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Integrating ecosystem services into sustainable landscape management: A collaborative approach

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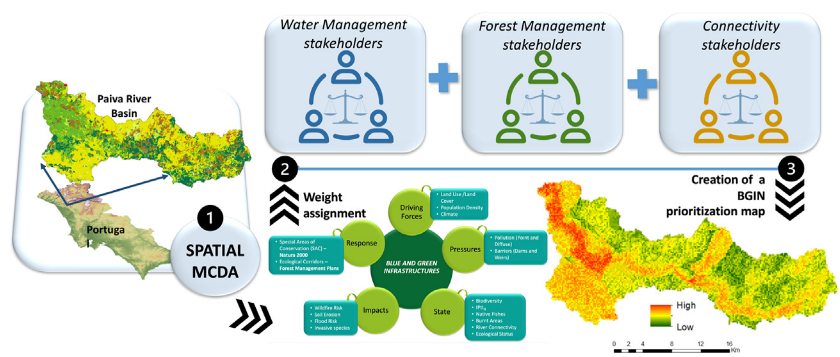
HIGHLIGHTS

- The implementation of blue and green infrastructure networks (BGINs) will improve ecosystem services.
- Multicriteria decision analysis (GIS-MCDA) used to prioritize areas to implement the BGINs.
- Considering stakeholder's active involvement encourages the selection of BGINs in the priority areas.
- A participative approach is a powerful tool to improve ES and biodiversity conservation.

GRAPHICAL ABSTRACT



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ABSTRACT

The Paiva River is considered one of the least polluted rivers in Europe and its watershed has a high conservation value. However, the Paiva River basin suffers pressures related with recurrent disturbances in land use, such as forest fires, agricultural activities, urbanization and pressures that affect the natural hydromorphological conditions and the continuity of watercourses. Blue and Green Infrastructures (BGINs) emerge to improve biodiversity, sustainability and the supply of ecosystem services while improving socioeconomic aspects.

Thus, this article aims to identify priority areas in the basin, for intervention with these infrastructures. For that, a spatial multicriteria decision analysis (MDCA) was carried out according to several data related to the Paiva River Basin. As local politicians and responsible entities for the natural resources management are the main experts on the problems and their possible solutions at the local level, they were involved in this decision-making model. Therefore, these specialized stakeholders did the weighting assignment according to the most or least importance of the same for the work.

The map of priority locations to implement BGINs was obtained in the sequel. To the top 5 priority areas, stakeholders attributed the best solutions based on nature. The most recommended BGINs were recovery/maintenance of riparian vegetation and conservation and reforestation of the native forest, both presented in four of the five areas, and introduction of fuel management strips presented in three of the five areas. Thus, we concluded that it is extremely important to include the communities and the competent entities of nature and environment management in scientific projects related to conservation, forming a synergy that makes it possible to combine scientific knowledge with local experience acquired in the field. This project uses a very flexible methodology of local data and can be a great example to be implemented in other hydrographic basins anywhere in the world.

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1. Introduction

Ecosystem services are crucial for the sustainability of human development in economic, social, cultural and ecological terms, as they regulate and support natural and human systems through processes such as cleaning, recycling and renewing biological resources (Daily et al., 1997). According to the Common International Classification of Ecosystem Services - CICES, an essential characteristic of final services is that they retain a connection to the underlying ecosystem functions, processes and structures that generate them. Ecosystem services can be classified into three main groups: provisioning, regulation and maintenance, and cultural. The first covers all nutritional, non-nutritional, material and energetic outputs from living systems. The regulation and maintenance group is concerned with all the ways in which living organisms can mediate or moderate the environment that affects human health, safety or comfort. The last group includes all the non-material, and normally non-rival and non-consumptive, outputs of ecosystems that affect the physical and mental states of people (Czúcz et al., 2018). However, as the world population and the global economy grows, in the future the demand for these services and the likelihood of negative impacts are expected to increase (François et al., 2005).

To promote and restore ecosystem services, the United Nations declared 2021–2030 as the Decade on Ecosystem restoration, challenging the states to scale up restoration efforts into degraded ecosystems massively. In this context, to restore, protect and preserve ecosystems, a new approach has been developed inspired in nature. So, nature based solutions (NbS) can offer an innovative, cost-effective, and responsive way to manage ecosystems, namely through Blue and Green Infrastructures (BGINs), providing a more sustainable management (Santoro et al., 2019). According to Mell (2008), BGINs (e.g. Wetlands, wildlife habitats …) can promote biodiversity, maintain natural ecological processes, sustain air and water resources, and contribute to health and quality of life. BGINs can be adapted to local conditions at different spatial scales to tackle social, environmental, and economic challenges, achieving multiple benefits and ecosystem resilience. The study and implementation of this type of infrastructure have become increasingly important in terms of ecological sustainability. The European Commission introduced in 2013 the “Green Infrastructure Strategy”, demonstrating the relevance of these measures to protect natural capital in terms of focusing on nature conservation and biodiversity (EC, 2013; Slätmo et al., 2019). This strategy also expects to maintain and enhance ecosystems by establishing and developing these infrastructures to restore at least 15% of degraded ecosystems by 2020 (Maes et al., 2015; Mguni et al., 2016). In 2016, it was introduced as a guideline “Supporting the implementation of green infrastructure” by the European Commission (EU Commission, 2019). The BGINs use natural, semi-natural, and artificial green spaces, providing ecosystem services from supply to support, including air purification, climate regulation, carbon storage, reduce the risk of extreme events, biodiversity conservation, integrated water resources management and aesthetic and cultural services (Alves et al., 2018; Huang et al., 2018; Opperman et al., 2010; Valente et al., 2020; Van Oijstaeijen et al., 2020; Yao et al., 2017; Zhang et al., 2015; Zhang and Muñoz Ramírez, 2019; Martos-Rosillo et al., 2019). In addition, they offer an ecological integrity function and a holistic perspective to build resilience and address complex urban challenges, in which several problems need to be handled concurrently, with limited resources and space constraints (Alves et al., 2016; Frantzeskaki et al., 2019). The ecosystem condition (its structure and processes) is essential for the ability of the ecosystem to supply services. Therefore, any increasing pressure on the ecosystem (e.g. by changing the land use type) influences its services' supply or the trade-offs between different services.

The Driver-Pressure-State-Impact-Response (DPSIR) framework is a tool developed by the Organization of Economic Cooperation and Development (OECD, 1993) and the European Environment Agency (EEA, 1995) to be applied to adaptive management. It links cause-effect relationships among the categories of the framework and has been used for analysing and assessing the social and ecological problems of aquatic systems subject to anthropogenic influence (Kagalou et al., 2012; Porta and Poch, 2011).

Integrative landscape planning could be a challenge at the watershed scale since it involves several stakeholders at different levels (from policy makers, local government, managers, economic activities, scientists, NGOs, and local communities) and should address several societal challenges. Therefore, it is necessary to find a tool that enables stakeholders to develop and evaluate alternative landscape management scenarios. The rights of stakeholders to participate in decision-making processes, are increasingly recognized in the last decade and have been highlighted in the Agenda 21 and in the 2030 Agenda for sustainable development as absolutely essential to their success (UNESCAP, 2018). Thus, there is a demand for tools that can include several stakeholders and institutional components, enabling participation, social equity, and transparency. In this context, the link between social research methodologies with multicriteria evaluation emerged as a tool for participatory multicriteria evaluation.

The spatial multicriteria decision analysis (MCDA) is a methodology widely applied in studies at the watershed scale, which has proven to be very accurate and effective to evaluate and compare options involving the achievement of multiple objectives (Cochran et al., 2011; Terêncio et al., 2017, 2018, 2021). The application of MCDA in prioritization of potential ecosystem services locations has already been made (Langemeyer et al., 2020; Velázquez et al., 2019). Some works were carried out with the help of stakeholders in the allocation of weighting (Meerow and Newell, 2017) and with a focus on the selection of BGINs considering co-benefits and stakeholder's involvement (Alves et al., 2018; Miller and Montalto, 2019; Santoro et al., 2019). Nevertheless, the works developed were usually addressing the issues individually, whether in prioritizing BGINs at the local and urban level, considering the involvement of stakeholders in the allocation of weights, or in the selection of ecosystem services.

The present work seeks to unify and improve upon the dissimilar approaches of these studies by offering an innovative methodology at the watershed level with direct input from stakeholders in the complete assignment of weights from MCDA. Thus, we hypothesize that the implementation of the BGINs can improve the biodiversity conservation and ecosystem resilience. The great challenge was to combine multicriteria analysis and scenario building, by collaborative mapping, through a participatory approach involving different stakeholders as the deliberative technique.

2. Material and methods

2.1. Study area

The study area is the Paiva River, one of the main left-margin tributaries of Douro River basin (Portugal). It has a basin with a total area of 795 km^2, with a total extension of nearly 115 km fragmented with 119 barriers (dams and weirs) (Terêncio et al., 2021). The Paiva River headwaters rise up to 1000 m in the Serra de Leomil, and ends into Castelo de Paiva, on the Douro River. Part of the Paiva River watershed integrates the Natura 2000 network through 3 Special Areas of Conservation (SACs) such as the “River Paiva”, “Serra de Montemuro” and the “Serras da Freita and Arada” (Fig. 1). It has a high diversity of species (flora and fauna), habitats and ecosystems, some of which considered priority at the European level (annexe B-I of DL no. 49/2005). Some good examples of fauna species are the water mole (*Galemys pyrenaicus*), the otter (*Lutra lutra*), the boga (*Chondrostoma polylepis*), the fox (*Vulpes vulpes*), the wild rabbit (*Oryctolagus cuniculus*), the wolf (*Canis lupus*), and the occurrence of one of the rare populations of river mussel (*Margaritifera margaritifera*) (Rodrigues et al., 2006).

The Paiva River watershed is mainly occupied by forest, in the middle and lower parts, where monocultures of maritime pine and

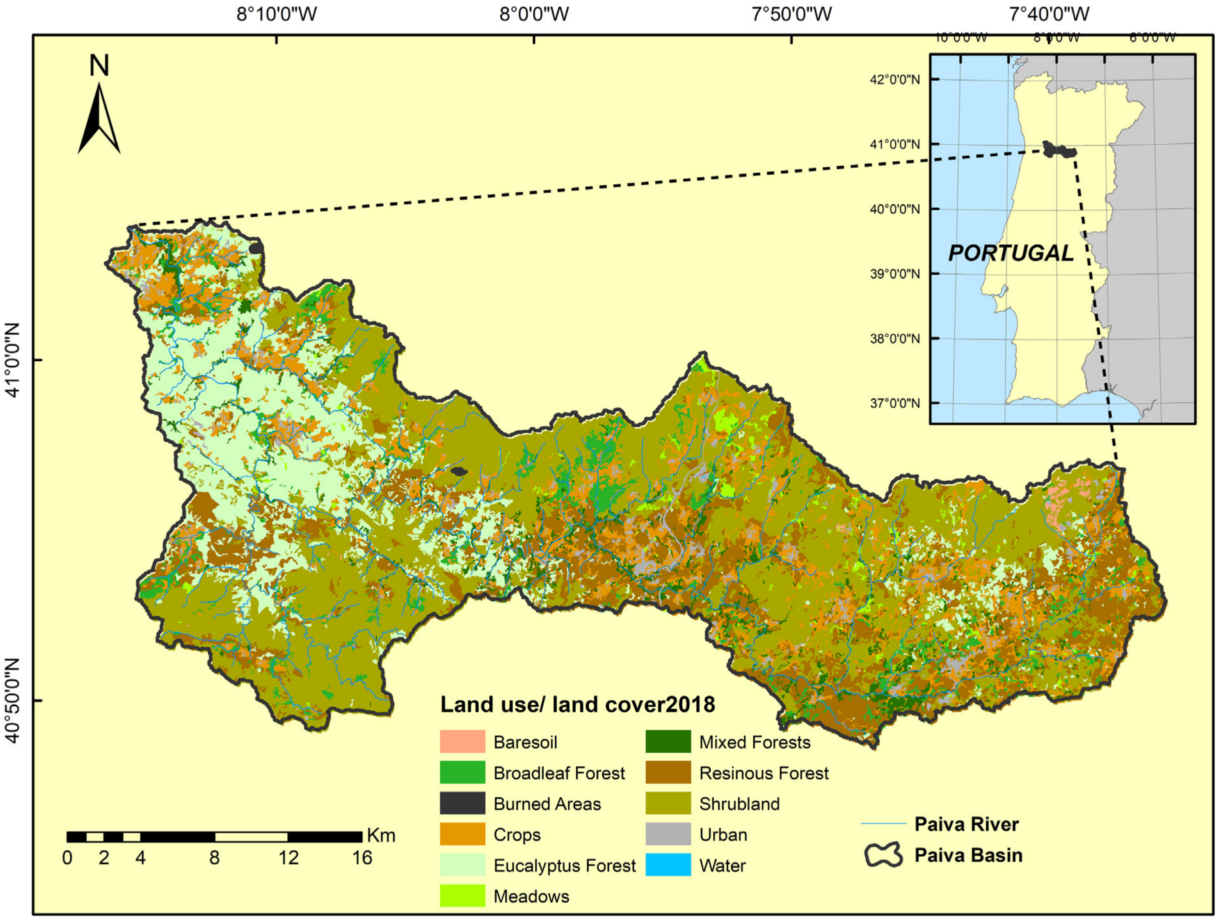

Fig. 1. Location map illustrating the Paiva River watershed in Portugal. In evidence is the land use map – COS 2018.
Source: DGT - http://www.dgterritorio.pt.

eucalyptus predominate. Concerning to this last species, in the last decade it has been observed a very significant expansion of its distribution area. Extensive agriculture develops along alluvial valleys and through small terraces (Fonseca et al., 2020; ICNF, 2020). It presents a temperate Mediterranean climate with an average annual temperature of 13 °C, and average annual precipitation greater than 1000 mm (APA-SNIAmb, 2021; Barceló and Nunes, 2011; Quercus, 2016).

2.2. Conceptual framework

The methodology implemented in this work used a GIS-based multicriteria decision analysis supported by a participatory process with stakeholders engaged in the project to develop scenarios for future management of the Paiva River watershed under a changing climate (Fig. 2). The model development involved the accomplishment of five tasks: **(a) Setting up the goal**: this is the prioritization of the Paiva River watershed areas with the greatest need to improve ecosystem services through the implementation of BGINs, based on selected criteria and restrictions. **(b) Raw data acquisition and organization** (see Table S1): the criteria organization that allows identifying the most vulnerable areas was based on the DPSIR framework (Drivers, Pressures, State, Impact and Response model of intervention (European Environment Agency, 1998; Stanners and Bourdeau, 1995)). The DPSIR is based on a succession of causal links from socio-economic and climate driving human activities which can increase or mitigate pressures on the environment (*Drivers*, e.g., population density, climate). *Pressures* represent the stresses that human activities exert on the environment (e.g. discharge of nutrients and contaminants) and the *State* is the ecosystem condition resulting from the combination of the physical, chemical and biological characterization (e.g., biodiversity, water quality). *Impacts* on ecosystems and human health, are the effects of environmental degradation. Finally, *Responses* refer to replies from the society to the environmental situation (e.g. political approaches) and can affect any part of the chain between driving forces and impacts. Fig. 3 shows a schematic representation of the DPSIR framework applied to the case study analysed. The criteria and respective indicators, were widely discussed between the multidisciplinary scientific team and key stakeholders from the Paiva River watershed according to the available literature and their individual knowledge. A detailed explanation of each criterion and indicator is provided in Section 2.3; **(c) Standardization**: the matrix of criteria, indicators, their meanings and quantitative descriptions, are displayed in Table S1. The indicators were divided into quantitative (e.g., temperature) and qualitative classes (e.g., special areas of conservation or wildfire risk). The quantitative variables were described in numerical scales while the qualitative classes were translated into categorical ratings. To become comparable, the indicators were standardized to a common dimensionless scale ranging from 1 to 5. The highest scores were given to classes more suited to the BGINs implementation and the lowest ones to classes less suited for that purpose; **(d) Determination of weight coefficients**: this step aimed to differentiate the selected criteria as well as the adopted indicators according to their importance for prioritizing BGINs implementation (Malczewski, 2006). Weight coefficients vary between 1 and 5 and were determined through a participatory approach with the stakeholders directly or indirectly linked to the Paiva River basin; **(e) Aggregation**: a global suitability index based on weighted factors and Boolean constraints was computed for each point in the target region using an aggregation rule; **(f) Sensitivity analysis**: this step is frequently used to overcome the ambiguity of factor weighting.

2.3. Participatory approach

The participatory process for the Paiva River watershed was constructed as three separate workshops. The first workshop introduced participants to the context and method, allowing to identify the main driving forces and pressures with participant input. In the second workshop, the stakeholders classified the main areas with degraded ecosystems and identified the possible BGINs to mitigate environmental problems. In the last workshop, the MCDA was applied to identify the main vulnerable priority areas to implement the selected BGINs. For the MCDA, stakeholders were divided into three specialty groups: Water Management, Forest Management, and Connectivity, so that weights were assigned according to their area of expertise.

The stakeholder forum emerged from the ALICE project (https://project-alice.com/alice-project/) and involved policy makers, regulators and managers (Portuguese Environmental Agency - APA, Administration of the Northern Hydrographic Region- ARH North and Centre, Institute for the Conservation of Nature and Forest - ICNF North and Centre, and several municipalities); economic and tourism activities (enterprises related to: wood production, nature tourism, ecosystems rehabilitation); NGOs (environmental and social organizations); and community members or beneficiaries (forest associations and others that defend natural and cultural values). Working together, scientists and stakeholders improved engagement and involvement necessary to generate consensus about what is important towards shared goals. Bringing key stakeholders into the decision-making process to set up the capacities and systems to support collaborative adaptive management.

2.4. Database for the DPSIR and MCDA analyses

For each of the five criteria, indicators are defined to measure how well the criterion is met. In Fig. 3 it is possible to see the distribution of the criteria and corresponding indicators that make it possible to map the prioritary BGINs. The indicators and final maps were prepared in the ArcGIS/ArcMap software (https://www.esri.com/). The option for ArcMap of ESRI company relates to the authors' experience of using this program in numerous hydrologic, decision making and environmental applications (Acuña-Alonso et al., 2020; Fernandes et al., 2019, 2020; Martins et al., 2020). All the indicators, regardless of the type, format or spatial coverage were converted to raster format. After that, the raster file was reclassified in the predefined standardization classification (1–5), with the Reclassify tool of ArcMap. Finally, the raster files were processed in the Map Algebra tool to produce the prioritization maps. Table 1 provides an overview of selected criteria for the GIS-MCDA, as well as their data format and sources. All the criteria and respective indicators data preparation will be described in detail in the next sections.

2.4.1. Driving forces

The indicators that compose the *Driving forces* criterion are the population density indicator, climate and the Land use/land cover. The population density data are obtained through censuses (surveys carried out at the national level in 2011 by INE), where we export the resident population and the local area shapefile (CAOP 2015). Through the Join tool of ArcMap, these files are joined and thus the number of inhabitants per km^2 is calculated. The Climate item combine two variables – temperature and maximum stream flow of Paiva River. The average temperature and peak flow data were developed with a spatial resolution of ~1 km and were calculated from historical data (from 1950 to 2018). The original data (~10 km spatial resolution) was retrieved from E-OBS v20e database. Additionally, a statistical downscaling methodology was applied for temperature with the following exploratory variables: latitude, elevation and Euclidean distance to coastline. The final database spans the period of 1950 to 2018 with a spatial resolution of 0.01 latitude × 0.01 longitude (~1 km spatial resolution). The statistical downscaling was performed with the Ordinary Least Squares (OLS) with yearly daily means. To obtain the final temperature dataset, the daily anomalies are added to the estimated raster from the OLS. For precipitation, a simple bilinear interpolation was used to produce the ~1 km spatial resolution. Lastly, the both raster are reclassified using the Reclassify Tool of ArcGIS (Table S1).

For the land use/land cover indicator, the COS2018 shapefile was used. From here, for both indicators, the files were converted to raster and then reclassified (standardization) using the Reclassify Tool of ArcGIS (Table S1).

2.4.2. Pressures

The data related to the *Pressures* criterion are point and diffuse pressures and the watercourse barriers (dams and weirs). The point

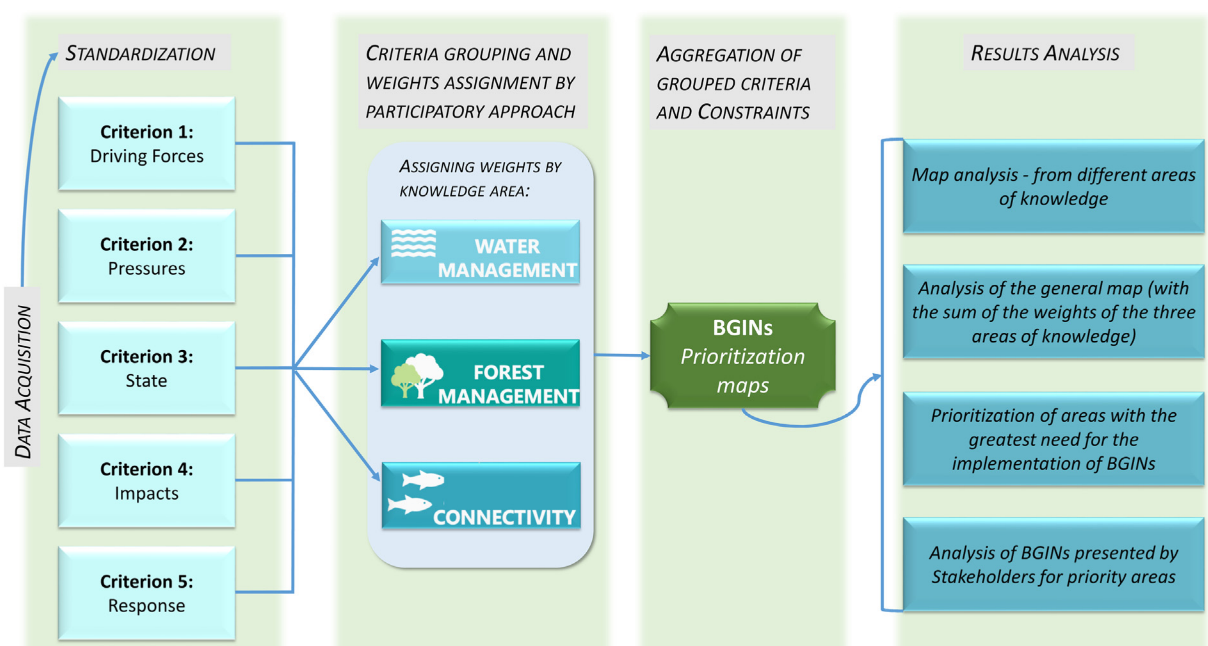

Fig. 2. Flowchart describing the spatial multicriteria prioritizing BGINs implementation through a participatory approach.

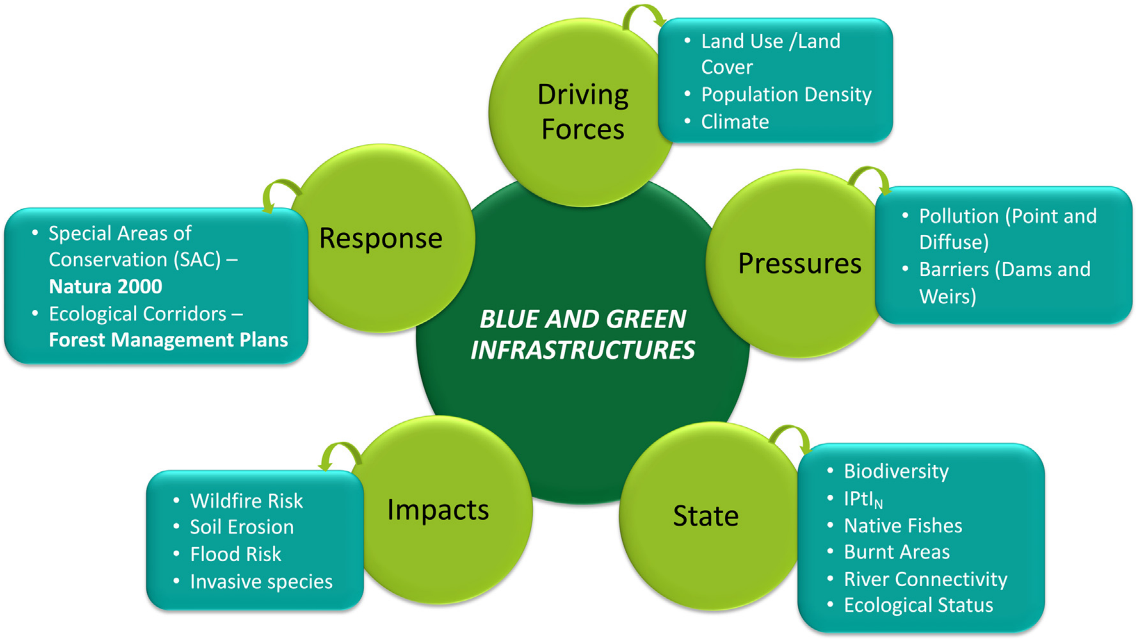

Fig. 3. Criteria and indicators used on the GIS-MCDA for the prioritization BGINs implementation.

pollution is related to the concentration of Chemical oxygen demand (COD), Biochemical oxygen demand (BOD_5), phosphorous and nitrates. The diffuse pollution relates with the phosphorous and nitrate concentrations from the agroforestry and livestock sectors. The data base of these indicators were compiled from the APA monitoring stations (Table 1). Firstly, the average concentrations of each indicator were interpolated over the Douro River basin into a shapefile format, then converted to raster format and, finally, reclassified into five classes ranging from 1 (non-priority) to 5 (priority), using the Reclassify Tool of ArcGIS (Table S1). The barriers indicator was determined based on a previous work (Cortes et al., 2019). The vectors were converted into a raster format and finally reclassified into two values, corresponding to locations inside and outside the protected areas (Table S1).

2.4.3. State

The indicators that comprise the *State* criterion were biodiversity, burnt areas, water quality classification, river connectivity, North Invertebrate Portuguese Index ($IPtI_N$), and native fish of the Paiva River basin. The biodiversity indicator was obtained using the Simpson Index (Simpson, 1949) that quantifies the biodiversity of a habitat. It takes into account the number of species present, as well as the abundance of each species. Simpson's index produces values from 0 to 1, where 0 represents infinite diversity and 1, no diversity. That is, the bigger the value of Simpson's index, the lower the diversity. The original data was retrieved from Global Biodiversity Information Facility database (Table 1). The geoinformation (GI) on burned areas recurrence interval (vector format, shapefile) for the study area was produced by using the historical

Table 1
Data types used as source data for GIS-MCDA prioritizing BGINs implementation. In the table are shown the data identification, units, format and data sources. Websites were assessed in October 2020.

Criterion	Indicators	Period	Unit	Format	Source/URL
Driving Forces	Population density	CAOP - 2018 Census - 2011	Inhabitants/ Km^2	Attribute table and vector	DGT- http://www.dgterritorio.pt/ INE - http://censos.ine.pt/
	Land use/land cover COS2018	2018	Dimensionless	Vector	DGT- http://www.dgterritorio.pt
	Temperature	1950–2018	°C	Raster	Calculated with Ordinary Least Squares (OLS)
	Peak flow	1950–2018	$m^{-3}.s^{-1}$	Raster	Calculated with Ordinary Least Squares (OLS)
Pressures	Point source and diffuse pollution	2018	$Kg.km^{-2}$	Attribute table	APA - https://sniamb.apambiente.pt/content/geo-visualizador?language=pt-pt
	Barriers	2019	Dimensionless	Vector	(Cortes et al., 2019)
State	Biodiversity	1978–2020	Dimensionless	Attribute table	GBIF - https://www.gbif.org/
	Burnt areas	1990–2018	Dimensionless	Vector	ICNF - http://www.icnf.pt/
	Water quality	2010–2017	Dimensionless	Attribute table	APA - https://sniamb.apambiente.pt/content/geo-visualizador?language=pt-pt
	River connectivity	2019	Dimensionless	Attribute table and vector	Calculated with Conefor Sensinode 26
	$IPtI_N$	2019	Dimensionless	Attribute table	Calculated with AMIIB@ application of APA
	Native Fish	2013/2017/2019	Dimensionless	Vector	APA - https://apambiente.pt/
Impacts	Wildfire risk	2019	Dimensionless	Raster	ICNF - http://www.icnf.pt/
	Soil erosion	2016	$Ton.ha^{-1}.year^{-1}$	Raster	(Pacheco and Sanches Fernandes, 2016)
	Flood risk	2019	Dimensionless	Raster	(Martínez-López et al., 2019)
	Invasive species	2018	Dimensionless	Vector	APA - https://apambiente.pt/
Response	Natura 2000	2018	Dimensionless	Vector	ICNF - https://geocatalogo.icnf.pt/catalogo.html
	Ecological corridors	2019	Dimensionless	Vector	https://geocatalogo.icnf.pt/catalogo.html

data for the period 1990–2018, obtained through the Institute for the Conservation of Nature and Forest – ICNF (Table 1). For each year, a raster map was drawn with the reclassification of the fire location set to 1. This procedure was carried out for all the years of fire registrations. Subsequently, the raster maps were overlapped and the fire locations added using the Math Algebra Tool of ArcMap. For water quality indicator it was used the ecological status (from poor to excellent) of Portuguese water bodies under the ecological approach of the WFD. The data were obtained from APA (Table 1), corresponding to the period of 2010–2017. The data was joined to the corresponding water body geometries in the ArcMap, and then the status was extrapolated over the Paiva River watershed. The spatial distributions of ecological status derived from raster maps that were subsequently reclassified into standardized values (Table S1). River connectivity indicator derived from the dPC connector, which was calculated by using Conefor Sensinode 2.6 (CS26) computer package. The fraction dPC connector assesses how much the river segment contributes to the overall network connectivity. The dPC connector is an important conservation parameter because if a given segment ranks high, it is not advisable to build a barrier there because the connectivity of the system will drop. These data were compiled from a previous paper (Cortes et al., 2019) in vector format (lines). The $IPtI_N$, based on aquatic macroinvertebrate taxa collected from fieldwork (vector format) in 2018, were computed using the AMIIB@ application of APA. The indicator native and endangered fish (vector format) considered the species with the greatest expression, identified in Paiva watershed for the years 2013, 2017 and 2019: *Anguilla anguilla*, *Salmo trutta*, *Pseudochondrostoma duriense*, *Squalius alburnoides*, *Squalius carolitertii*, *Luciobarbus bocagei* and *Achondrostoma oligolepsis.*

All variables, used in the State criterion, that were obtained initially in a vector format were then converted into a raster format and reclassified into standardized values (see Table S1).

2.4.4. Impacts

As *Impacts*, it was considered the wildfire risk, soil erosion, flood risk and invasive species. All of these data are indicators related to risks and pressures in the Paiva River watershed. The wildfire risk, using ICNF data (Table 1), was produced based on the methodology developed by Verde and Zêzere (2007) in a GeoTIFF format. The data were reclassified into five classes ranging from 1 (non-priority) to 5 (priority), using the Reclassify Tool of ArcGIS (Table S1). The erosion indicator was obtained from a previous work published by Pacheco and Sanches Fernandes (2016), at national level and currently clipped to the Paiva watershed. The method used by these authors was the well-known Universal Soil Loss Equation (Renard et al., 1997; Wischmeier and Smith, 1978), which is based on the assessment and combination of various parameters: rainfall erosivity, soil erodibility, hillside slope and length, land cover and landscape management practices. The data were reclassified using the Reclassify Tool of ArcGIS (Table S1). The flood risk indicator was developed by ARIES through a publicly accessible code repository (ARIES team, 2018). This indicator has as output the topographic wetness index (TWI), mean annual precipitation, and the mean temperature of the wettest quarter. The methodology can be consulted in detail in (Martínez-López et al., 2019). The flood risk raster was reclassified using the Reclassify Tool of ArcGIS (Table S1). Concerning the invasive species indicator, those of flora and fauna have been taken into account. Regarding flora, the abundance of *Acacia Sp*., open forests of invasive species, forest of invasive species and mixed forests with invasive species were accounted for. With regard to the fauna, were considered the presence of invasive fish *Gobio lozanoi* and the freshwater clam – *Corbicula fluminea.* This data was merged and converted to raster format. Then, the raster was reclassified into two values, corresponding to locations presence or absence of native fish (Table S1).

2.4.5. Response

Response criterion considered two indicators the Natura 2000 network, more precisely the Habitats Directive Sites - Special Areas of Conservation (SAC), and the Ecological corridors of the Paiva River watershed obtained from Regional Forest Management Plans (Trás-os-Montes e Alto Douro, Litoral Centre, and Entre Douro e Minho RFMP) and Hydrographic Region Management Plans (Douro RH3 RBPM 2016–2021). As mentioned earlier, Paiva River watershed, consists of an interesting area in terms of biodiversity, thus it should be protected and maintained in order to support the existence of the habitats, the living species and further the quality of the water resources. Increased urbanization and, generally, land use changes have led, through housing or road development projects, to the deterioration of the habitats, the degradation of spawning and nursery areas, the extinction of fish species. For conservation purposes the "Natura 2000 sites" through the implementation of Habitats Directive (92/43/EEC) are crucial areas. An integrated monitoring and conservation plan should be set up taking into consideration besides the traditional conservation efforts on priority habitats and endangered species, also on the whole ecosystem's functioning through the evaluation of its goods and services. The Regional Forest Management Programmes (RFMP) are sectoral territorial management instruments, provided for the Basic Law on Forest Policy (Law no. 33/96 of 17 August) and regulated by Decree-Law no. 16/2009 of 14 January. RFMP establish specific standards for the use and exploitation of forest areas, with the aim of ensuring the sustained production of the set of goods and services. Thus, the RFMP assess the potential of forest areas in terms of their dominant uses, define the list of priority species, and identify the sustainable use of resources and management models. The European Community recognizes that water is a heritage to be protected and defended, establishing a framework for Community action in water policy - Water Framework Directive (WFD - 2000/60/EC). The environmental objectives set out in the WFD must be achieved by implementing programs of measures specified in the River Basin Management Plans (RBMPs). Therefore, in compliance with the Portuguese Water Law, particularly in its article 29, the RBMPs are water planning instruments, aimed at the management, protection and environmental, social and economic enhancement of waters at the level of the hydrographic basin. Point sources, related to urban and industrial activities (BOD, COD), and diffuse pollution by agricultural (N, P) are the main anthropogenic pressures for river basins. Reducing nutrient charges is a major issue to achieve a good ecological status, according to WFD.

All the cartographic data of the Protected Areas, SAC and ecological corridors indicators came from the ICNF (Table 1). After converting the vector data to a raster format, the standardization was done with only two values, corresponding to locations inside and outside the protected areas. The Table S1 provides the detailed results obtained with the rating of Response indicators.

2.5. Model development for spatial multicriteria decision analysis

For the indicators above described, explicative factors (scored indicators) and Boolean constraints ("no data" indicators, corresponding to regions where the MCDA model will not be applied) were given. Explicative factors were classified into numeric (e.g., temperature) and qualitative (e.g., land use land cover) classes. To these classes standardized scores ranging from 1 to 5 were stablished (Table S1). The highest scores were assigned to classes with more urgent need for BGINs implementation, and the lowest ones to classes less fitted for that purpose. After gathering and standardizing all the criteria and indicators, the respective weights were assigned by the stakeholders. The weighting procedure for all criteria and indicators was implemented, to the three speciality groups: Water Management, Forest Management and Connectivity, accordingly what was described in Section 2.3. The final weight results from the average of these three groups. After standardization and weight assignment, the model was developed by a suitability index calculated by the following aggregation rule:

$$\text{BGINs Suitability} = \sum_{i=1}^{m} w_i^g \left[\sum_{j=1}^{p} w_j^f F_{j,i} \right] \prod_{k=1}^{q} C_{k.} \quad (1)$$

where superscripts *f* and *g* represent specific factors/ indicators (e.g., temperature) or groups of factors/criterion (e.g., the physical conditions), respectively. $F_{j,i}$ is the standardized score of indicator *j* in criterion *i*. $W_{j\,f}$ and $W_{i\,g}$ are the weights of indicator *j* and criterion *i*. C_k is the Boolean score of constraint *k*, which is set to 1 if regions are to be included in the analysis and 0 otherwise. The *m*, *p* and *q*, in that order, are the number of criteria (5, representing the sets of *Driving forces*, *Pressures*, *State*, *Impacts* and *Response*), factors (3 for the *Driving forces*, 3 for *Pressures*, 6 for *State*, 4 for *Impacts* and 2 for *Response*) and constraints (related to the absence data). The $W_{j\,f}$ and $W_{i\,g}$ were optimized for the three speciality groups. Finally, the reclassified raster files were processed in a Map Algebra tool of ArcMap for the development of the suitability maps.

3. Results

3.1. Outcomes of DPSIR and MDCA analyses

The spatial distribution of all the indicators is displayed in Figs. 4–8. The *Driving forces* criterion is represented in Fig. 4. In this criterion, land use/land cover was spatially represented (Fig. 4a). A great portion of Paiva River watershed are is occupied by shrubland, followed by the monocultures of eucalyptus and pines in the centre and west zone. Concerning the population density (Fig. 4b), the vast majority of the watershed area is unpopulated. The urban sprawl is concentrated in a few urban areas in the northwest (Castelo de Paiva), the central area of the basin (Castro Daire) and in the southeast (Vila Nova de Paiva). The rest of the area is dominated by rural areas with very low population density.

The spatial distribution of peak flow (Fig. 4c) shows the highest flows allocated to the main water course (Paiva River) increasing significantly downstream. Regarding temperature (Fig. 4d), the mean values ranged between 11 °C and 15 °C, with the highest temperatures located on the west and near to the river mouth, linked to the deepest valleys.

The indicators of criterion *Pressures* are displayed in Fig. 5. Accordingly, the water pollution related to point sources (Fig. 5a), makes evident that the majority of the watershed has low chemical (COD) and organic loads (BOD_5), and nutrient concentrations (N and P). The highest loads are associated to the largest urban areas (Castelo de Paiva and Castro d'Aire). The nutrient loads related to diffuse pollution (Fig. 5b) are higher, namely in the upper part of the watershed. The Paiva River watershed presents a low longitudinal connectivity, presenting 119 barriers (Fig. 5c), mostly along the main water course.

The indicators' spatial distribution of the *State* criterion are illustrated in Fig. 6. The Paiva River watershed has a high biodiversity with more than 44% of the sample locations with an index score above 0.5 (Fig. 6a). Nonetheless, the biodiversity is not homogeneously distributed through the watershed showing that the higher levels of the Simpson index are located at higher altitudes (<750 m). According to the $IPtI_N$, (Fig. 6b), the watershed has an excellent and good status over its entire length, but cautions should be taken into account due to the limited number of samples. Native fish species (Fig. 6c) presented a wider distribution along the watershed, with the most vulnerable species occurring in the main river and from the middle zone to downstream. The longitudinal connectivity of the hydrographic network is quite fragmented (Fig. 6d), due to the huge concentration of barriers. The areas with the best connectivity index are to the southwest, where the barriers are less abundant and concentrated. Fig. 6e, depicts

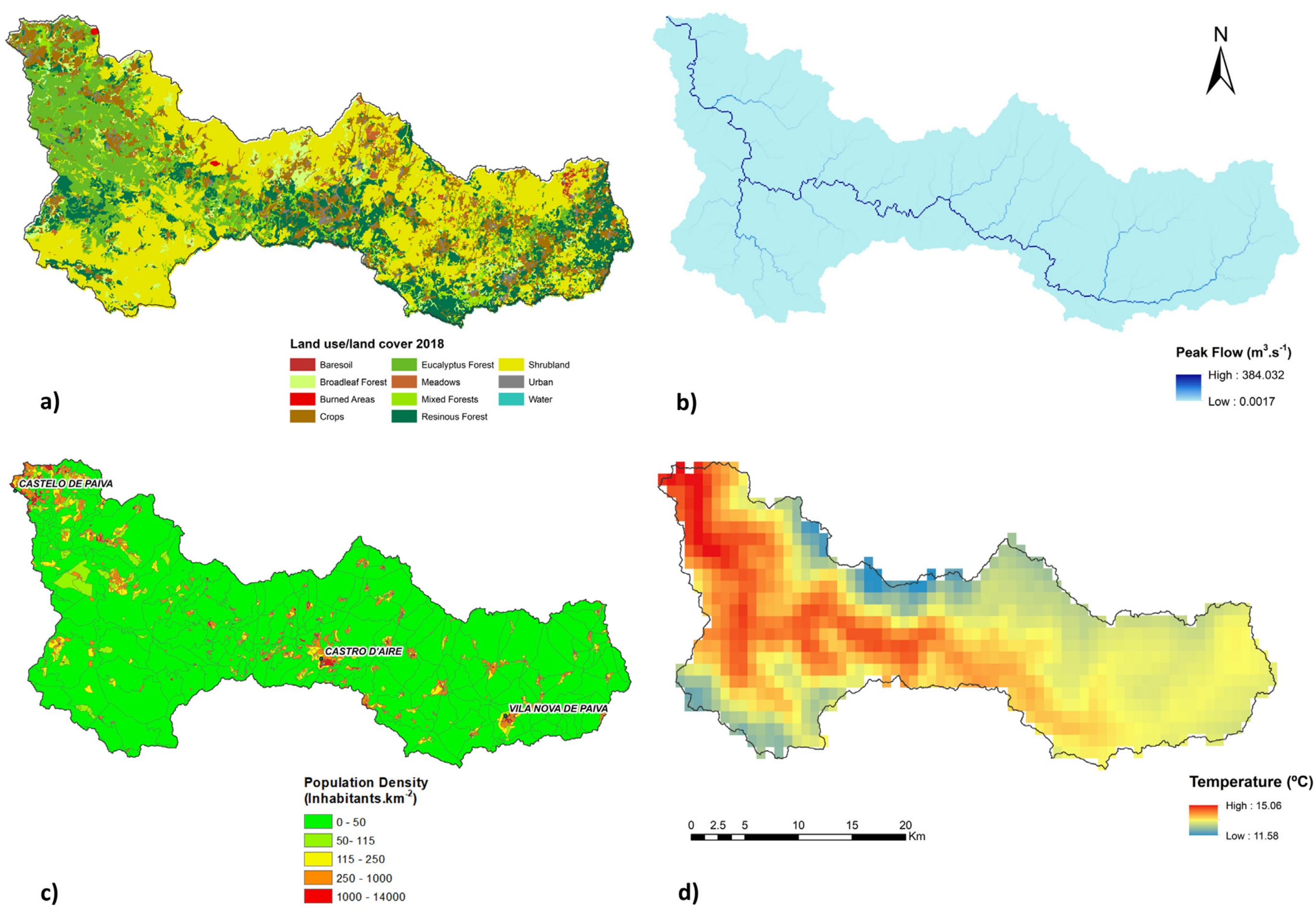

Fig. 4. Spatial distribution of Driving forces criterion. The figure displays the land use/land cover map (a), population density (b), Flow peak (c) and Mean Temperature (d).

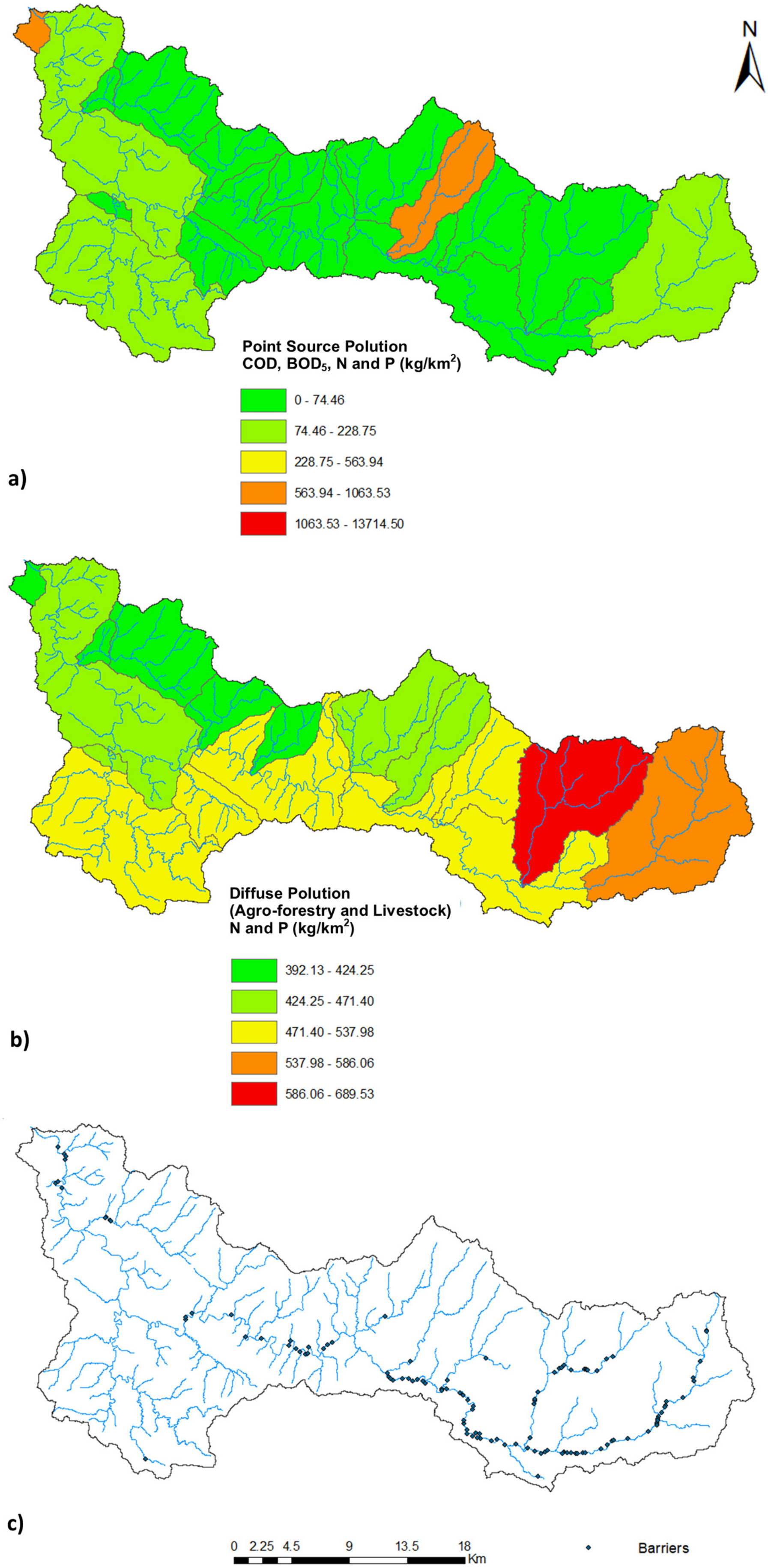

Fig. 5. Spatial distribution of Pressures criterion. The figure shows the total pollution - Point-source (a), diffuse (b), and the barriers distribution map (c).

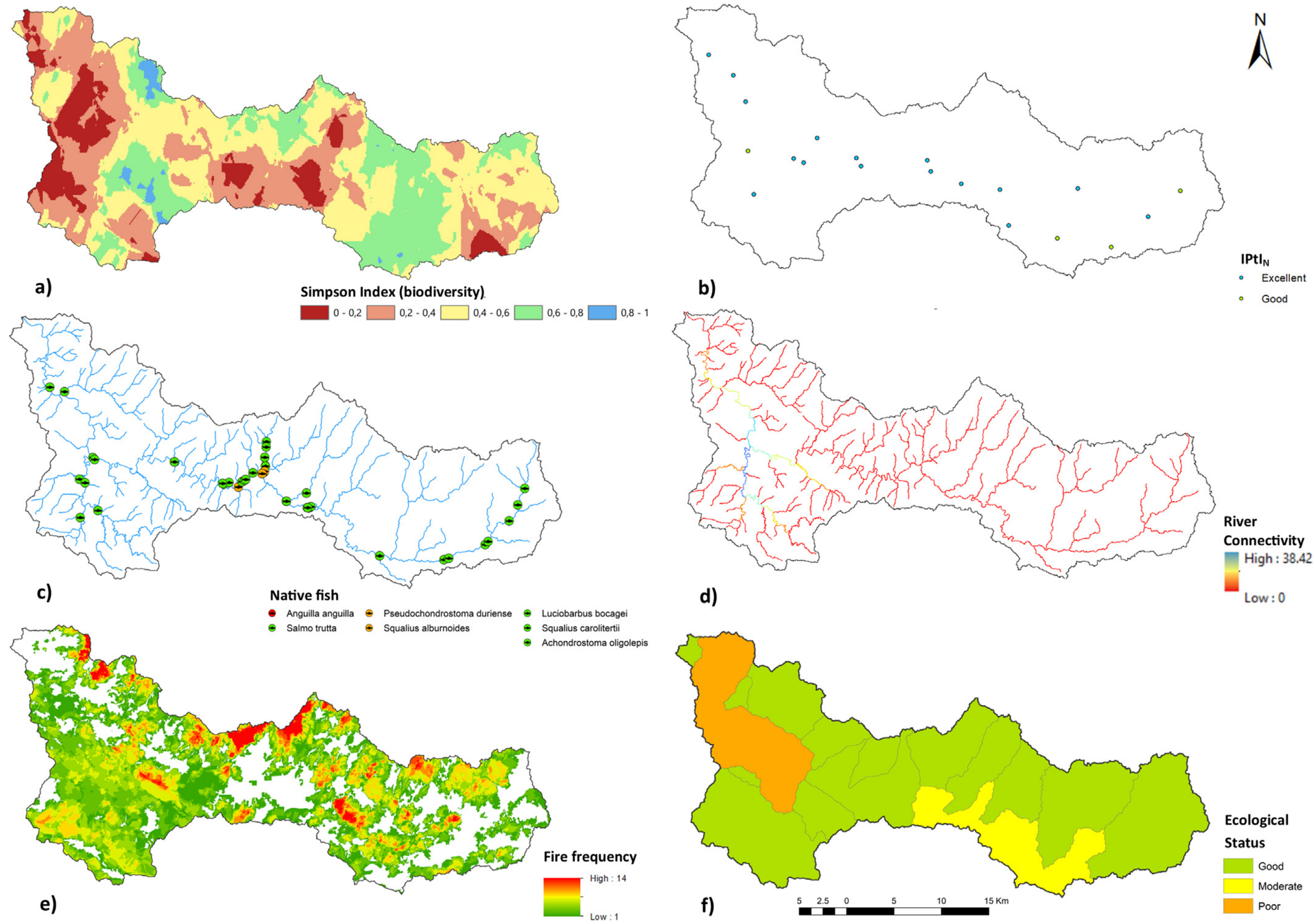

Fig. 6. Spatial distribution of state criterion. The figure illustrates the biodiversity index (a), forest fire frequency (b), ecological state based on WFD (c), longitudinal river connectivity (d), Northern Invertebrate Index (IPtIN) (e), and the native fish belonging to the IUCN red list (f).

the frequency of forest fires over a period of 28 years (between 1990 and 2018). For this period, there was a wide variation in the recurrence of fires: from virtually non-burned areas (in white) to a recurrence of burned areas up to 14 years (in red), i.e. the same area burned in 14 different times. The areas that have burned most frequently are mainly small grazing areas in mountainous areas. In what concerns to the water ecological status, the Paiva River watershed (Fig. 6f) presented good ecological status, with the exception of the sub-basin at the river mouth, which had bad quality and a more central subbasin which had poor quality.

For the criterion *Impacts* (Fig. 7) the indicator wildfire risk (Fig. 7a), almost the entire watershed presented a very high risk. Only the East part of the basin had less risk, but just in a few areas. The areas with smaller soil losses (Fig. 7b) were on the eastern part related to the plateau of the watershed. For the flood risk indicator the results (Fig. 7c) revealed that the most susceptible areas are located in the lower part and close to the river mouth. The upper part of watershed presented the least vulnerable areas. Finally, and relatively to the invasive species indicator, the highest prevalence of invasive fauna species occurred in the western areas, as well as invasive flora (*Acacia* sp.). Acacia, despite existing throughout the basin, in the western areas has denser populations, while in the eastern part its populations are sparser. Also, the Fig. 7d shows that the presence of this species is mainly spread along the main water course.

Related to the *Response* criterion, the two indicators Natura 2000 network and the Ecological corridors of the Paiva River watershed, are shown in Fig. 8a and b, respectively. The indicator SAC (Fig. 8a) includes 3 conservation areas, one linked to riverine system (Rio Paiva), and two associated to mountain ecosystems (Serra de Montemuro and Serra da Freita e Arada). The ecological corridors (Fig. 8b) are represented mainly by a buffer representing the riparian vegetation of the Paiva River and tributaries.

3.2. Outcomes from the participatory approach

The three stakeholder groups specialized in river connectivity, water management and forest management did individual surveys by assigning weights from 1 to 5 to the different criteria and their indicators, to determine the priority areas for the implementation of Blue and Green Infrastructures (Table S1). For each group, the average values were calculated for criteria and indicators. These results were spatially projected giving rise to three maps (Fig. 9), the ranges of which varied from 23 to 2800 (Table S1). Regarding the *River connectivity* (Fig. 9a), the range of the suitability map varied from 429 to 1056, about half from the maximum value, however, being the one with the highest values. The areas with higher vulnerability and more sensitive, and therefore with more urgent need for intervention/conservation, are connected with the main water course more intensively next to the river mouth (Fig. 9a). These results mostly influenced the weights assignment, and according to Tables 2 and 3, the stakeholders attributed higher weight to the *State* and *Response* criteria. The same pattern was observed with the indicators, “barriers”, “ecological status”, “river connectivity”, “native fish” and “SAC”.

For the *Water management* suitability map (Fig. 9b) the range was from 380 to 881. This map had the lowest values which can be explained by the scores presented in Tables 2 and 3. The highest weights (5) were

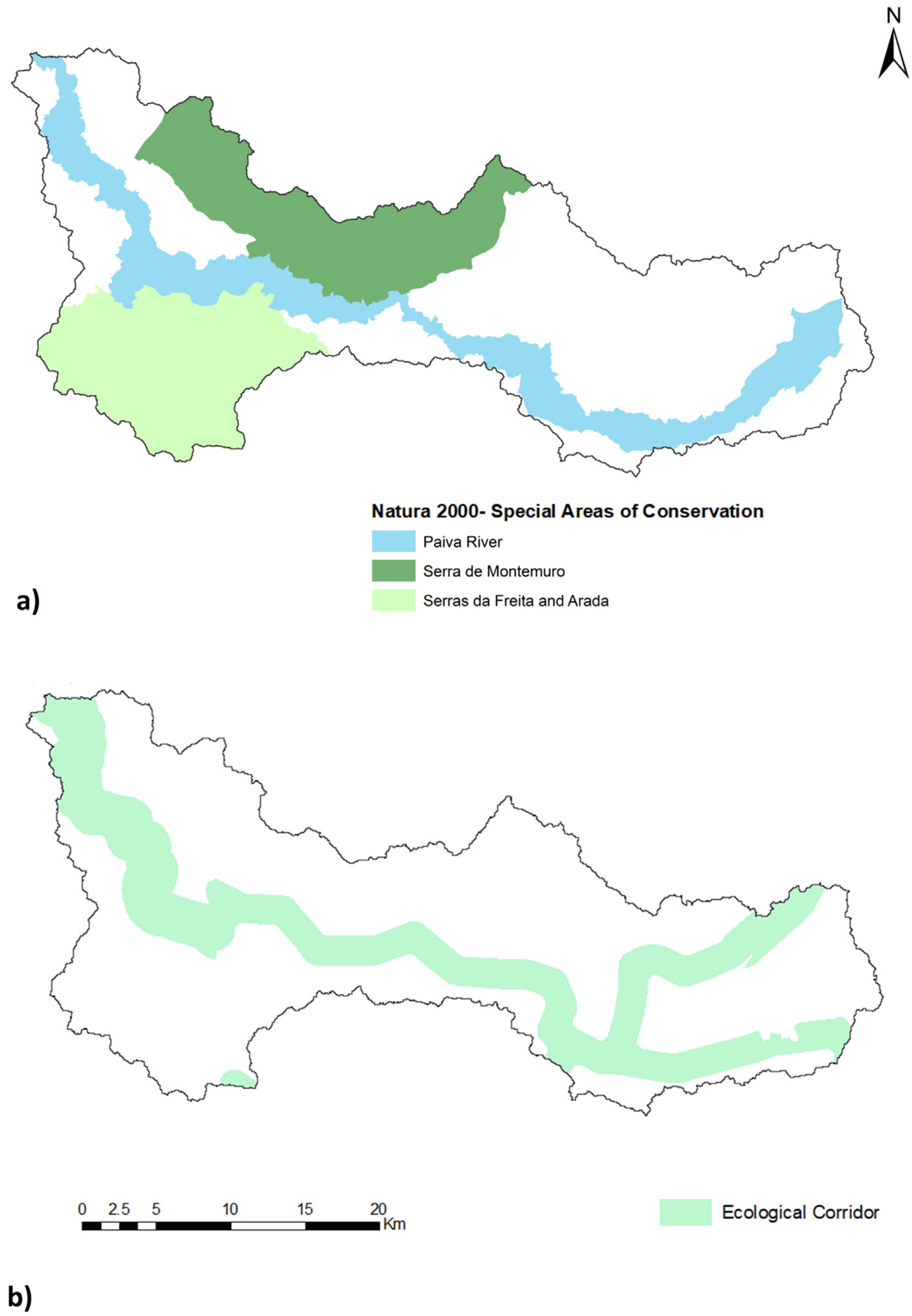

Fig. 7. Spatial distribution of protected areas criterion. The figure displays the Natura 2000 – Special areas of conservation (a), and the ecological corridors (b).

not assigned, and on average, the most assigned values were (3). However, we can still point out that *State* and *Pressure* criteria had the highest values. Consequently, the areas with higher vulnerability and more sensitivity, are related with the lowest water ecological status, near to the mouth of Paiva River, and with the highest loads linked to point and diffuse pollution indicator in the central part of the watershed (Fig. 9b).

Concerning *Forest management* (Fig. 9c), the range of the suitability map varied from 345 to 837. According to Tables 2 and 3, these results reveal that stakeholders attributed greater weight to the *Pressures* criterion. The indicators “burnt areas”, “wildfire risk” and “SAC” were considered to be the most important ones. Accordingly, the areas with higher vulnerability and more sensitivity, are related with the very high wildfire risk, the biggest areas of eucalyptus monoculture, and with the ecological corridors associated to the riparian vegetation. This vulnerability is also related to the highest temperature values in the watershed (Fig. 9c).

3.2.1. BGINs prioritization map

In general, the three maps from different stakeholder's groups present very similar priority areas for the implementation of BGINs. Although there is some variation in the attribution of weights and the total suitability values, in terms of spatial distribution it is clear that the areas that most need intervention are found next to the water lines, increasing from upstream to downstream (Fig. 10). In general, downstream areas are subject to greater pressures, which makes them the most priority areas for BGINs implementation. The five areas with the highest priority were identified and stakeholders identified the main BGINs to implement (Fig. 11). The most recommended BGINs were recovery/maintenance of riparian vegetation, conservation/

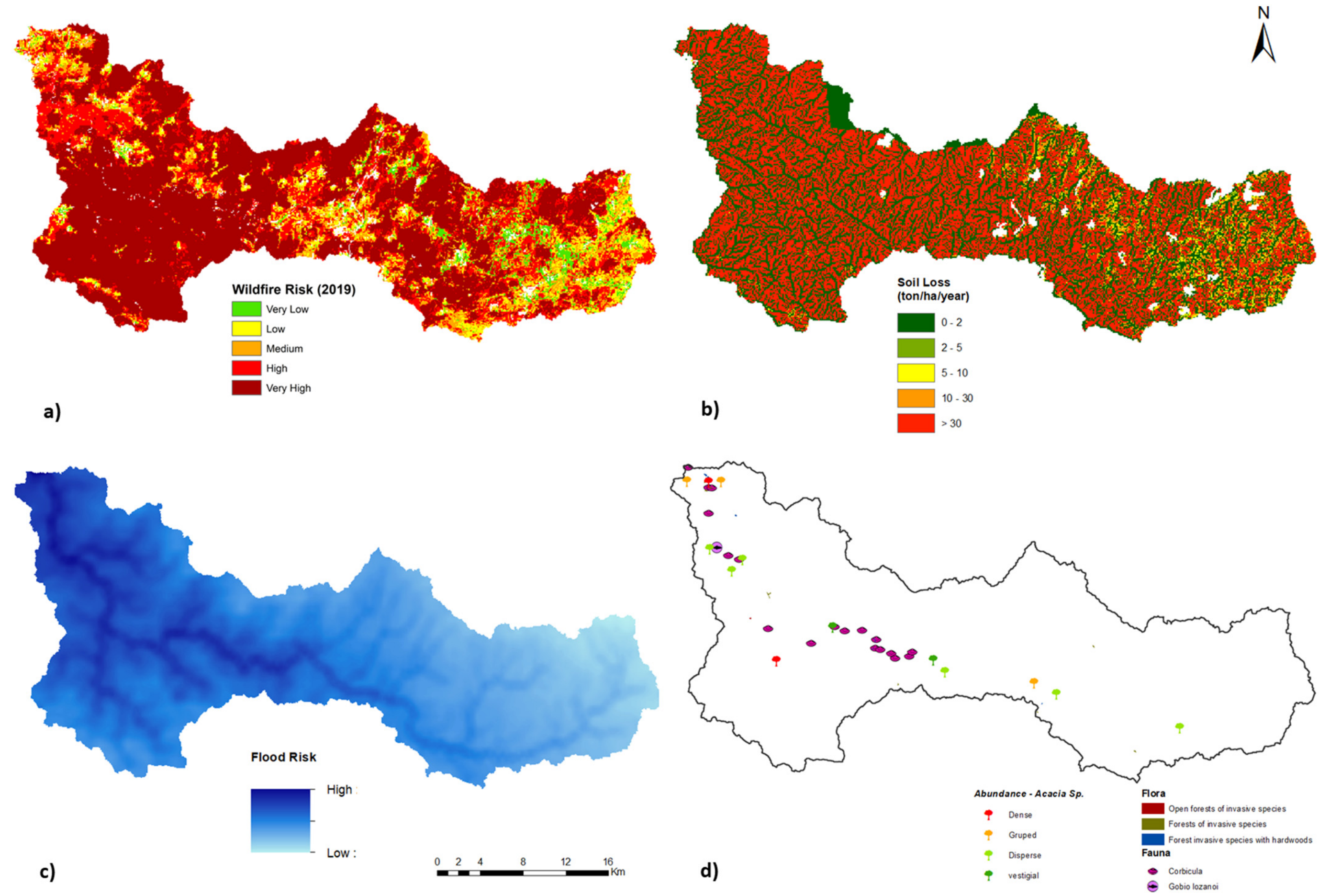

Fig. 8. Spatial distribution of physical conditions criterion. The figure illustrates the peak flow map (a), slope (b) and the average temperature (c).

reforestation of native forest both presented in four of the five areas, and introduction of fuel management strips presented in three of the five areas. The remaining solutions were all pointed out, at least in one area.

4. Discussion

This work presented a framework and the results of a spatial MCDA, with a collaborative approach, that aiming the prioritizing of areas to implement the BGINs and find the most appropriate ecosystem services for them with the help of stakeholders. This type of methodology has already been used in similar studies (Kuller et al., 2019; Langemeyer et al., 2020; Lin et al., 2020; Rocchi et al., 2020; Teotónio et al., 2020; Terêncio et al., 2021). One of the most valuable aspects of this work is to include the direct approach of the community and stakeholders in the allocation of weights in the spatial MCDA and also in the involvement in finding the ecosystem services that will most benefit the priority areas. For example, a study conducted in the city of Detroit USA highlighted the importance of stakeholder involvement in prioritizing areas to implement ecosystem services. According to Meerow and Newell (2017), this approach can assist local communities, planners, and agencies in identifying 'hotspots', assessing potential spatial trade-offs, and ultimately enabling these decision-makers to create green infrastructure plans that incorporate a wider range of socio-economic and environmental benefits and local resilience priorities. Besides, this work presents a comprehensive approach because it is a study at the scale of the hydrographic basin. Because of the literature found, only more specific studies have been done, within urban centres (Camps-Calvet et al., 2016; Langemeyer et al., 2020; Meerow and Newell, 2017), or residential buildings (Teotónio et al., 2020). It is also common to find studies aiming to address a specific problem, such as water management (Langhans et al., 2019; Versini et al., 2018), urban flood mitigation (Alves et al., 2020) or, even identifying socio-cultural values of ecosystem services (Kati and Jari, 2016).

This study was carried out on the Paiva River basin, where we obtained results of the priority areas for the implementation of BGINs taking into account criteria and indicators selected for analysis, such as the assignment of their weights made by the stakeholders. The final prioritization map (which brought together the three large groups of experts) has a great influence on the criteria and in parentheses the most relevant indicators: Driving forces (Land use/Land cover), State (Biodiversity, Ecological status and River Connectivity), Impact (Wildfire risk and Invasive Species), and Response (Special Areas of Conservation and Ecological Corridors).

The wildfire risk is one of the most important indicators due to the constant increase of fires in the Mediterranean (Pausas and Paula, 2012; Shakesby, 2011), driven by socio-economic changes, including rural depopulation and abandonment of cultivated land, afforestation with flammable species (Fernandes, 2013; Moreira et al., 2011) coupled with the ongoing climate change (APA, 2018; IPCC, 2014).

The Paiva basin is home to a very rich and varied fauna, resulting from the diversity of ecosystems existing along with watercourses and on the river banks, being considered one of the best rivers in Europe in terms of water quality. However, society still looks at ecosystem services as public goods without a market or price, being rarely detected by the current economic system, thus leading to a decline in biodiversity and a continuous degradation of ecosystems (Buckley, 2011). That is why it is necessary to point out places with a decline in biodiversity as priorities in the introduction of ecosystem services and give them deserved value and sustainability. The same applies to the Special Areas of Conservation and Ecological Corridors, which include Montemuro

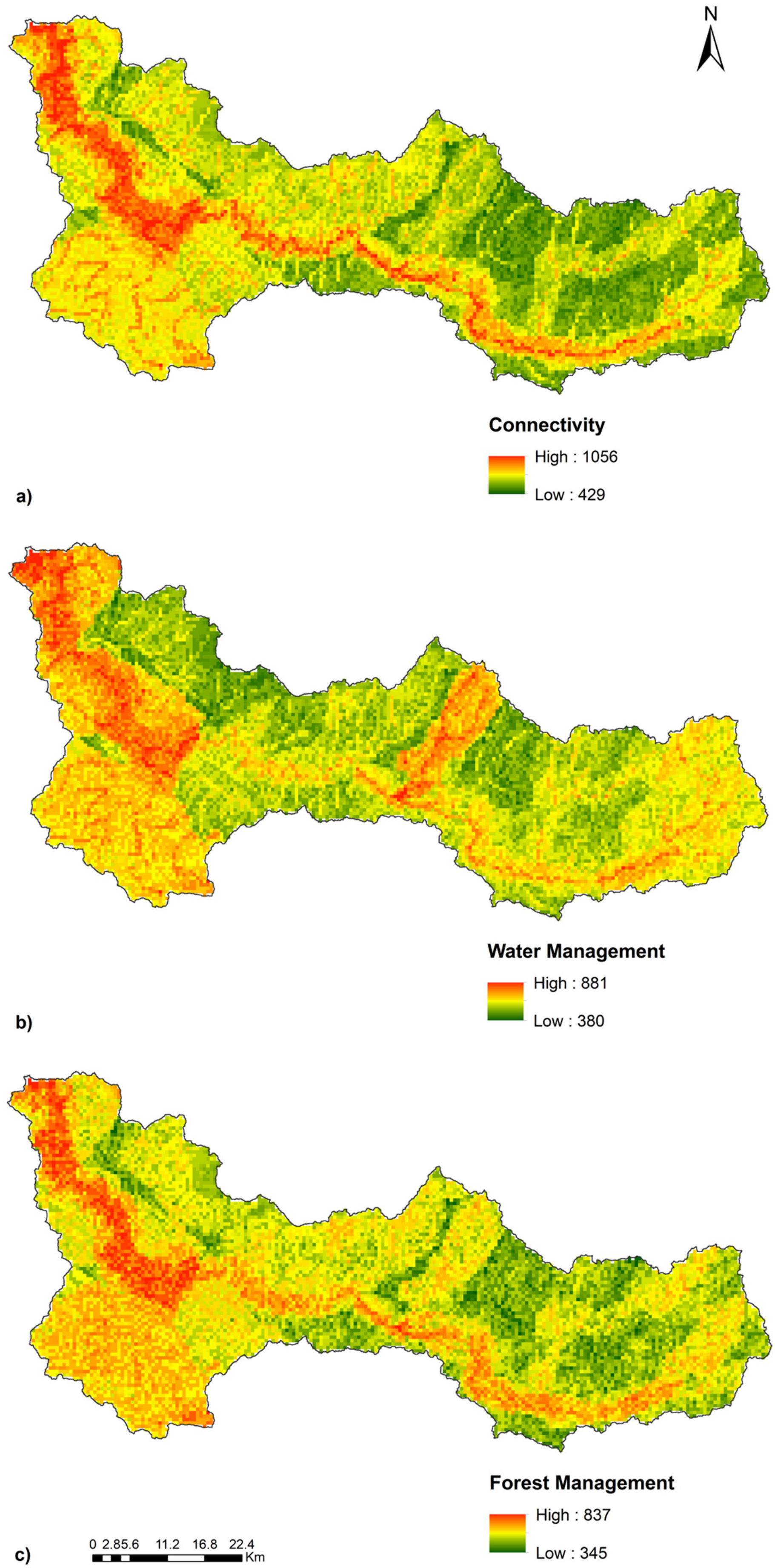
N
Connectivity
High : 1056
Low : 429
a)
Water Management
High : 881
Low : 380
b)
Forest Management
High : 837
Low : 345
c)
0 2.8 5.6 11.2 16.8 22.4
Km

Table 2
Average and standard deviation (in brackets) of the criteria weights assigned per group of stakeholders and their final average.

Criterion	Connectivity (n = 8)	Water management (n = 8)	Forest management (n = 10)	Total average (n = 26)
Driving Forces	3 (1.0)	3 (0.8)	3 (1.1)	3 (1.0)
Pressures	4 (0.5)	4 (0.7)	5 (0.9)	4 (0.7)
State	5 (0.9)	4 (1.0)	3 (1.0)	4 (1.0)
Impacts	3 (0.5)	3 (1.0)	4 (0.9)	3 (0.8)
Response	5 (1.1)	3 (0.9)	4 (1.2)	4 (1.1)

Mountain, Freita Mountain and Paiva River. These are areas should always be at the top of priority when using MCDA like this one. They are part of the European network of ecological protected areas, called “Natura 2000 Network”. It is a form of nature conservation in the European Union focused on species and habitats, on both land and sea areas, established under the unified regulatory framework of the Habitat (Directive 92/43/EEC) and Birds (Directive 2009/147/EC) Directives. Its success requires the application of management measures and the assumption of the network as a national responsibility, providing a unique opportunity to demonstrate that environmental concerns can be integrated with other policies and be compatible with social, cultural and economic development. (Schägner et al., 2016; Tomaskinova et al., 2019).

From the results of the BGINs final prioritization map, five vulnerable areas stand out (Fig. 10), where there is an urgent need to improve ecosystem services and solve socio-environmental problems. For these five areas, several BGINs were appointed by stakeholders to solve local problems and increase ecosystem services (Fig. 11). **Area 1** is located at the mouth of the Paiva River. It is a place introduced in an urban area with the presence of crops, a weir, mixed forest and resinous forest. Stakeholders attributed to this area four types of BGINs listed in Table 4:

Table 3
Average and standard deviation (in brackets) of the criteria's indicators weights, assigned per group of stakeholders and the respective final Mean.

Criterion	Indicators	Connectivity	Water management	Forest management	Total average
Driving forces	Land use/Land cover	4 (0.9)	3 (1.1)	4 (1.2)	4 (1.1)
	Population density	4 (1.2)	3 (1.3)	3 (1.3)	3 (1.3)
	Temperature	4 (0.7)	3 (1.3)	3 (1.2)	3 (1.1)
	Peak flow	4 (0.9)	2 (1.3)	2 (1.2)	3 (1.1)
Pressures	Point and diffuse pollution	2 (1.0)	4 (0.9)	2 (1.3)	3 (1.1)
	Barriers (weirs)	5 (0.8)	3 (1.4)	2 (1.3)	3 (1.2)
State	Biodiversity	4 (0.9)	4 (1.1)	4 (1.4)	4 (1.2)
	Burnt Areas	3 (1.2)	3 (1.4)	5 (1.4)	3 (1.2)
	Ecological status	5 (0.5)	4 (1.0)	3 (1.4)	4 (1.0)
	River Connectivity	5 (0.7)	4 (1.3)	3 (1.2)	4 (1.1)
	IP_tI_N	4 (0.8)	2 (1.0)	2 (1.3)	3 (1.0)
	Native Fish	5 (0.5)	3 (1.0)	2 (1.5)	3 (1.0)
Impacts	Wildfire risk	3 (1.4)	4 (1.3)	5 (1.5)	4 (1.4)
	Soil erosion	4 (0.7)	4 (0.9)	4 (1.2)	3 (0.9)
	Flood risk	4 (1.1)	3 (0.9)	2 (1.2)	3 (1.0)
	Invasive species	4 (1.5)	3 (0.7)	4 (1.4)	5 (1.2)
Response	Special areas of conservation	5 (0.4)	3 (0.9)	5 (1.5)	4 (0.9)
	Ecological corridors	4 (1.4)	3 (1.0)	4 (1.4)	4 (1.3)

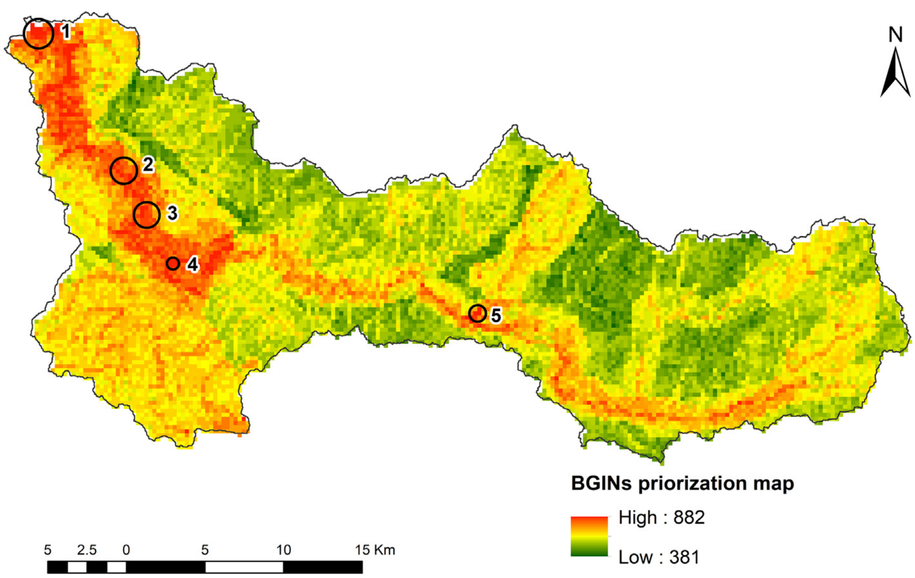

Fig. 10. Final prioritization map, with the five priority areas selected to the attribution of the most suitable BGINs by stakeholders.

Fig. 9. Map of vulnerable and priority areas for the BGINs implementation, according to the weighting of each group of stakeholders: connectivity group (a), Forest management (b) and water management (c).

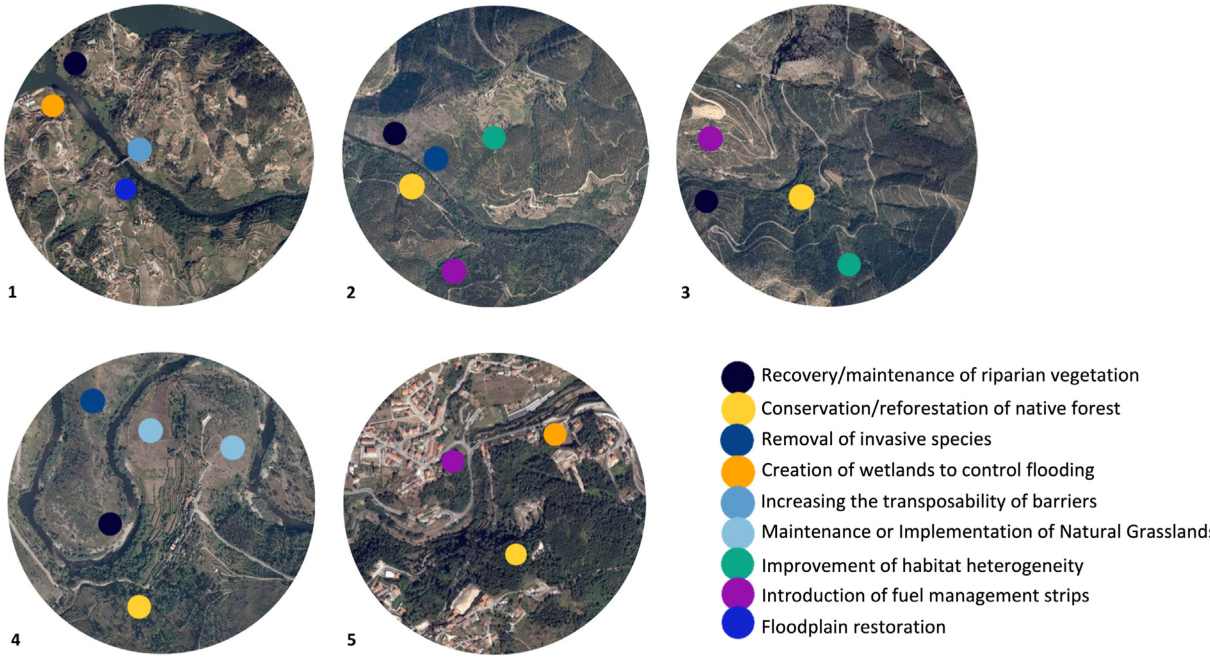

Fig. 11. Satellite images of the five priority areas with the selection of the BGINs (listed in Table 4) by the stakeholders.

Recovery/maintenance of riparian vegetation near the mouth in an area that no longer has riparian vegetation and currently has only shrubs. According to Mander (2008) the management and restoration of riparian zone is one of the most relevant ecotechnological measures for sustainable catchment management. Some examples of the most riparian management schemes are the Riparian buffer zones and riparian buffer strips; **Creation of wetlands for control flooding** in an area next to the river, represented by crops next to the urban area. This is an area with a high probability of occurrence of floods (Fig. 5b) and which is inserted in an urban area, presenting a danger to the population. It is recognized that wetlands can help in flood reduction by storing, holding, and percolating water (Acreman and Holden, 2013; Bullock and Acreman, 2003). Agricultural areas along the river are a major cause of the loss of wetlands over the years. Although agriculture is important, it would be necessary to change some of this area by wetlands to mitigate the effect of possible floods; **Increasing transposability of barriers** near the weir to increase connectivity. Particularly concerning fish populations, dams reduce connectivity and thereby hamper fish migration up or downstream, increasing demographic isolation of the biological populations (Rincón et al., 2017; Schick and Lindley, 2007). To solve the loss of connectivity it is necessary to plan a dam reengineering or removal, particularly in ageing infrastructures (Pan et al., 2016). When dam removal is not a feasible option, other options as Fish passage facilities, such as fish ladders, combined with ecological flows, have long been used to provide fish passage to re-establish habitat connectivity (DVWK, 1996; Ghimire and Jones, 2014). **Floodplain Restoration** upstream of the weir, is an area with land use to the south of the river mixed forests and the north crops. Transforming floodplains to decrease flood risk can be achieved in two ways: (1) by increasing water storage capacity; or (2) by improving water conveyance through the floodplain (European Commission, 2006). Apart from the benefits of reducing the risk of flood damage, restoring floodplains may also fulfil other policy objectives, such as restoring biological and chemical balance. Natural measures usually consist of enlarging the retention area, increasing the water storage capacity of floodplains and thus preventing water from occupying areas where human activities take place(European Environment Agency, 2017);

Table 4
List of the BGINs selected by the stakeholders for the five priority areas in the Paiva watershed.

	Area 1	Area 2	Area 3	Area 4	Area 5
Recovery/maintenance of riparian vegetation	✓	✓	✓	✓	
Conservation/reforestation of native forest		✓	✓	✓	✓
Removal of invasive species		✓		✓	
Creation of wetlands for control flooding	✓				✓
Increasing the transposability of barriers	✓				
Maintenance or implementation of natural grasslands				✓	
Improvement of the habitat heterogeneity		✓	✓		
Introduction of fuel management strips		✓	✓		✓
Floodplain Restoration	✓				

Land use in **Area 2** consists of eucalyptus, mixed forest, brushwood, agriculture and water lines. Stakeholders attributed five types of BGINs to this area. **Recovery/maintenance of riparian vegetation** in an area where the land use is undergrowth. This change would bring huge benefits without major capital investments; **Conservation and reforestation of the native forest** in an area where there is currently mixed forest but also monoculture of eucalyptus. Here it would be interesting to be able to reach an agreement with the owners of the eucalyptus forest to be able to reserve, from that area, a percentage destined to the plantation of an autochthonous forest. These areas of eucalyptus forest monoculture or resinous forest are of little benefit to the basin and even to the productivity of the same species. Thus, it could also bring advantages to producers. According to Forrester and Smith (2012), trees grew faster in mixtures compared with their monocultures. The conversion of coniferous monocultures in particular to mixed forests appears to provide a higher delivery of ecosystem goods and services, especially biodiversity, improved risk management, soil properties, and recreational value (Huuskonen et al., 2021); **Removal of invasive species** in a shrubland and eucalyptus monoculture area. Although there is no evidence of invasive species in the area, there is a lack of recovery of native forest or riparian vegetation in this area. It would be more beneficial in this zone to have one of the BGINs **Recovery/maintenance of riparian vegetation** or **Conservation/reforestation of native forest**; **Improvement of the habitats heterogeneity** in an agricultural area. According to Benton et al. (2003) habitat heterogeneity is associated with greater biodiversity in the cultivated landscape, whether measured on a small or large scale. Heterogeneity of habitat is important in maintaining biodiversity within agricultural landscapes, providing resources over time for communities species richness. This heterogeneity of habitats and the consequent increase in biodiversity is beneficial in combating pests through predators instead of using pesticides (Kaur and Garg, 2014). **Introduction of fuel management strips** in a eucalyptus forest area. Eucalyptus is the forest species with the greatest representation in the national territory. Since this species is flammable, this type of solution will be pertinent (Marques et al., 2011).

Area 3 is represented by a land-use of eucalyptus forest, mixed forests, shrubland, meadows, broadleaf forest, resinous forests, crops and water line. Stakeholders attributed four types of BGINs to this area: ***a***-Recovery/maintenance of riparian vegetation in a eucalyptus forest area. This recovery would be beneficial for the ecosystem, as it would bring about an improvement in biodiversity; **Conservation/reforestation of the native forest** in a mixed forest area. In this case, the most important thing would be to conserve the mixed forest tissue, as native and other species are present, improving biodiversity. **Improvement of the habitats heterogeneity** in an area of a eucalyptus forest. The eucalyptus forest area is an area with little habitat heterogeneity. It would be important to take measures such as leaving a 10 m strip parallel to the waterline free of intervention and creating ecological conditions there for the movement and shelter of terrestrial fauna and preservation of endemic vegetation (Barbosa, 2014). However, the decisions made for land use, even though they need legal support for their implementation, are mostly individual, considering that 97% of the forested area in mainland Portugal belongs to private owners. Such decisions are closely linked to economic issues, and social institutions cannot separate themselves from them (Canadas and Novais, 2014; Silva et al., 2007); **Introduction of fuel management strips** in a shrubland area.

In area 4, land uses are represented by scrub, eucalyptus forest, broadleaf forest, resinous forest, agriculture and water line. Stakeholders attributed four types of BGINs to this area: **Recovery/maintenance of riparian vegetation** in an area of resinous forest. The area in question is devoid of any type of vegetation, being the most viable to introduce species of riparian vegetation instead of using the current land use typology; **Conservation and reforestation of the native forest** in an area of resinous forest. What will be beneficial for the area, being able to introduce native species close to the resinous forest, enhancing the increase in biodiversity; ***c***- Removal of invasive species in a shrubland area; **Maintenance or implementation of natural grassland** in an area of forest and agriculture. The importance of this solution is more and more recognized taking into account the role of the areas occupied by meadows, permanent pastures and temporary pastures in mitigating climate change, not only in capturing and fixing large amounts of $C0^2$ in the non-mobilized soils occupied by these crops, as well as reducing the quantities of food produced in the form of fodder sown locally or produced and transported from distant locations, which require emissions of greenhouse gases in the processes of their production and transport (Teixeira et al., 2011).

Area 5 is represented by mixed forest, resinous forest, agriculture and urban fabric. Stakeholders attributed three types of BGINs to this area; **Conservation and reforestation of the native forest** in a resinous forest area; **Creation of wetlands to control flooding** in a resinous forest area. According to the selected area, it would be more functional to choose a BGIN that has more to do with increasing the local biodiversity or improving the heterogeneity of habitats, since it is not an area with a water line but an urban zone; **Introduction of fuel management strips** in a mixed forest area. Different BGINs could have been assigned in these 5 areas, the chosen ones are questionable as it would be necessary to conduct a study at the sites to see if they would really be the best solutions. However, this participatory approach is a powerful tool to collect empirical and technical knowledge among institutions. Improving cooperation among institutions to an integrated action for the improvement of ecosystem services.

5. Conclusion

This work arises in the context of a European project whose main objective is to promote sustainable investments in blue-green infrastructure networks (BGINs) through the identification of the benefits of ecosystem services at the terrestrial-aquatic and terrestrial-maritime interfaces of the Atlantic region. In addition, the project has a vast multidisciplinary team including scientists, universities, research institutes, local and national governments, Non-profit organizations and Small and medium-sized enterprises. Thus, with the realization of this work at the Paiva River basin-scale, it was possible to verify how important it is to combine these local political entities and the managers of natural resources with the scientific community. When this happens, more robust and reliable results are obtained. This allows management and planning of the places that present the greatest pressure (anthropic and natural), directed at the community and ecosystems. This type of approach makes it possible to locate the priority areas to implement BGINs and to present suitable and personalized solutions. Thus, allowing to improve and make ecosystem services more efficient. This is a comprehensive approach that can be extrapolated and replicated in any river basin, as long as the most representative data is selected and there is an institutional and political determination to bring together local interested participants (community representatives) with stakeholders and the scientific community for the benefit of ecosystem services.

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CRediT authorship contribution statement

D.P.S. Terêncio: Methodology, Software, Investigation, Formal analysis, Writing – original draft. **S.G.P. Varandas:** Writing – review & editing. **A.R. Fonseca:** Methodology, Investigation, Formal analysis. **R.M.V. Cortes:** Methodology, Writing – review & editing. **L.F. Fernandes:** Resources, Software. **F.A.L. Pacheco:** Resources, Software. **S.M. Monteiro:** Writing – review & editing. **J. Martinho:** Methodology, Software. **J. Cabral:** Review & editing. **J. Santos:** Methodology, Revew & editing. **E. Cabecinha:** Project administration, Funding acquisition, Supervision, Conceptualization, Methodology, Visualization, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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