize the assessment of consequences, double-entry tables such as the one shown in Table 12 may be used. he table is fed with qualitative threat estimates and previous vulnerability estimates, which can also be carried out with a qualitative approach, or by considering some more precise approximation, such as the semi-quantitative method described above.

Table 12 Examples of qualitative assessment of consequences

MAGNITUDE THREAT	VULNERABILITY				
	Very low	Low	Medium	High	Very high
Low	Negligible	Negligible	Negligible	Minor	Minor
Medium	Negligible	Minor	Minor	Moderate	Serious
High	Negligible	Minor	Moderate	Moderate	Extreme

8.2. Tools based in Geographical Information Systems

When threats can be easily represented in space, such as, for example, the area that will be flooded by the rising sea level, the regression of the coastline caused by erosion processes or the alteration of seabeds caused by trawling, the easiest manner to assess the consequences is using tools based on Geographical Information Systems (GIS). With this approach, by simply cross-referencing the information layers of the area surface modified by the threat and the spatial distribution of the environmental units under study, it will be possible to identify and quantify at least which units and which area of each of them will be potentially impacted.

In addition, if the territory has been classified on the basis of a vulnerability index or scale, a more accurate estimation of the consequences can be obtained by incorporating the sensitivity and resilience of the different environmental units into the analysis.

As mentioned above, the use of this approach based on Geographic Information Systems, and of other approaches in which cartographic information is used or created, requires that cartographic layers comply with minimum standards in accordance with the objectives of the European INSPIRE Directive (Directive 2007/2/EC), transposed into Spanish law by means of Act 14/2010, of 5 July, on geographic information infrastructures and services in Spain (LISIGE). As a reference, it is recommended to follow the instruction of the IMS Protocol of the IP INTEMARES project (https://intemares.es/sites/default/files/protocolo-sig_intemares.pdf). Besides, this information must be compatible with the Nature Data Bank(https://www.miteco.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/) and the InfoMAR platform (http://infomar.cedex.es/). In this manner, the harmonization and interoperability of mappings is guaranteed.

8.3. Ecological models

When the approach to assess the environmental unit considered is to assess its species, one of the most frequent tools to assess potential species distribution patterns are ecological models, which may be more or less complex.

Correlative Species Distribution Models (SDM) combine occurrence data with environmental variables, thus offering a representation of the ecological requirement of the environmental unit considered. The main advantage of SDM is that they only require the geographical location of the environmental unit considered to create eligibility data of the geographical space. However, SDM do not explore existing biotic relationships between the different elements that are part of the same community, and which also play a key role in the distribution of environmental units.

Different approaches, with different levels of complexity and development, are proposed to solve this limitation. The first is the development of mechanistic models that define interactions between species through equations. The problem with such approaches is the considerable amount of information required for parametrisation, which limits their applicability over large areas or for a large number of species or habitats.

Another possibility, which is being increasingly used, is the combination of physiological information obtained from experimentation with SDM in so-called hybrid models, as they improve the predictive capacity of the models. However, this approach requires the development of species-specific experimentation, which is difficult to implement since it is time- and resource-consuming.

Finally, as an evolution of SDMs, joint species distribution models (JSDMs) are presented. Those models are capable of capturing the effects of biological interactions in communities, allowing information on biotic interactions to be obtained more efficiently than by experimentation, especially when working over large areas or with a large number of environmental units.

9. RISK ASSESSMENT

Risk is defined as the product of the consequences and the probability of occurrence of the threat, so any definition of risk will depend on how the corresponding threat has been defined. If the threat has been estimated statistically, the probability of occurrence would already be implicit in the threat characterisation.

Similarly, the results of most ecological models are expressed in probabilistic terms.

If the entire process has been carried out with a qualitative approach, the risk could be classified into different categories, established on the basis of the crossing of the consequences and their probability of occurrence, which, following the approaches set out in the previous sections, could be as shown in Table 13.

Table 13 Example of qualitative risk scale.

PROBABILITY THREAT	CONSEQUENCES				
	Negligible	Minor	Moderate	Serious	Extreme
Rare	Low	Low	Low	Low	Low
Unlikely	Low	Low	Moderate	Moderate	Moderate
Possible	Low	Moderate	Moderate	High	High
Probable	Low	Moderate	High	High	Extreme
Almost certain	Low	Moderate	High	Extreme	Extreme

10. DEFINITION OF ENVIRONMENTAL ADJUSTMENT AND MONITORING MEASURES

Once the risks have been identified and quantified, the next step is to create and set out the priorities of a programme of measures for the management of PMSs and adjacent areas in order to reduce the magnitude of the identified risk for the most threatened and vulnerable environmental units. Reducing risk will require promoting ecosystem adjustment to climate change by acting on the relevant threats, exposure and/or vulnerability. Measures will be selected according to the following priorities:

- Effectiveness: preferably the risk components (i.e. threat, exposure and/or vulnerability) previously identified as critical will be addressed with measures that further reduce the risk. Based on this, the effectiveness of the measure in reducing the risk will be estimated qualitatively as low, moderate or high.
- Economic value: the cost of the measure considered shall be valued in a qualitative (as qualitatively as low, moderate or high) or quantitative manner.

Finally, both rankings will be combined to obtain priority measures, so that measures with high effectiveness and low cost will be prioritised and vice versa. The need to ensure the participation of all administrations and key actors in the whole process of defining, prioritising, designing and implementing adaptation measures must be emphasized.

It is also advisable to develop environmental monitoring programmes for the most threatened environmental parameters or units, so that deviations from the conservation objectives established for each area can be detected, as well as to update the estimations in terms of the changes expected in the different climatic and anthropogenic scenarios.

Using the recommendations in the manual “Protected areas in a context of global change: incorporation of adjustment to climate change in planning and management”, (EUROPARC España, 2017) and the measures proposed within the project “*Risk mapping of natural systems under climate change in estuaries in the Cantabrian coast*(MARES)“ (IHCantabria - Biodiversity Foundation, 2018) as a reference, a list of possible management measures aimed at improving or maintaining the elements that make up natural systems and their capacity to provide ecosystem services follows (Table 14). This proposal for measures is a general approach that can be used as a reference for specific objectives and measures adapted to the different case studies. It is recommended that the specific proposal of goals around which measures are to be structured be based on the SMART (Specific, Measurable, Achievable, Relevant and Time-bound) format.

The proposal for general measures has been organised into operational objectives, for each of which different kinds of management measures are identified, which can be broadly classified as follows:

- Conservation measures: aimed at maintaining or enhancing biodiversity and ecosystem services.
- Restoration measures: aimed at reversing situations where habitats and species are deteriorating or declining.

- Research measures: related to improving knowledge (e.g. R&D&I) of planning factors.
- Governance measures: aimed at promoting integrated management between all public entities of all levels involved (General National Administration, Regional Administrations, Local Administrations), and belonging to different sectors, given that the potential climate scenarios and the magnitude of the changes to be tackled will require a cross-cutting approach. In addition, these measures must engage the different users and stakeholders involved in the design and implementation of the measures.
- Communication measures: aimed at enhancing social support through information, education and awareness-raising initiatives.

Table 14 Structure of the adjustment measures proposal

MEASURES	ADJUSTMENT			
	THREAT	EXPOSITION	VULNERABILITY	CROSS-CUTTING
Conservation	✓	✓	✓	
Restoration	✓	✓	✓	
Research				✓
Governance				✓
Communication				✓

* Adapted from the project "*Risk mapping of natural systems under climate change in estuaries in the Cantabrian coast (MARES)*" (IHCantabria – Biodiversity Foundation, 2018).

ACTION AGAINST EXISTING THREATS

Operational goal 1: Reducing non-climate related anthropogenic stressors in order to minimize the vulnerability of habitats and species to climate change.

- Restricting the development of activities that caused degradation of ecosystems critical for conservation and protection against the effects of climate change in the environment of habitats sensitive to the pressures of such activities.
- Restoring natural processes (e.g. water and sediment flows) affected by the presence of anthropogenic structures (e.g. dam removal).
- Promoting effective nutrient management.
- Reducing pollution from land-based sources, promoting the monitoring and review of existing discharge authorisations in coastal areas and encouraging surveillance to identify unauthorised spillages.
- Modifying the exploitation and use of natural resources towards a system of sustainable exploitation.

- Promoting the implementation of plans for the detection, control, management and monitoring of invasive species.
- Promoting social awareness of the effects of climate change and the importance of natural ecosystems as an element of adaptation and mitigation.
- Promoting the establishment of buffering or transition zones between natural resources and human activities for the protection of the natural environment

ACTION AGAINST EXPOSURE

Operational goal 2: Enabling migration of habitats and/or species in order to facilitate the evolution of an ecosystem towards a new status adapted to climate change and its variability that allows the maintenance of natural capital, preserving ecosystem services.

- Restricting the development of new anthropic protection structures that prevent the migration of aquatic and coastal habitats and promote the elimination of disused or poorly preserved infrastructures that favour the migration of natural habitats as an adaptation to any climatic changes that may occur.
- Promoting connectivity across the territory through the creation and preservation of corridors between natural spaces in order to enable migration and dispersion of ecosystems and their species.
- Promoting the creation of buffering or transition zones around SPMs.
- Attracting of national and European funding (e.g. LIFE projects) for the implementation of these measures.

Operational goal 3: Addressing threats to biodiversity through nature-based solutions capable of delivering the ecological, economic and social benefits that promote coastal sustainability in a climate change framework.

- Implementing green infrastructure to protect habitats of special conservation interest and other key socio-economic elements from extreme events caused by rising sea levels due to climate change.
- Restoring or encouraging the development of new habitats with a high capacity to buffer the effects of extreme events.
- Developing good practice manuals for the restoration of natural habitats by enhancing their capacity to provide services (e.g. protection services).

ACTION AGAINST VULNERABILITY

Operational goal 4: Reducing the effect of climatic stressors (temperature, precipitation, acidification) associated with climate change to minimise the vulnerability of habitats and species faced with climate change.

- Enhancing biodiversity (i.e. diversity of habitats, species and genetics).
- Recovering lost elements of biodiversity.
- Enhancing landscape heterogeneity.
- Guaranteeing connectivity.
- Enabling species dispersion.

Operational goal 5: Maintaining or improving habitat status in order to increase their resistance and resilience to climate change and associated extreme events.

- Guaranteeing the conservation of or restoration to optimal environmental conditions and/or regulating those activities that pose a risk to the achievement of good conservation status for habitats and species of community importance (Habitats Directive, 92/43/EEC)
- Guaranteeing the conservation of or restoration to optimal environmental conditions and/or to regulating activities that pose a risk to achieving good ecological and chemical status of water bodies according to the Water Policies Framework Directive (2000/60/EC).
- Encouraging the development of actions on the coastline to pay attention to the most vulnerable elements, prioritising the conservation of habitats and species of interest, endemic, scarce or at risk.
- Promoting the development of early warning systems for threats and changes in the state of habitats.

Operational goal 6: Buffering substantial alteration or loss of ecosystems and the services they provide.

- Adopting adaptive management approaches to changing conditions for the use of ecosystem services (e.g. agriculture, livestock, forestry, fisheries, etc.).
- Developing early warning systems for extreme events that pose a threat to ecosystems.
- Promoting the implementation of management and restoration plans for natural ecosystems after disturbances caused by extreme events associated with rising sea levels on the ecosystem and the provision of services, as a tool in the short and medium term or as long as environmental conditions do not differ too much from baseline conditions.

CROSS-CUTTING INITIATIVES

Operational goal 7: Increasing knowledge on habitats and ecosystem services and their interaction with climate change.

- Developing research programmes and networks on the effects of global change and management actions on ecosystems and the services they provide.
- Developing methodologies for the homogeneous assessment of the services provided by coastal and marine ecosystems and their implications in a climate change scenario.
- Systematic monitoring of coastal and marine habitats and the services they provide to society.
- Transferring the results of research and monitoring to management.

Operational goal 8: Improving social support and awareness of the effects of climate change in a context of global change.

- Communicating the effect of global change on ecosystems and its contribution to common well-being through the services they provide, using a language understandable by everyone.
- Encouraging the creation of cooperation networks and environmental volunteering.
- Developing and implementing an environmental education plan on sustainability and climate change.
- Promoting active communication and information exchange policies related to climate change and ecosystems.
- Promoting training and capacity building on good practices for the conservation of ecosystems and the services they provide to society in a complex socio-ecological and climate change scenario.

Operational goal 9: Developing new governance models that integrate and coordinate climate change mitigation and adaptation into public policies and sectoral strategies.

- Including the conservation of ecosystem services and essential ecological processes explicitly in climate change mitigation and adaptation policies.
- Establishing inter-sectoral coordination mechanisms that ensure the incorporation of environmental criteria and measures of adjustment to global change in all territorial policies.
- Creating and strengthening inter-administrative coordination procedures between the areas with competence in global change, in order to avoid duplicated efforts.
- Create specific coordination bodies for implementing climate change adjustment measures, at different scales.
- Developing management models that favour synergies with other public sector entities and that are articulated around ecosystem services (e.g. health, education).
- Encouraging partnerships that stimulate private participation in nature conservation.

- Exploring new funding mechanisms for conservation and/or restoration of protected areas (e.g. service charges).
- Implementing methodologies for assessing the tangible and intangible costs and benefits of adaptation to compare and prioritise investments.

11. Application examples

This section includes three examples of risk assessment, which have different specific objectives and apply different methodological approaches to the assessment of hazard, exposure and vulnerability, and thus to the estimation of consequences and risk.

CASE STUDY 1 Application of expert criteria in the assessment of Neptune grass in the Mediterranean.

In this case, a qualitative assessment is carried out, developed by the writing team specifically for this document. A more detailed description of the procedure followed can be found in Annex II.

CASE STUDY 2 Application of Geographical Information Systems (GIS) in the assessment of the impact of the rising sea level on the ecosystem services of an estuary in the Cantabrian coast.

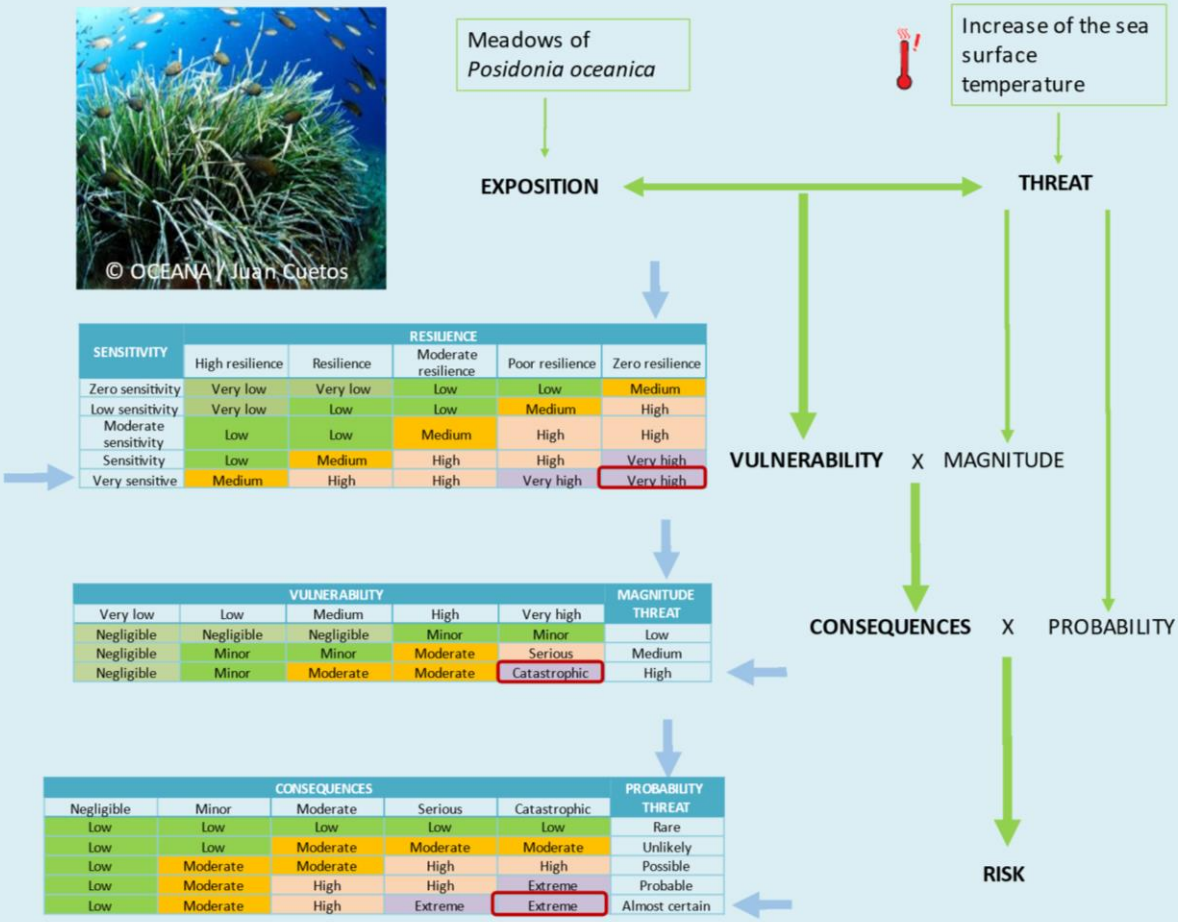
This example is adapted from the project “Risk mapping of natural systems under climate change in estuaries in the Cantabrian coast (MARES)“ developed in 2018 by IHCantabria and funded by Biodiversity Foundation (IHCantabria – Biodiversity Foundation, 2018).

CASE STUDY 3 Application of ecological models in order to determine the potential distribution of *Gelidium corneum* in the Spanish Atlantic coasts.

This example is part of the project "The fields of *Gelidium corneum* red algae on the Spanish Atlantic coast: Is its conservation compatible with its commercial exploitation? (GELIDIUM)", still in execution phase, also developed by IHCantabria and funded by Biodiversity Foundation (IHCantabria - Biodiversity Foundation, 2020).

CASE STUDY 1 Application of expert opinion in the assessment of Neptune grass in the Mediterranean Sea

The goal of this assessment is to determine whether Neptune grass (*Posidonia oceanica)* will be threatened by rising sea temperatures, in the time horizon 2100 and RCP 8.5, in a Mediterranean PMS. This species is known to occur in the area of this PMS, but detailed mapping is not available, so an approach consisting in a qualitative assessment based on expert judgement has been chosen instead. According to available information, the Mediterranean will be one of the areas most affected by the rise in sea surface temperatures, so the <u>magnitude</u> of the threat is considered high. According to the IPCC report (2019), the projected temperature increase is very likely, so that, according to the defined scale, the probability can be considered as <u>virtually certain</u>. A sensitivity assessment would require an evaluation of its ecology by experts. By way of example, and based on existing literature, it could be considered <u>sensitive</u>, given that its propensity to suffer negative effects in cases of temperature increases has already been reported in different locations, including the Balearic Islands. Neptune grass grows very slowly and therefore has a low capacity for recolonisation, which is why it is considered to present <u>low resilience</u>. As a result, it its also <u>highly vulnerable</u>. Crossing a high magnitude threat with the high vulnerability results in <u>moderate consequences</u> which, in turn, when crossed with a probability classified as virtually certain, yields a <u>high risk</u>.



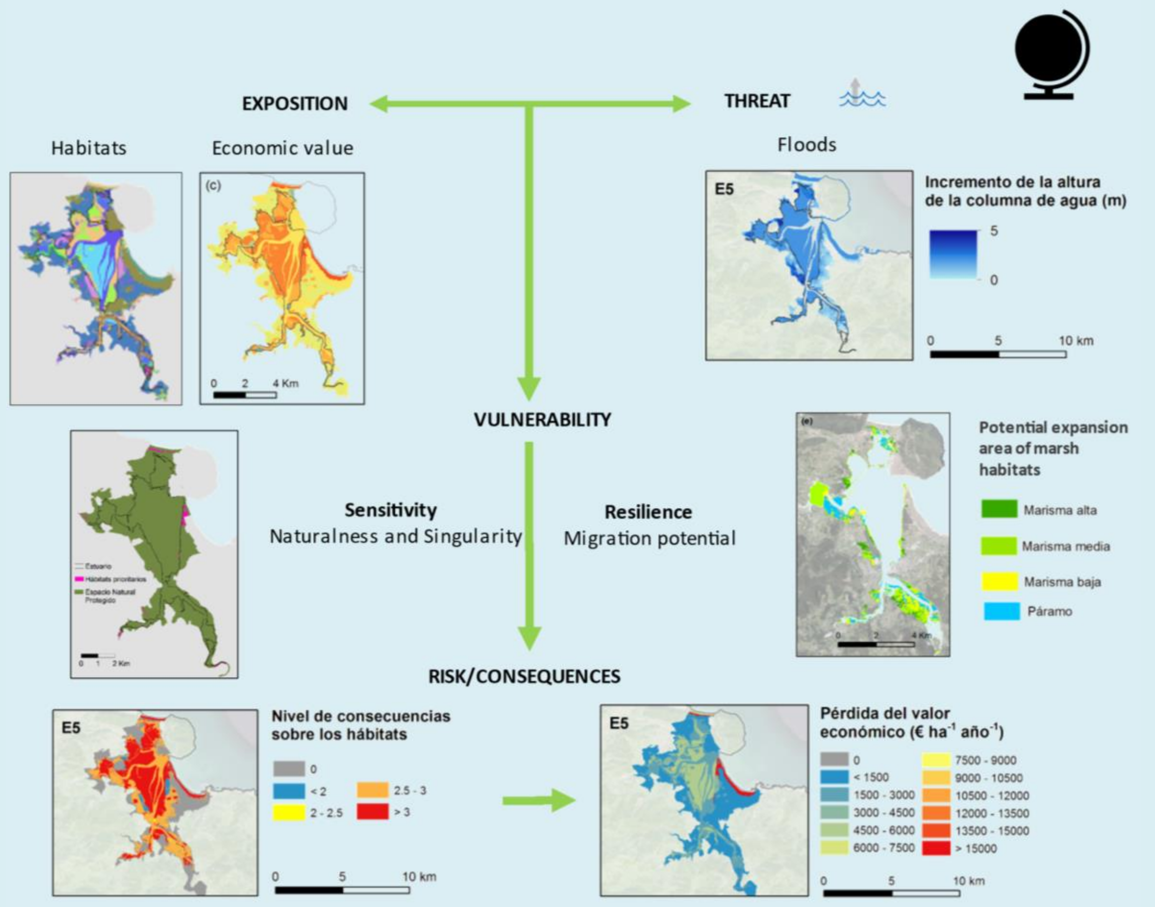
SENSITIVITY	RESILIENCE: High resilience	Resilience	Moderate resilience	Poor resilience	Zero resilience
Zero sensitivity	Very low	Very low	Low	Low	Medium
Low sensitivity	Very low	Low	Low	Medium	High
Moderate sensitivity	Low	Low	Medium	High	High
Sensitivity	Low	Medium	High	High	Very high
Very sensitive	Medium	High	High	Very high	Very high

VULNERABILITY: Very low	Low	Medium	High	Very high	MAGNITUDE THREAT
Negligible	Negligible	Negligible	Minor	Minor	Low
Negligible	Minor	Minor	Moderate	Serious	Medium
Negligible	Minor	Moderate	Moderate	Catastrophic	High

CONSEQUENCES: Negligible	Minor	Moderate	Serious	Catastrophic	PROBABILITY THREAT
Low	Low	Low	Low	Low	Rare
Low	Low	Moderate	Moderate	Moderate	Unlikely
Low	Moderate	Moderate	High	High	Possible
Low	Moderate	High	High	Extreme	Probable
Low	Moderate	High	Extreme	Extreme	Almost certain

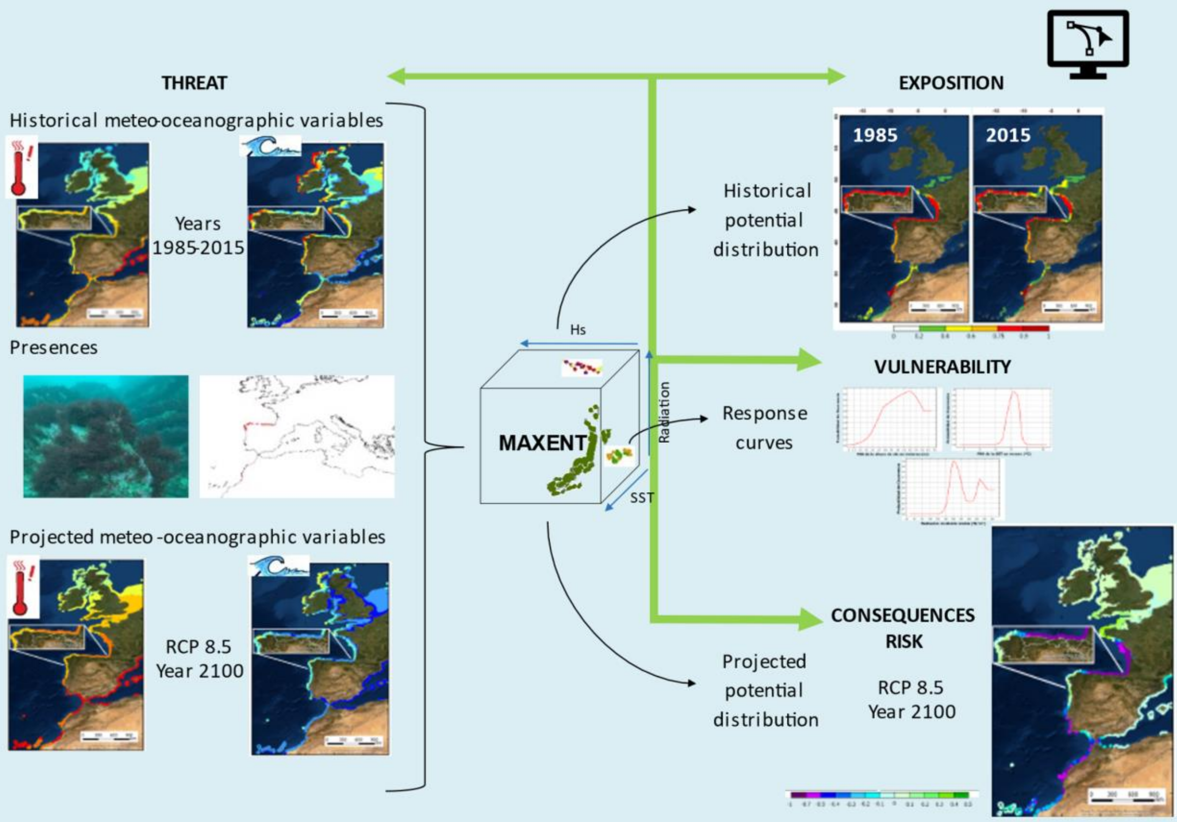
CASE STUDY 2 Application of Geographical Information Systems (GIS) in the assessment of the impact of the rising sea level on the ecosystem services of an estuary in the Cantabrian coast.

In this case study the threat considered is a sea level rise of 2 m in the 2100 time horizon, characterised through two indicators: permanent inundation of currently terrestrial habitats and an increase in the maximum height of the water column in aquatic habitats. The threat was obtained from the specific modelling for the study area (RFSM model), so the information obtained was space-specific and could be evaluated with GIS techniques. The environmental unit under assessment was the ecosystem services provided by the estuaries in the Cantabrian coast, which were assessed on the basis of the habitats providing these services. For this reason, the exhibition was characterised on the basis of present habitats, thus creating a homogeneous cartography, based on the EUNIS classification systems and habitats of Community interest in the sense of the Habitats Directive (92/43/EEC). The classification of the most relevant ecosystem services for each of the habitats identified was based on the types established in CICES, taking into account their singularity, the capacity of the habitat to provide the services and the availability of data. Vulnerability was assessed on the basis of sensitivity indicators related to naturalness (Protected Natural Areas) and singularity (priority habitats), and resilience indicators (migration capacity of each different habitat). Based on the space-related information of the threat (where probability is already incorporated) and the existing habitats in the area under study, a series of indicators were defined to assess the consequences/risk to the habitats and thus to the ecosystem services they provide, expressed in monetary terms.



CASE STUDY 3 Application of ecological models in order to determine the potential distribution of *Gelidium corneum* in the Spanish Atlantic coasts.

The goal of this assessment is to determine changes in the distribution of the *Gelidium corneum* algae, a biological resource of high ecological value due to its use in the production of agar-agar. For this purpose, a species-level assessment has been carried out using the MaxEnt correlative ecological model (Phillips et al., 2006). Sea level temperature and wave energy have been considered as threats and obtained from the OCLE database (https://ocle.ihcantabria.com/). The model was based on occurrence data and environmental variables for the period 1985-1990 and then projected to 2010-2015, to test its transferability over time and, once validated, to obtain the historical distribution of the species (exposure). The outputs of the model include the response curves of the species, that is, its vulnerability, represented as its probability of occurrence against each of the threats considered. This approach integrates consequences and risk, as the probability of the threat is built into the modelling process. The results of this model include an estimate of the probability of occurrence of the species in the area of interest, for the different scenarios and time horizons considered. In this specific case, the model predicts a regression of the species along the entire Cantabrian coast, while the Galician coasts could be considered a climatic refuge in the medium and long term.



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