

Case Study 2 – Annex

Intercontinental Biosphere Reserve of the Mediterranean: Andalusia (Spain) – Morocco[1]

[1]See full case study report for author and project information. Further information at https://aquacross.eu/content/case-study-2-analysis-transboundary-water-ecosystems-and-greenblue-infrastructures

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Annex 1: Data

Title of the dataset	Resources	AQUACROSS Information Platform *url*
List of targeted species included in the species distribution assessment (Species Distribution Modelling, SDM)	List of targeted species	http://dataportal.aquacross.eu/dataset/group-intercontinentalbiosphere-listofspeciesibrm
Aggregated probability of occurrence of each species per planning unit	Probability of species occurrence	http://dataportal.aquacross.eu/dataset/group-intercontinentalbiosphere-probabilityofspeciesoccurrence
Ecosystem services (ES)	ES water-ARIES ES carbon-ARIES ES sediment-ARIES ES recreational-ARIES ES pollination-ARIES ES flood-ARIES ES capacity	http://dataportal.aquacross.eu/dataset/group-intercontinentalbiosphere-ecosystemservices
Ecosystem condition	Ecosystem condition	http://dataportal.aquacross.eu/dataset/group-intercontinentalbiosphere-ecosystemcondition
Human Footprint Index ((HFI)	Human footprint index (HFI)	http://dataportal.aquacross.eu/dataset/group-intercontinentalbiosphere-hfiibrm
Green and Blue Infrastructure (GBI).Best solution: baseline and EBM scenarios	Green and Blue infrastructure scenarios-best solution	http://dataportal.aquacross.eu/dataset/group-intercontinentalbiosphere-gblsolution
Green and Blue Infrastructure (GBI). Frequency of selection: baseline and EBM scenarios	Green and Blue infrastructure scenarios-frequency	http://dataportal.aquacross.eu/dataset/http://dataportal.aquacross.eu/dataset/group-intercontinentalbiosphere-gblfrequency
Planning units and boundaries for the analysis of aquatic ecosystems in the International Biosphere Reserve of the Mediterranean and its Area of Influence	Planning units in the CS2	http://dataportal.aquacross.eu/dataset/group-intercontinentalbiosphere-pus
List of habitats in the CS2	Habitat types	http://dataportal.aquacross.eu/dataset/group-intercontinentalbiosphere-list-of-habitats-in-the-cs2
Detailed description of policies in the CS2	Overview of the policy context	http://dataportal.aquacross.eu/dataset/group-intercontinentalbiosphere-detailed-description-of-policies-in-the-cs2

Detailed information on existing management measures	Existing management measures	http://dataportal.aquacross.eu/dataset/group-intercontinentalbiosphere-detailed-information-on-existing-management-measures
Connectance between activities, pressures and ecosystem components	Connectance	http://dataportal.aquacross.eu/dataset/group-intercontinentalbiosphere-connectance
List of activities and pressures in the CS2	List of activities and pressures	http://dataportal.aquacross.eu/dataset/list-of-activites-and-pressures-datasets

Annex II: Stakeholder process

The stakeholders have actively participated in the CS development and they have been interrogated at several stages of the project.

Summary of the participation of stakeholders in the CS2

Background: According to the stakeholders, the spatial extent selected for conducting the CS2 is a key area in terms of supporting the achievement of EBM objectives, due to the development of activities which impose important pressures on the IBRM.

Co-design of objectives: We have discussed with stakeholders on the pressures, key activities and environmental values in the CS2 area, and specifically in the IRBM, in order to achieve an integrative policy characterisation of the CS2. The outcomes from the stakeholders have also served to complete the assessment of the SES. In addition, policy characterisation was possible thanks to the data and information provided by the stakeholders. The EBM targets were defined by the technicians and stakeholders, in agreement with EU targets (EU Biodiversity Strategy 2020) as well as with national and regional policies (Hydrological management plans, marine strategy, protected figures, and coastal protection).

Co-design of D-P-S: stakeholders participated in the identification of the main threats, conflicts present in the case study area.

Co-design of causal relationships: The identification of ecosystem components, functions and services were possible thanks to the support of the local experts on biodiversity, ecology, sustainable development and spatial planning in each CS2 sections, namely managers of the protected sites and of the IBRM, as well as coastal and marine planners, planners on water management, and actors playing a relevant role in the different economical activities developed in a sustainable way in the CS2 area. Technical and local experts also helped during the data/information compilation. In addition, the involvement of the stakeholders was crucial in the process of defining indicators since they sourced the data required for their quantification.

Scenario development: The stakeholder participation was a key piece in the entire scenario building process, especially in three different phases: initial phase for the assessment of the SES, second phase for the discussion of the baseline and define the EBM targets and measures, third phase during the modelling exercise for the discussion of the modelling results. On a local level Biosphere Reserve's Management Council and Stakeholders Network are involved. Regional actors are, for example, the Ministry of the Environment and spatial planning, ecologic transition, sustainable development. On a national level, actors of importance are the Ministry of the Environment and Planning. The international drivers are biodiversity, water and marine directives whereas the Sustainable Development Goals are Biodiversity Archi Targets are also important.

The stakeholder preferences were used as inputs in the Marxan with Zones analyses (Annex III). The spatial priorities for the EBMs were based on the planning goals expressed by the stakeholders. GBI approach allowed the integration of several conservation and exploitation objectives expressed by different stakeholders in the same area. According to stakeholder requirements, we considered four different GBI management zones including, two with conservation aims (the core zone and conservation zone), one to manage trade-offs between biodiversity conservation, maintenance of compatible ES and incompatible ES (the sustainable use zone)(Hermoso et al. 2018)(Hermoso et al. 2018), and a fourth one to implement the restoration objectives considered in the EBM scenario (the EBM restoration zone**Fehler! Verweisquelle konnte nicht gefunden werden.**). To spatially distribute the management zones in the GBI, we followed stakeholder preferences thus we selected core zones that are connected through another core zone or through a conservation zone. Restoration zones were spatially arranged following the same criteria as conservation zones but paying attention on the unfavourable habitats.

Steps and outcome of the stakeholder mobilisation process

Workshops: Two kick-off workshops were organized to present the CS2 project and discuss for the first time the pressures, key activities and environmental values of the CS2 area (and specifically of the IRBM) among stakeholders:

The first workshop was organized in **April 2016 in Seville**, with delegates representing the Regional Ministry of Environment of Andalusia - Ministry of Environment and Spatial Planning of Andalusia, including the director of the IBRM.

A similar workshop concerning the Moroccan section of the IBRM was organized in **October 2016 in Tangier** (Morocco), with the Regional Observatory of the Environment and Sustainable Development (OREDD) of Tangier-Tetouan.

The results derived from the assessment of the SES and of the spatial explicit assessment of the current baseline were presented and discussed with the stakeholders in a third workshop, organized in **February 2018 in Facinas** (Tarifa, Spain), namely with representatives of the Regional Ministry of Environment of Andalusia - Ministry for Ecologic Transition ("Consejería Medio Ambiente y Ordenación del Territorio Ministerio para la Transición Ecológica", in Spanish) and the High Commission for Waters, Forests and Desertification of Morocco ("Haut Commissariat Aux Eaux Et Forets Et A La Lutte Contre La Desertification", in French), representatives from UNESCO Man and Biosphere Programme and the Biosphere Reserve Network, representatives from protected sites within the IBRM, and representatives of the main sustainable economic activities developed in the study area, namely farmers, livestock producers, manufacturers, as well as local non-profit organizations devoted to nature conservation and restoration.

The outcomes from the first two workshops served to complete the assessment of the SES by identifying the main threats, key socio-economic activities and the biodiversity value, that were latterly translated into data for the SES assessment. On the other hand, during the third workshop the CS2 technical/scientific team and the stakeholders worked interactively to define the baseline in the CS2 and to determine EBM targets and GBI management zones taking into consideration the trade-offs and synergies between biodiversity and ES.

Working groups: During the workshop held in Facinas (February 2018), we allowed stakeholders to discuss and identify the main planning goals desired for the CS2 area by means of working groups. As main goals for the CS2 area, stakeholders highlighted the following:

- protecting biodiversity
- reducing the current pressures
- restoring ecosystems and improving their services
- promoting green and blue growth

During the development of these working groups, other issues relevant for the implementation of an EBM approach in the CS2 emerged. These issues are summarized below:

- The IBRM is not well-known among the local community;
- The importance, complexity and challenges of the transboundary management
- The fact that IBRM itself and CS2 area integrate several protected figures;
- The importance of the involvement of the local community for the success of the IBRM;
- The importance of the region for biodiversity and ecological conservation as well as for socioeconomic development in relation to green economy and tourism;

Contacts with local experts: Simultaneously to the workshops development, technical and local experts (namely managers of the protected sites and of the Intercontinental Biosphere Reserve, as well as coastal and marine planners, planners on water management, and actors playing a relevant role in the different economical activities developed in a sustainable way in the CS2) were contacted for data / information compilation. This contact was made not only during the meetings with local experts but through the data request online channel, and by email. This contact contributed to the involvement of these local experts on the identification of ecosystem components, functions and services.

Meeting local actors: For a better understanding of the SES in the CS2, we met the local actors at their daily life (namely artisanal local fishermen, the Maritime Rescue Coordination Centre, responsible for rescue of human life at sea, prevention and control of marine pollution, monitoring and control of maritime traffic as well as a factory and shop where canned artisanal canned and other preserved fish products are produced (Tarifa, Spain). We also visited a natural peri-urban park in northern Morocco (Tangier).

Annex III: Assessment methods and tools

Study area

According to the MaB programme, the objective of the Biosphere Reserves is to promote solutions to reconcile the conservation of biodiversity with its sustainable use, therefore the IBRM per se is a useful instrument for the conservation of transboundary ecosystems that go beyond the national borders, supporting the implementation of common policies across the area (Consejería de Medio Ambiente de la Junta de Andalucía, 2011). Although, northern and southern sections of the IBRM share common policies and synergies can be appointed among the key policies that are currently implemented or being implemented such as biodiversity strategies, coastal management plans, protected areas and river management plans. However, the common policies are not always in conformity in both sections of the IBRM.

The climate conditions induce a rich and diverse vegetation. On both parts of the study area woodland/forest is the dominant ecosystem. The southern part of the case study is mountainous and humid with the highest national precipitation rate, comprising a variety of ecosystems mostly characterised by woodland and forest cover (47%) and agriculture (35%), together with shrubland (9%) and grassland (7%) (Copernicus Global Land Service 2017). In the northern section woodland/forest occupies more than 56% of the total extent, followed by grassland (15%), shrubland and agriculture (11%). Artificial areas, including urban and industrial as well as infrastructures cover 7% and rivers and lakes occupy 3% of the total area (SIOSE 2016).

The economic activities in both the northern and southern sections of the case study area are based on agriculture, livestock, fisheries, and tourism, all of which are highly dependent on terrestrial and aquatic resources. The aquatic ecosystems provide a vital range of provisioning goods and services for sustaining human well-being (water and biomass provision, regulation and maintenance ES, traditional cultural uses, among others). In addition, this area is highly demanded for recreational and tourism activities.

Spatial planning approach

We used Marxan with Zones to identify priority areas for the designation of the GBI. Marxan with Zones makes use of the concept of systematic conservation planning to optimize the allocation of GBI zones (Watts et al. 2009). Systematic conservation planning ensures key planning principles such as comprehensiveness, efficiency, flexibility, complementarity and “irreplaceability” of the selected spatial units (called planning units; PUs) to be included in the protected area network (Margules and Pressey 2000; Margules and Sarkar 2007). Typically, such plans are based on species distribution models (SDM), habitat type or ecosystem distribution and/or spatial distribution of ES and allow costs, alternative land-use needs, and other types of spatial restrictions to be integrated in the spatial solution (Hermoso et al. 2018; Moilanen et al. 2011; Snäll et al. 2016). Here we used Marxan with Zones to design a multifunctional GBI considering the trade-offs between ES and biodiversity, as well as different EBM restoration alternatives. Marxan with Zones outputs , i.e. alternative spatial configurations of the GBI, were used as a basis for discussions with stakeholders in order to achieve an optimal solution both in terms of spatial prioritisation and of stakeholders needs (Jumin et al. 2017).

Planning units: three realms – three spatial structures

The selection of areas for investment in GBI was based on PUs that differed in size across the different realms. For freshwater ecosystems ,we used river sub-catchments derived from HydroSHEDS level 12 as PUs (Lehner and Grill 2013; World Wildlife Fund (WWF) 2017). Each sub-catchment included the river reach and its contributing area, representing an appropriate PU for freshwater conservation planning (Hermoso & Kennard, 2012). In total, 336 sub-catchments were used, covering between 89 and 118 km2. Coastal PUs (i.e. 10km buffer from the shoreline; European Environmental Agency (EEA), 2015) and marine PUs were derived from two regular grids. The PU size in the coastal and the marine realm was a compromise between the resolution of the available data and the extent of the study area. The PUs of the marine realm were represented through a grid of 10 km x 10 km, whereas the coastal PU grid was 1 km x 1 km (**Fehler! Verweisquelle konnte nicht gefunden werden.**, **Fehler! Verweisquelle konnte nicht gefunden werden.**). The decision to apply a refined resolution in the coastal areas was based on the diversity of activities and higher presence of human pressures in the coast compared to the marine area, as well as on the more detailed spatial resolution available for the information in coastal areas.

Table AIII.1. Statistical resume of the freshwater, coastal and marine planning units of the IBRM and its area of influence.

Case study sub-region	Realm	Resolution	Count	Minimum km2	Maximum km2	Area km2	Mean km2	Std. Deviation km2
Northern section	Freshwater	Sub-catchment level 12	150	0.17216	469	14,160	112,5	62
Southern section			186	0.17559	338	20,597	114	58
Northern section	Coastal	1 km2 regular grid	-	-	-	3.531	-	-
Southern section			-	-	-	3,393	-	-
Ocean	Marine	10 km2 grid	-	-	-	25,828	-	-

Conservation features

In order to provide robust results, spatial planning tools require consistent and robust distribution data of the conservation features to be managed (European Commission 2013c). Data sources and data treatment used in our study are detailed below. The data used for this study has been stored in a PostgreSQL (version 9.6) relational database with the PostGIS (version 2.3) extension installed. All the data processing was carried out using Python (version 2.7).

Ecosystem condition

In order to achieve the representation of healthy ecosystems in the GBI, habitat types (EUNIS level 2) at favourable ecosystem condition were included as additional conservation features. On the other hand, degraded ecosystems were used to identify potential restoration areas where EBM measures should be implemented within the GBI (EBM scenario). Degraded ecosystems have lower biodiversity and offer fewer services than their healthy counterparts. By restoring degraded ecosystems, we ensure that the network of healthy ecosystems and semi-natural areas is managed as a coherent, multifunctional resource (European Environment Agency et al., 2014).

We followed the recommendations from Maes et al. (2018) to quantify ecosystem condition in the study area considering three different classes of conservation status: 'Favourable', 'Unfavourable-inadequate' and 'Unfavourable-bad', whereas 'Unfavourable' meant that management policies for these habitats should be implemented and/or changed. This classification was applied to all freshwater, coastal and marine habitat types identified in the study area.

Spatial information on human pressure (i.e. the human footprint) was used as a proxy of ecosystem condition. According to Maes et al. (2018), given the strong causal relationship between pressures and ecosystem condition, this variable can be used as a proxy for ecosystem condition. For the freshwater realm, we used the human footprint data provided by the Socioeconomic Data and Applications Center (SEDAC) (2009) available at 1km grid in a raster format. For the marine area, we used a regional product that resulted from an assessment of the activities and pressures in the study area. In order to obtain dimensionless values that can be compared among freshwater and marine realms, both products were standardized separately for aquatic and marine ecosystems, and for the northern and southern regions of the study area. Based on this standardized data, three different human pressure categories, according to three realm-specific quantile thresholds, were established. Finally, an ecosystem condition category was attributed to each habitat type (EUNIS habitat classification levels 1 and 2). Habitats in the best condition category were at a favourable condition, whereas habitats in the two lower ecosystem condition categories were at unfavourable-inadequate and unfavourable-bad condition, respectively.

Ecosystem types

For mapping the ecosystem capacity to supply services, we used the ecosystem map and the linkage framework matrix ecosystem component- ecosystem services.

The definition and delineation of the ecosystems spatially and explicitly is crucial understand their natural condition, trends and the pressures to which they are exposed. The aim of this section is to define the ecosystem types at the IBRM area and mapping their structure.

Ecosystem structure can be mapped using data on land cover, climate, soil types, bathymetry, salinity, digital elevation models and high-resolution data that allow the refinement of the land cover maps. Ecosystem boundaries are likely to coincide with discontinuities in these factors. Geographic Information System technologies has strong capabilities to delineate the structure of the ecosystem by overlapping information on land use, climatic, geophysical and biochemical condition and land cover (Maes et al., 2013).

We used three different sources for mapping the Ecosystem types at the IBRM case study: Andalusia (Spain) section; Morocco section and marine section.

For the Andalusia (Spanish section) we extracted the data directly from the "Ecosystem types of Europe" 100m product dataset. This dataset combines the Corine based MAES ecosystem classes with the non-spatial EUNIS habitat classification for a better biological characterisation of ecosystems across Europe. As such it represents probabilities of EUNIS habitat presence for each MAES ecosystem type (European Environmental Agency (EEA) 2015b). This map combines spatial information on land cover, the Corine Land Cover 2006 v16- CLC) (European Environmental Agency (EEA) 2012) with the non-spatially data on habitats distribution (European Nature Information System - EUNIS) (Davies, Moss, and Hill 2004; Lengyel et al. 2008 and European Environmental Agency (EEA) 2015c). The CLC06 map has been remapped using the EUNIS habitats (European Environmental Agency (EEA) 2015a) In addition the land cover maps have been refined using ancillary data which allow a better delineation of the ecosystem types such for example forest data, water bodies, soil types. This method allows the spatially distribution of the habitat presence for each MAES ecosystem type thus improving their biological description. The benefits of combining CLC and EUNIS, especially for ecosystem service assessments at national to regional scales, have been demonstrated by Vihervaara et al. (2012) (Vihervaara et al. 2012 ; European Environment Agency (EEA) 2016).

For the Morocco section, we extracted and remapped the Land Cover Copernicus product 100 m for Africa. The legend used is based on the UN land cover classification system. This legend has been translated into the EUNIS Level 1 and Level 2 for the Coastal Habitats (B) and Inland Surface Waters (C). For this purpose we used the cross walk method between the Copernicus land use classification system to EUNIS adapted from CLC / EUNIS to map the MRC habitats (European Environmental Agency (EEA) 2015a). For more information see the

1- Mapping ecosystem types in Morocco: cross-walk table between Copernicus 100m and EUNIS Level 1 and Level 2.

The marine habitats have been mapped using the data from the EU Sea map from EMODnet. This dataset comprises the final output of the broad-scale habitat map (EUSeaMap) created as part of the EMODnet Seabed Habitats project in 2016. The data are presented in the EUNIS classification system where possible, and amalgamated into the MSFD predominant habitats.

1- Mapping ecosystem types in Morocco: cross-walk table between Copernicus 100m and EUNIS Level 1 and Level 2

Domain	MAES_L2	EUNIS L1	EUNIS code	EUNIS name	Copernicus Africa 100m
Coastal	Lagoons, coastal wetlands and estuaries	B Coastal habitats	B1	Coastal dunes and sandy shores	Method: extract 1000m the coastline and reclassify the land uses: 20 – shrubland 30 – herbaceous vegetation also included 80 – permanent water bodies 81 – temporary water bodies
Freshwater	Rivers and Lakes	C Inland surface waters	C1	Surface standing waters	80 – permanent water bodies + open water from CIFOR global wetlands V3
			C2	Surface running waters	80 – permanent water bodies
			C3	Littoral zone of inland surface waterbodies	81 – temporary water bodies
Terrestrial	Wetlands	D Mires, bogs and fens			90 – herbaceous wetland
	Heathland and shrub	F Heathland, scrub and tundra			20 – Shrubland
	Woodland and forest	G Woodland, forest and other wooded land	G1	Broadleaved deciduous woodland	114 – Deciduous broadleaf closed forest 124 – Deciduous broadleaf open forest
			G2	Broadleaved evergreen woodland	122 – Evergreen broadleaf open forest 112 – evergreen broadleaf closed forest
	Sparsely or unvegetated land	H Inland unvegetated or sparsely vegetated habitats			60 – Bare / sparse vegetation
	Urban	J Constructed, industrial and other artificial habitats			- Urban

2 – Ecosystem types based on EUNIS level 1 and EUNIS level 2 legend

Legend

Ecoystem types based on Based on EUNIS habitat classification level 2

- X1 Estuaries
- A Marine habitats
- A3 Infralittoral rock and other hard substrata
- A4 Circalittoral rock and other hard substrata
- A5 Sublittoral sediment
- A6 Deep-sea bed
- B Coastal habitats
- B1 Coastal dunes and sandy shores
- B3 Rock cliffs, ledges and shores, including the supralittoral
- C1 Surface standing waters
- C2 Surface running waters
- C3 Littoral zone of inland surface waterbodies
- D Mires, bogs and fens
- D5 Sedge and reedbeds, normally without free-standing water
- E Grasslands and land dominated by forbs, mosses or lichens
- E1 Dry grasslands
- E2 Mesic grasslands
- E3 Seasonally wet and wet grasslands
- E6 Inland salt steppes
- E7 Sparsely wooded grasslands
- F Heathland, scrub and tundra
- F2 Arctic, alpine and subalpine scrub
- F5 Maquis, arborescent matorral and thermo-Mediterranean brushes
- F6 Garrigue
- F7 Spiny Mediterranean heaths (...) and related coastal cliff veg
- FB Shrub plantations
- G1 Broadleaved deciduous woodland
- G2 Broadleaved evergreen woodland
- G3 Coniferous woodland
- G4 Mixed deciduous and coniferous woodland
- G5 Lines of trees, small anthropogenic woodlands, early-stage woodland
- H Inland unvegetated or sparsely vegetated habitats
- H2 Screes
- H3 Inland cliffs, rock pavements and outcrops
- H5 Miscellaneous inland habitats with very sparse or no vegeation
- I1 Arable land and market gardens
- I2 Cultivated areas of gardens and parks
- J Constructed, industrial and other artificial habitats
- J1 Buildings of cities, towns and villages
- J2 Low density buildings
- J3 Extractive industrial sites
- J4 Transport networks and other constructed hard-surfaced areas
- J5 Highly artificial man-made waters and associated structures
- J6 Waste deposits

Annex 2.1 – Aquatic and marine habitats in the CS2 area. EUNIS habitat classification.

ES	MAES_L2	EUNIS L1	EUNIS code	EUNIS name
Marine	Marine	A Marine habitats	A1	Littoral rock and other hard substrata
			A3_4	Infralittoral (A3) and circalittoral (A4) rock and other hard substrata
			A5	Sublittoral sediment
			A6	Deep-sea bed
			A7	Pelagic water column
			A8	Ice-associated marine habitats
			X1	Estuaries
			X2_3	Sublittoral sediment
Coastal	Lagoons, coastal wetlands and estuaries	B Coastal habitats	B1	Coastal dunes and sandy shores
			B2	Coastal shingle
			B3	Littoral rock and other hard substrata
Feshwater	Rivers and Lakes	C Inland surface waters	C1	Surface standing waters
			C2	Surface running waters
			C3	Littoral zone of inland surface waterbodies
			D1	Raised and blanket bogs
Terrestrial	Wetlands	D Mires, bogs and fens	D2	Valley mires, poor fens and transition mires
			D3	Aapa, palsa and polygon mires
			D4	Base-rich fens and calcareous spring mires
			D5	Sedge and reedbeds, normally without free-standing water
			D6	Inland saline and brackish marshes and reedbeds
			E1	Dry grasslands
	Grassland	E Grasslands and land dominated by forbs, mosses or lichens	E2	Mesic grasslands
			E3	Seasonally wet and wet grasslands
			E4	Alpine and subalpine grasslands
			E6	Inland salt steppes
			E7	Sparsely wooded grasslands
			F1	Tundra
	Heathland and shrub	F Heathland, scrub and tundra	F2	Arctic, alpine and subalpine scrub
			F3	Temperate and mediterranean-montane scrub
			F4	Temperate shrub heathland
			F5	Maquis, arborescent matorral and thermo-Mediterranean brushes
			F6	Garrigue

ES	MAES_L2	EUNIS L1	EUNIS code	EUNIS name
			F7	Spiny Mediterranean heaths (phrygana, hedgehog-heaths and related coastal cliff vegetation)
			F8	Thermo-Atlantic xerophytic scrub
			F9	Riverine and fen scrubs
			FA	Hedgerows
			FB	Shrub plantations
			G1	Broadleaved deciduous woodland
	Woodland and forest	G Woodland, forest and other wooded land	G2	Broadleaved evergreen woodland
			G3	Coniferous woodland
			G4	Mixed deciduous and coniferous woodland
			G5	Lines of trees, small anthropogenic woodlands, recently felled woodland, early-stage woodland and coppice
			H1	Terrestrial underground caves, cave systems, passages and waterbodies
	Sparsely or unvegetated land	H Inland unvegetated or sparsely vegetated habitats	H2	Screes
			H3	Inland cliffs, rock pavements and outcrops
			H4	Snow or ice-dominated habitats
			H5	Miscellaneous inland habitats with very sparse or no vegetation
			H6	Recent volcanic features

Biodiversity

Biodiversity is a key conservation feature of the GBI design. According to the data availability, we considered endangered species at the national level in Morocco and at the regional level in Spain (Andalusia region). Specifically, species of freshwater fishes, aquatic birds, and amphibians were included for the southern section of the study area (Global Biodiversity Information Facility (GBIF) 2018; International Union for Conservation of Nature and Natural Resources (IUCN) 2000). In addition, invertebrate species and characteristic plant species of aquatic and associated transitional ecotone habitats (dunes, sand and coastal cliffs) were included for the North section of the study area (Consejería de Agricultura Pesca y Medio Ambiente de la Junta de Andalucía 2016). To represent marine biodiversity of the northern section, we used 28 marine species, including invertebrates, mammals and birds, from the Andalusian Catalogue of Endangered Species and the Andalusian List of Species in Special Protection Regime. In the southern section, the data set of marine species was enriched with data on these marine species provided by the Global Biodiversity Information Facility (GBIF), (2018).

All of the species data were scarce and mostly based on presence-only data (lacking reliable information on true absences). Therefore, to obtain the complete information on spatial distribution required by Marxan with Zones, we developed models predicting the probability of presence of these species across the study area. Species occurrences were first aggregated to the planning units (sub-catchments and grids). We then used species distribution models (SDM) to map the range-wide potential distribution of each species within its realm (i.e., freshwater, coastal and marine). These models related species occurrences to the environmental conditions at those locations (Domisch et al. 2017). For each realm, we used a specific set of predictors that were not highly correlated (Spearman correlation coefficient < /0.7/. In the freshwater realm, we used mean annual air temperature (Fick and Hijmans 2017) averaged across each sub-catchment, downstream-accumulated annual precipitation (Fick and Hijmans 2017) as a proxy for discharge (Domisch, Amatulli, and Jetz 2015), average cover of broadleaf closed forest, broadleaf open forest, and urban areas as predictors, which we sourced from regional land cover data (Copernicus Global Land Service 2016; SIOSE 2016). In the coastal realm, we used bathymetry (Weatherall et al. 2015), sublittoral sediment coverage (European Marine Observation and Data Network (EMODNET) 2012), mean annual air temperature, mean annual surface water temperature (both required as the coastal area overlaps with the land and sea masks), and mean current velocity (Tyberghein et al. 2012). In the marine realm, we used bathymetry, mean annual surface water temperature, mean current velocity, mean annual salinity, mean annual primary productivity (Tyberghein et al. 2012), and coverage of coastal habitats and estuaries (European Marine Observation and Data Network (EMODNET) 2012) as predictors.

For each realm, we selected species that occurred in at least five sub-catchments or grids (as a minimum pre-requisite for building the model). We then used the “biomod2” R-package (R Development Core Team 2018) and three machine-learning algorithms (Random Forest, Boosted Regression Trees and Maximum Entropy), where 70% of the species data were used to train the model, and the remaining 30% were used to validate the model. After a 10-fold cross-validation, we combined all single projections per species into a consensus prediction, where predictions yielding a higher model evaluation score (as given by the True Skill Statistic; Allouche, Tsoar, & Kadmon, 2006) received a higher weight in the final consensus prediction using the default weighting factor of 1.6 (Thuiller, Georges, and Engler 2013). The mapped probability of occurrence of each species per PU was then used as a “conservation feature” in the subsequent spatial prioritisation analyses (see below).

Ecosystem services (ES)

Considering ES during the spatial planning process is crucial to guide the GBI designation (Maes et al. 2015). In this study, ES were presented as spatially explicit indicators, representing the capacity of provision. In agreement with previous studies, ES were classified as “incompatible” or “compatible” ES, depending on whether they do or do not represent conflicts with conservation goals (Chan et al. 2006; Hermoso et al. 2018).

The ES indicators on flood regulation, carbon sequestration, pollination, soil retention and potential recreational opportunities have been produced using the ARtificial Intelligence for Ecosystem Services modelling platform (Villa et al. 2014). ARIES is an open-source technology capable of selecting and running models to quantify and map all aspects of ES provision, including biophysical generation, flow and extraction by sinks and beneficiaries (Willcock et al. 2018). The pollination model calculates pollination supply in a first step, the suitability of the environment to support wild insect pollinators, based on nesting suitability and floral availability (Koh et al. 2016; Lonsdorf et al. 2009; Zulian, Polce, and Maes 2014). The model also includes the positive effect of the presence of water bodies (streams and lakes), on the probability of presence of pollinators based on an inverse weighted distance to them, as well as the effect of ambient temperature and solar radiation (Corbet et al. 1993). We estimated globally demand pollination based on the weighted sum of crop pollination dependencies (Klein et al. 2007), multiplied by their production for 55 crop types requiring insect pollination to increase their production (Monfreda, Ramankutty, and Foley 2008). The carbon storage model follows the tier 1 IPPC methodology and quantifies aboveground and belowground carbon storage in vegetation.

The recreation model is inspired by the ESTIMAP model of nature-based outdoor recreation, developed by Paracchini (2014). Recreation supply is an additive function of naturalness based on land cover type and the Euclidean distance to nature-based factors of attractiveness (e.g., distance to protected areas, water bodies, or mountain peaks). Recreation demand considers the likelihood of taking a day trip to a certain point and the population defining the "catchment area" of that point, based on distance to main cities and travel time. The flood regulation model identifies areas providing greater flood regulation as those with higher hazard probability, population density, and water retention by soils and vegetation. The sediment regulation model is an implementation of the Revised Universal Soil Loss Equation RUSLE; (Renard et al. 1997). By calculating RUSLE – first using existing land cover, then changing all land cover to bare soil – we can estimate the ecosystem service provided by vegetation in retaining soil (i.e., avoided soil erosion). The water supply model used averaged long-term data on total annual precipitation, groundwater depth, population, potential evapotranspired water volume, water supply inter-annual variability and total blue water (the accumulated runoff upstream of the catchment plus the runoff in the catchment) to produce a ratio of water availability. A more detailed description of the models can be found in this special issue (Martínez-López, J. et al. n.d.).

For ES that we were not able to map based on ARIES due to data availability constraints, we used a simplified approach that allowed mapping the spatial distribution of the capacity based on the ecosystem types. This approach (for a detailed description, please see Teixeira et al. in this special issue) was used in previous studies to map the supply and demand of ES (Burkhard et al. 2011; Burkhard B and J 2017) as well as the spatial distribution of marine ES capacity in the European Seas (Tempera et al. 2016).

Addressing connectivity

Connectivity is a key element of the GBI (EUROPARC Federation 2018). In marine and coastal realms, connections between PUs were based on the Euclidean distances among the centroids of pairs of units. In the freshwater realm, connectivity was based on the longitudinal connections between PUs along the river network. Following Hermoso et al. (2018), we assigned weighted penalties according to this longitudinal distance.

GBI management zones

Management zones considered in the analysis are in agreement with the principal components of the GBI as presented in the EU policy initiative "Building a Green Infrastructure for Europe" (European Commission 2013c; European Commission – Directorate-General for the Environment 2016) (European Commission – Directorate-General for the Environment, 2016).

To spatially distribute the management zones in the GBI, we buffered the core zone with the conservation zone in all realms. Therefore, we identified core zones that are connected through another core zone or through a conservation zone. Additionally in the freshwater realm, we used a special spatial arrangement of PUs inspired by Abell, Allan, & Lehner (2007), where core zones were mainly buffered upstream by conservation zones. Conservation zones played two different roles: as connectors of core zones and upstream buffers of these core zones. Restoration zones in scenario 2 were spatially arranged following the same criteria as conservation zones but paying attention on the unfavourable habitats. The spatial arrangement of the zones was done by means of the boundary zone file in Marxan with Zones (Watts et al. 2008).

Conservation targets, costs other parameters

The zone target file in Marxan with Zones was used for specifying the contribution of each zone to achieve the biodiversity and ES targets. Conservation targets for compatible ES and biodiversity were mainly achieved in the core and conservation zones, whereas sustainable use zones mainly contributed to the achievement of targets for the provision ES.

We considered costs of each PU to be the area covered by the respective PU. This avoided the overrepresentation of large PUs providing larger contributions towards the achievement of targets just because of a matter of size (Ardron, Possingham, and Klein 2010). Area-based PU costs were used in the core zone, conservation zone, and in the sustainable use zone.

Number of runs and iterations per run, feature penalty factor parameter, and bound cost parameters (zone bound cost file in Marxan with Zones) were calibrated in order to determine the most suitable values for our study in terms of target achievement and spatial configuration of the zones (Watts et al. 2009). After calibration, we ran Marxan with Zones 100 times for the different scenarios (10 million iterations each). We set a high species penalty factor (SPF = 100) to ensure the full achievement of targets. Out of the 100 runes we kept the best solution, which was the solution with the lowest score for the objective function, as well as the frequency of a PU to be selected. Due to the differences in connectivity and PU size, we ran separate models for freshwater and marine-coastal realms.

The proportion of conservation features (biodiversity, compatible ES and protected sites) represented within the core and conservation zones, was considered as an indicator of potential co-benefits between biodiversity conservation and met ES provided by the GBI. Contrastingly, the proportion of conservation features in the sustainable use zone or outside the GBI (i.e., "available zone" in Marxan with Zones), and the inclusion of provisioning ES in the core and conservation zones, were considered as incidental representation. Following

Hermoso et al. (2018), this incidental representation was interpreted as the proportion of conservation features that would be compromised in the GBI and the proportion of provisioning ES that would be lost due to conservation, respectively (Hermoso et al. 2018).

We checked for differences between scenarios using Kendall's rank correlation coefficient, comparing the selection frequency of PUs (Vallecillo et al. 2018). Since PUs included in the best solution was a binary variable, the degree of consistency between the best solution obtained for each scenario and the selection frequency of PUs (i.e., degree of overlapping between PUs with high frequency of selection and PUs in the best solution) was quantified using Generalized Linear Models (GLM) with binomial distribution and logit link function. Best solution was included as the dependent variable in the GLM models, whereas frequency of selection was the explanatory variable. In order to quantify differences in consistency among realms, we also included an interaction term between the frequency of selection and the realm (marine or freshwater) as an additional factor in the GLM. All statistical analyses were performed using R (Core Development Team).

EBM restoration measures

Mapping the EBM measures (i.e. restoration features) was carried out as follows: (1) In the northern section, riparian areas were extracted from the Copernicus programme potential riparian zones in Europe dataset (European Environment Agency (EEA) – Copernicus programme 2015). In the southern section, the map of potential riparian vegetation was based on the Hassen forest layer (Hansen et al. 2013, 2017), applying a 500 m buffer to the NASA cover for rivers and streams (World Wildlife Fund (WWF) 2017). Only riparian areas located on farmland (and therefore not containing riparian vegetation) in unfavourable ecosystem condition were kept. Data on farmland occurrence was derived from Copernicus Africa LCSS 100m in Morocco and from SIOSE in Spain. (2) For identifying wetlands in the northern and southern sections, we used the global data source on wetlands from the Centre for International Forestry Research (CIFOR; Gumbricht et al., 2017). From these locations, only areas overlapping with habitats in unfavourable ecosystem condition were kept. Mangroves (CIFOR code = 20) were used as surrogates for coastal wetlands, whereas all other values were considered inland and coastal wetlands. (3) As priority areas to restore marine habitats, we selected sites with presence of cold water corals and seagrass. Location of cold water corals and seagrass was provided by the UNEP data base (Freiwald et al., 2017; André. Freiwald et al., 2004; OSPAR, 2015; UNEP-WCMC, 2017). Areas at poor ecosystem condition within a buffer of 5km surrounding coral and seagrass locations were selected for restoration.

Protected areas

According to the EU Birds Directive (79/409/EEC Modified by 2009/147/EC) (European Community 1979) and the Habitats Directive (92/43/EEC) (The Council of the European Communities 2013), ensuring the structural and functional ecologically coherence of the Natura 2000 network is a key objective of GBIs. The implementation of a GBI beyond protected areas helps reinforce the protected areas network, such as Natura 2000, by making the core areas more resilient and providing buffers against impacts on the sites. Therefore, it is critical to consider existent protected areas when identifying optimal places for the enhancement of habitats (European Commission 2013a).

In the northern section of the case study, we considered the Natura 2000 network of Andalusia, namely the Special Conservation Areas (SCA), selected from the National List of Places of Community Interest (SCI) and all the Special Protection Areas (SPA) declared under the Birds Directive (EEC / 409/79 on the conservation of wild birds) as existing protected areas. Coastal Areas of Special Protection in Spain were considered as additional protected sites in the northern section of the study area.

In the southern section, we used the most comprehensive global database on terrestrial and marine protected areas, i.e., the World Database on Protected Areas (WDPA; UNEP-WCMC & IUCN, 2018). Specifically, the following sites were included: biological and ecological interest sites; marine protected areas (OSPAR); national parks; natural monuments, natural parks, nature places, nature reserves, peri-urban protected areas, permanent hunting reserves, Ramsar sites (RAMSAR), wetlands of international importance; and specially protected areas of Mediterranean importance (Barcelona Convention).

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AQUACROSS PARTNERS

Ecologic Institute (ECOLOGIC) | Germany

Leibniz Institute of Freshwater Ecology and Inland Fisheries (FVB-IGB) | Germany

Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (IOC-UNESCO) | France

Wageningen Marine Research (WMR) | Netherlands

University of Natural Resources & Life Sciences, Institute of Hydrobiology and Aquatic Ecosystem Manag (BOKU) | Austria

Fundación IMDEA Agua (IMDEA) | Spain

Universidade de Aveiro (UAVR) | Portugal

ACTeon – Innovation, Policy, Environment (ACTeon) | France

University of Liverpool (ULIV) | United Kingdom

University College Cork, National University of Ireland (UCC) | Ireland

Royal Belgian Institute of Natural Sciences (RBINS) | Belgium

Stockholm University, Stockholm Resilience Centre (SU-SRC) | Sweden

Danube Delta National Institute for Research & Development (INCDDD) | Romania

Eawag – Swiss Federal Institute of Aquatic Science and Technology (EAWAG) | Switzerland

International Union for Conservation of Nature (IUCN) | Belgium

BC3 Basque Centre for Climate Change (BC3) | Spain

Contact	aquacross@ecologic.eu
Coordinator	Dr. Manuel Lago, Ecologic Institute
Duration	1 June 2015 to 30 November 2018
Website	http://aquacross.eu/
Twitter	@AquaBiodiv
LinkedIn	www.linkedin.com/groups/AQUACROSS-8355424/about
ResearchGate	https://goo.gl/IcdtZC