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Where and why to conserve grasslands socio-ecosystems? A spatially explicit participative approach

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Grasslands of southern South America are being replaced by annual crops and forest plantations. The environmental and social consequences of this expansion generate the need for its regulation. If a conservation policy were established, it would be critical to define which areas would have priority for conservation. Multi-criteria analysis techniques are useful tools in territorial planning processes since they allow incorporating diverse and even opposing opinions and objectives. We present a methodological approach to define the Grasslands' Conservation Value (GCV) from a spatially explicit territorial diagnosis, based on multiple criteria and incorporating explicitly and quantitatively the valuations and opinions of stakeholders. The study was developed as part of the strategy of a public inter-institutional entity to contribute in defining grasslands conservation policies. The methodological approach included workshops in which the definitions of the conservation criteria and their weighting were agreed upon. Definitions were based on a multidimensional technical characterization of the territory through indicators, for which the information used was compiled, analyzed, shared, and synthesized. Based on multi-criteria analysis, each of 12 stakeholders' groups representatives established the individual weighting of the criteria for determining the GCV and then, established a consensus weighting. The GCV was mapped by integrating territorial diagnosis of these criteria with the weightings carried out by the stakeholders. The degree of agreement among stakeholders in the differential valuation of the ecological criteria was high for 8 of the 12 stakeholders (Pearson's correlation coefficients >0.92), showing a high agreement between their opinions and those resulting from the group consensus. In all cases, the agreement about the spatial variation of conservation value was higher than on the criteria weights (Pearson's correlation coefficients ≥0.92 for 10 stakeholders). Furthermore, the sites with lower values in the consensus map corresponded mostly to those sites with lower agreement among stakeholders. The proposed methodology allowed the incorporation of different perceptions not only in the definition of conservation criteria but also in their prioritization, in a transparent and auditable process. This could contribute to the implementation of future regulations that restrict the replacement of grasslands, increasing the legitimacy of territorial planning processes.

KEYWORDS

territorial planning, decision-making, socio-ecological systems, multicriteria analysis, stakeholders, ecosystem services, remote sensing, GIS

1 Introduction

Temperate grasslands are one of the most threatened biomes (Sala, 2001; Carbutt et al., 2017) with one of the highest habitat losses and the smallest protected area at global scale (Hoekstra et al., 2005). During the last decades, land-use changes determined the loss of extensive areas of native grasslands in South America (Paruelo et al., 2006; Baldi and Paruelo, 2008; Hansen et al., 2013; Salazar et al., 2015). This process is part of a global trend where many factors interplay to determine these changes (Geist and Lambin, 2002; Modernel et al., 2016; Volante et al., 2016). Among them, land grabbing processes, commodities prices, and technological changes have been identified as major drivers (Borras et al., 2012; Rulli et al., 2013). In particular, the temperate grasslands of southern South America -Río de la Plata Grasslands region-represent one of the most extensive grassland ecosystems in the Neotropics (Soriano et al., 1992). In this region, the area of native grasslands was reduced by 19.4% between 2000 and 2019 (Mapbiomas Pampa, 2021). In the Uruguayan portion two type of transformations took place. On the one hand, an increase in the area devoted to annual crops (mainly soybean) and, on the other, an expansion of forest plantations (mainly Eucalyptus and Pinus) (Baldi and Paruelo, 2008; Vega et al., 2009; Oyarzabal et al., 2019; FAO, 2020). The environmental and social consequences of this process (Brazeiro et al., 2008; Piñeiro, 2010; Eclesia et al., 2012; Texeira et al., 2015) highlighted the need to regulate agricultural and forestry expansion (Paruelo et al., 2006). In fact, a Law that regulate forest plantations expansion is current under debate in the Uruguayan Congress (Parlamento del Uruguay, 2021).

If a conservation policy for natural grasslands were established, it would be critical to define which areas would have a priority for conservation. The criteria for assigning a high conservation value in an area were, historically, associated with the biodiversity preservation (Margules and Usher, 1981; Daniels et al., 1991; Scott et al., 1993; Humphries et al., 1995; Margules and Pressey, 2000; Egoh et al., 2007), which was the accepted overall objective of conservation policies for decades (Callicott et al., 1999). Recently, a more general concern for maintaining the capacity of ecosystems to sustain and regulate processes (e.g., nutrient and water dynamics, and carbon balance) has gained consensus (Goldman et al., 2008; Naidoo et al., 2008). Such concern is clearly related to the link between ecosystem functioning and the Ecosystem Services (ES) supply (Fisher and Turner, 2009; Haines-Young and Potschin, 2010). Noss (1990) provide an integrative view of the biodiversity concept including not only compositional aspects but also structural and functional dimensions at different levels of organization, from genes to landscapes. Even considering a broader definition of biodiversity and including other ecological criteria it is critical to also consider the human component and its interaction (Collins et al., 2011). In many cases, conservation planning failed due to insufficient consideration of social, economic, cultural, or institutional aspects (Ban et al., 2013). To identify which criteria related to the human dimension are important, why they are important, and how they should be quantified, integrated, and interpreted has proven a challenge (Pacheco-Romero et al., 2020). In this context, the subject of conservation should be the socio-ecosystem (Berkes et al., 2000) and given that the conservation value is linked to the capacity to provide ES (Eastwood et al., 2016), it should be characterized at the level those services are provided, the landscape. At this level occurs the most intense interactions between people and nature, consequently the composition and configuration of a landscape deeply affect and are affected by human activities (Wu, 2013).

Another critical aspect when a conservation policy is planned is who will determine the priority areas for conservation. As both the representativeness of the stakeholders and their ability to influence the results of the process increase, legitimacy in the implementation of these results is likely to increase as well (Reed, 2008; Aguiar et al., 2018). In turn, successful implementation of the results will depend on conservation interventions that are ecologically appropriate and socially acceptable (Ban et al., 2009; Dudley and Stolton, 2010). In this sense, stakeholder's participation in the prioritization of conservation needs is key to increasing the legitimacy and transparency of decisions. To incorporate the opinions and visions of the different stakeholders is a major challenge, as the process is influenced by the social (Auer et al., 2020) and symbolic (Benn and Jones, 2009) capital of the stakeholders and by the power relationships among them (Reed, 2008; Sterling et al., 2019). Furthermore, given that decisions are based on the interaction between values, interests, emotions (Levine et al., 2015) and available evidence (Sterling et al., 2017), specific methods are needed that consider this complexity of factors (Mukherjee et al., 2018). One way to do this is to explicitly separate the objective and subjective components of this process. For this, is critical to generate mechanisms to make explicit and document both, the criteria that are considered to determine the conservation value and how they are spatially applied, as well as the different perceptions of stakeholders involved in the process.

Multi-criteria analysis techniques are very useful tools in territorial planning processes, since they allow diverse opinions to be considered and the coexistence of opposing objectives or visions (Saaty, 1977, 2014; Saaty and Peniwati, 2008). This method makes it possible to quantify, record and document systematically the different opinions, bringing transparency to the decision-making process. However, many of the studies that use these techniques for conservation-related decision-making do not involve stakeholders in the formulation of criteria and weight them based on hierarchies defined by experts, instead of collecting stakeholder concerns (Esmail and Geneletti, 2018). In turn, often some techniques are used to reduce the variability of stakeholder weightings (Proctor and Drechsler, 2006), which does not allow assessing the degree of agreement among them. The studies linked to the prioritization of conservation areas in Uruguay, were based exclusively on ecological aspects and weighting of criteria was defined by experts (Bilenca and Miñarro, 2004; Soutullo et al., 2013; di Minin et al., 2017; Brazeiro et al., 2020).

In this article we present and apply a novel methodological approach to characterize the Grasslands' Conservation Value (GCV) from a spatially explicit territorial diagnosis based on multiple criteria (ecological and socioeconomic) and incorporating explicitly and in quantitative terms the assessments and opinions of stakeholders. From the results of the process, we quantify the degree of agreement among stakeholders both in the differential assessment of the criteria and in the spatial variation of the conservation value. We also evaluate which criteria contribute to the differentiation of the assessments. The analyses were performed in the South-Central region of Uruguay, in the Río de la Plata Grasslands, which is undergoing profound land-use and land-cover changes. The process was carried out as part of the strategy of a public inter-institutional entity to contribute to the definition of grassland conservation policies.

2. Methods

2.1 Case description and study area

As part of the concern on the sustainability of cattle production on native grasslands, the Ministry of Livestock, Agriculture and Fisheries of Uruguay set up in 2012 the Board of Livestock on Natural Grasslands ("Mesa de Ganadería sobre Campo Natural", MGCN for its acronym in Spanish). The MGCN is a public inter-institutional entity whose objectives are aimed at the dynamic conservation of grasslands. It includes different institutions: representatives of the research and development system, rural extension, farmers' associations, non-governmental organizations, international cooperation institutions, and governmental agencies (Supplementary Table S1) (MGCN, 2021). In a context of growing concern about the transformation of grasslands into croplands and forest plantations, the MGCN initiated in 2017 action aimed to make a spatially explicit territorial diagnosis and to characterize the conservation value of grasslands of the South-Central region of Uruguay (Panario, 1987; Panario et al., 2014). This pilot area was selected by the stakeholders given its vulnerability to grassland losses. It has undergone major changes in land-use and is currently seriously threatened by the installation of a new pulp mill (http://upmpasodelostoros.com) that promotes future forestry production projects.

The South-Central region, with 2.3 million hectares, is characterized by gentle hills with soils originated from granitic bedrock and quaternary sediments (Panario et al., 2014). The climate is humid temperate, the average annual temperature is 17°C and the average annual precipitation varies between 1,100 and 1,200 mm per year (INUMET, 2021). Native grasslands, devoted to livestock production, occupied 42% of the South-Central region, annual crops lands (mainly soybean, corn, and winter crops) 54% and forest plantations the remaining 4% (Baeza et al., 2019) (excluding urban areas and water bodies). Two native grasslands communities are present in this region (Lezama et al., 2019). The first one corresponded to sparsely-vegetated grasslands. This community is characterized by meso-xerophytic species and includes stands with shallow or very shallow soils. It has two variants (sub-communities) in the study area, one of them is characterized by *Stenachaeniumcampestre-Andropogon ternatus* and the other one by *Aira elegantissima-Micropsisspathulata* (Lezama et al., 2019). The second plant community corresponds to densely-vegetated grasslands dominated by mesophytic species, encompassing stands with high plant cover values (near 100%) that occupied medium and deep soils. Again, this community present two variants in the region, one characterized by the presence of *Chevreuliasarmentosa-Danthonia* montevidensis and the other by *Lolium multiflorum-Nassellacharruana* (Lezama et al., 2019).

2.2 Methodology for determining the conservation value

The methodological approach included: 1) three workshops in April, May, and June 2017 in which the definitions of the conservation criteria and their weighting were agreed upon, and 2) technical work where the information to be used was prepared, analyzed, and synthesized (Figure 1). The workshops were convened by the MGCN as part of its regular meetings. Participants

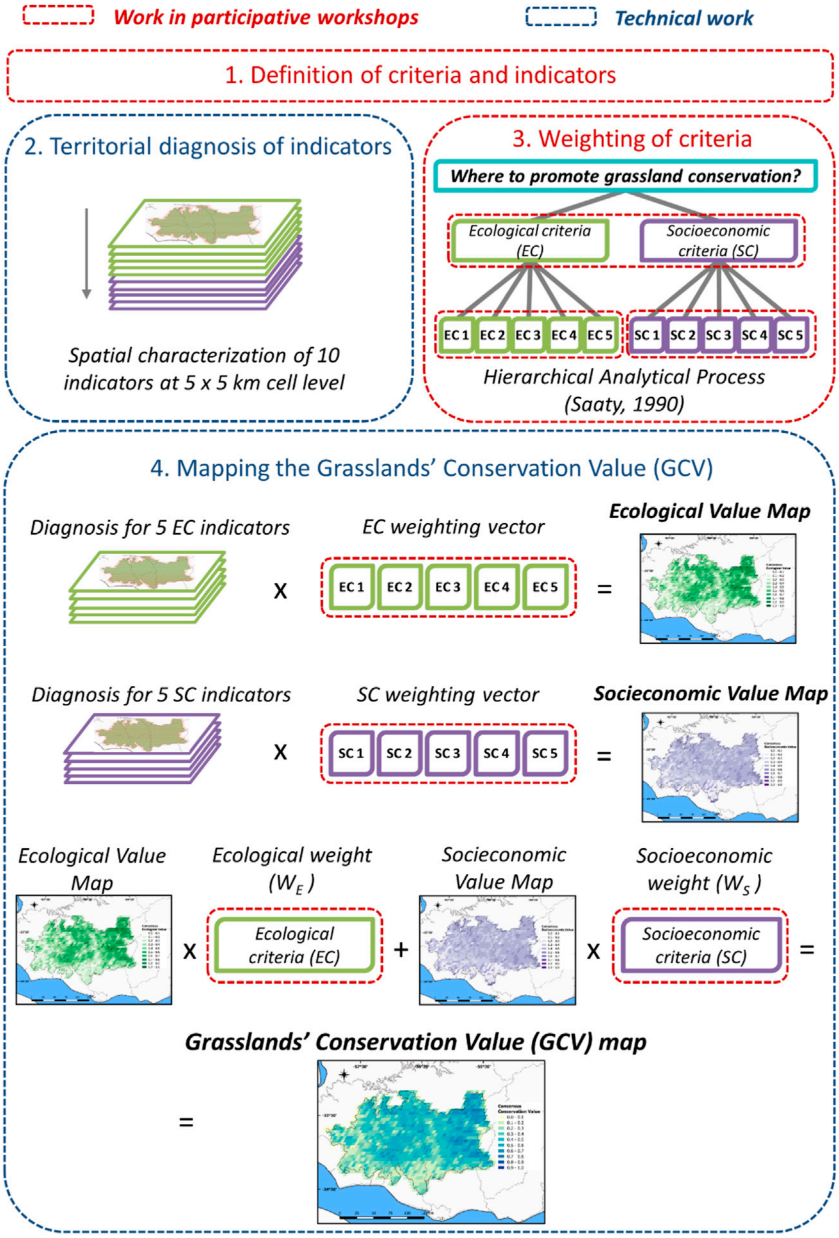
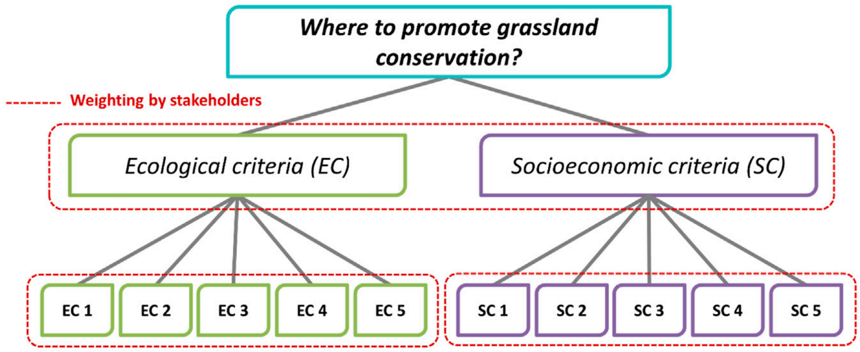


FIGURE 1
Methodological steps for defining the Grasslands' Conservation Value (GCV). The size of the boxes does not represent the relative importance of each stage in the process.

included representatives of the different organizations of the MGCN (each of the stakeholders has a representative on the MGCN, Supplementary Table S1) and the technical team (the authors of this article). Although the three workshops were attended by most of the representatives, there were some who participated in only 1 or 2 of the workshops. In the first workshop the criteria and indicators to be included in the territorial diagnosis were presented and discussed. The weightings of the ecological and socioeconomic criteria were carried out in the second and third workshop, respectively.

2.2.1 Criteria and indicators for the socio-ecological diagnosis

The first step included the definition of the criteria on which the conservation value was to be determined (Figure 1). The criteria corresponded to both biophysical and human components of the socio-ecological system. Before the first workshop, the members of



	Criterion	Indicator
EC 1	Protected areas	Presence / Absence
EC 2	Faunal diversity	Potential mean species richness of mammals, birds, amphibians, reptiles, and fish.
EC 3	Functional diversity	Shannon index of Ecosystem Functional Types
EC 4	Grasslands' area	% of grasslands
EC 5	Grasslands' Ecosystem services supply	% of grasslands withouth negative trends in Ecosystem Services Supply Index

	Criterion	Indicator
SC 1	Farm size	Median cadastral plot
SC 2	Family farming	% of grasslands on family farms
SC 3	Grasslands carrying capacity	Cattle carrying capacity
SC 4	Infrastructure	Km of road
SC 5	Population	Rural population density of the census segment

FIGURE 2
Hierarchical structure used to determine the Grasslands' Conservation Value (GCV). The question to be answered is which cells (5 x 5 km) have higher conservation value. The criteria to answer that question were grouped into two categories: ecological (EC 1 to EC 5) and socioeconomic (SC1 to SC5), which were characterized by a spatially explicit diagnosis of their indicators. Each dotted red box encloses the elements that the stakeholders compared in the three weightings carried out. Each comparison gives rise to a weighting vector representing the relative importance of each element with respect to the others, whose sum is equal to 1.

the MGCN, in the context of their regular meetings, worked on identifying important criteria to determine the GCV. A first list of criteria resulted from these meetings, and it was provided to the technical team. Indicators for these criteria were derived mainly from two sources, scientific articles and information from public institutions. In the first workshop, based on this proposal, the technical team, based on the previous work of the stakeholders, presented a first proposal of criteria to be included in the socio-ecological diagnosis. Each criterion was characterized by different indicators. Such indicators had to be spatially explicit to geographically discriminate areas with different conservation value. In turn, each indicator was evaluated by the members of the MGCN according to its relevance, source, and scale. Based on the comments of the workshop participants, the criteria and indicators considered were incorporated, modified, or discarded. Some new criteria were incorporated upon the comments of the attendants. A total of 34 indicators corresponding to 15 criteria were mapped and integrated into a Geographic Information System (Quantum GIS software) (Supplementary Table S2). Each indicator was summarized at a spatial resolution of 5 km (Figure 1) and scaled to the range (0–1) to make them comparable, using the following equation:

$$Xi\,scaled = \frac{Xi - X\min}{X\max - X\min} \qquad (1)$$

Where X_i *scaled* corresponds to the scaled value of indicator X for cell i, X_i is the value taken by indicator X in cell i, $X_{\min}$ is the minimum value taken by indicator X among all cells and $X_{máx}$ is the maximum value taken by indicator X. For each criterion, a single indicator was selected, and correlation analyses were performed between the indicators in each group to rule out redundancies among them (Supplementary Figure S1). In those cases where Pearson correlation coefficient between two indicators was greater than 0.65, only one of them was conserved (e.g., floristic diversity was excluded because it presented a high correlation with the proportion of grasslands, $r = 0.98$).

As a result, a final set of 10 criteria was agreed in the second workshop (Figure 1). The criteria were divided into two groups (ecological and socioeconomic). In the first group, 5 Ecological Criteria (EC) were included, characterized through 5 indicators (Figure 2, Supplementary Table S3, Supplementary Figure S2):

- EC1: Protected areas and priority sites for conservation, characterized by the presence/absence of both a protected area and areas integrated into the network of priority sites to be incorporated according to a plan proposed by the National System of Protected Areas (SNAP, 2015).

- EC2: Faunal diversity, characterized through 5 maps of potential species richness for mammals, birds, reptiles, amphibians, and fishes in ~66,000 ha cells for all of Uruguay (Brazeiro et al., 2008). A potential faunal diversity index was determined as the sum of the 5 specific richnesses summarized at the 5 × 5 km cell level.
- EC3: Functional diversity, characterized through the Ecosystem Functional Types (EFT) diversity. The EFT (Paruelo et al., 2001) result from combining three attributes of the annual dynamics of remotely sensed vegetation indices: the annual mean, the intra-annual coefficient of variation, and the moment of year of peak productivity. This approach allows to infer the degree of productive diversity. From the annual dynamics of the Enhanced Vegetation Index (EVI, derived from MODIS sensor images, product Mod13q1 with a spatial resolution of 250 m and a temporal resolution of 16 days), the EFTs were obtained for the year 2015. Four fixed levels were generated for the three attributes that were then combined to generate a map of EFTs (Alcaraz-Segura et al., 2013). The 250-m pixels corresponding to grasslands (identified from the EC4 land cover map corresponding to the same year) were excluded, and the Shannon Index was calculated to describe the functional diversity of the grassland surroundings.
- EC4: Remaining grassland area (proportion), obtained from a land-cover map for 2015, with a spatial resolution 30 m (Baeza et al., 2019).
- EC5: Grasslands' ecosystem services supply, determined by trends in the Ecosystem Services Supply Index (ESSI), a synoptic indicator that estimates and maps supporting and regulating ecosystem services related to water and carbon dynamics derived from remote sensing data (Paruelo et al., 2016). The support for using ESSI as a proxy of ecosystem service supply is based on its ability to explain between 48 and 66% of the variability of four ecosystem services estimated from empirical data or mechanistic models: groundwater recharge and avian richness in Dry Chaco forests and soil organic carbon and evapotranspiration in Río de la Plata Grasslands (Paruelo et al., 2016). It is based on two attributes of vegetation index annual dynamics, the annual mean (VI_{MEAN}, a proxy of total C gains) and the intra-annual coefficient of variation (VI_{CV}, an indicator of seasonality): $ESSI = VI_{MEAN} * (1—VI_{CV})$. Those sites where annual productivity is higher and more seasonally stable would have a higher ES supply. From the annual dynamics of EVI (derived from MODIS sensor images, product Mod13q1 with a spatial resolution of 250 m and a temporal resolution of 16 days), the annual ESSI values were obtained, and their trend was estimated during the period 2000–2015. Since the criterion aimed to capture the ecosystem services supply provided by grasslands in a cell, the proportion of pixels corresponding to grasslands (identified from the EC 4 mapping) without negative ESSI trends (i.e., where the ecosystem services supply has been maintained or increased) was calculated with respect to the total number of grassland pixels in the cell.

In the second group, 5 Socioeconomic Criteria (SC) were included, characterized through 5 indicators (Figure 2, Supplementary Table S4, Supplementary Figure S3):

- SC1: Farm size, characterized through the median of cadastral plots (Dirección Nacional de Catastro, 2017).
- SC2: Family farming, whose indicator was the proportion of grasslands in family farms with respect to the total area of grasslands in the cell. One of the stakeholders (representative of The Rural Development office of the Ministry of Livestock, Agriculture and Fisheries) provided the information of the family farms, protecting the identity of the owners.
- SC3: The grasslands carrying capacity was estimated as follows: $CC = \frac{ANPP*HI}{AIC}$ where, CC is the carrying capacity ($heads*ha^{-1}$), ANPP corresponds to the Aerial Net Primary Productivity ($kg*ha^{-1}*yr^{-1}$), HI represents the Harvest Index (kg consumed/kg produced), and AIC is the is the Annual Individual Consumption ($kg\ consumed*head^{-1}*año^{-1}$). The ANPP was estimated from remotely sensed data (EVI derived from MODIS sensor images, product Mod13q1 with a spatial resolution of 250 m and a temporal resolution of 16 days) using the Monteith model (Monteith, 1972; Piñeiro et al., 2006; Grigera et al., 2007; Paruelo et al., 2019). Mean annual ANPP for remnant grasslands, identified in the EC4 mapping, for the period 2000–2015 was estimated at a spatial resolution of 250 m. The HI was estimated from ANPP using a function proposed by Golluscio et al. (1998) and for annual individual consumption a value of 2,774 kg per year was taken as a reference, suggested by experts from the "Instituto Plan Agropecuario", a public cattle extension institution and member of the MGCN (Supplementary Table S1).
- SC4: An index of infrastructure of each cell was characterized through the sum of the kilometers of road of the official national road network (Ministerio de Transporte y Obras Públicas, 2017).
- SC5: Population, characterized by the rural population density reported in the National Census of Population, Housing and Households (Instituto Nacional de Estadísticas, 2011). The most detailed spatial resolution available corresponds to the census segment.

For the EC, stakeholders agreed that the relationship between the values of each indicator and the contribution to conservation value was positive (i.e., higher values of each indicator contribute to a higher conservation value). In the case of the SC, although

TABLE 1 Example of pairwise criteria comparison and obtaining the weighting vector corresponding to the ecological criteria. The row and column headings contain the criteria compared by the stakeholders using the Saaty scale in italic cells. Once the preferences had been assigned, the geometric mean was calculated for each row of the matrix and the geometric means of all the rows were summarized. The weighting value (relative importance) of each criterion was obtained by dividing its geometric mean (A) by the sum of the geometric means of all rows (7.52). These values determine the weighting vector (C), which indicates the relative importance of each criterion. The last row (B) is used to calculate the consistency level of the matrix.

Ecological Criteria (EC)	EC1	EC2	EC3	EC4	EC5	Geometric mean (A)	Weighting vector (C)
EC1: Protected areas	*1*	*1*	*3*	*1/7*	*1/5*	0.61	0.08
EC2: Faunal diversity	*1*	*1*	*3*	*1/5*	*1/3*	0.72	0.10
EC3: Functional diversity	*1/3*	*1/3*	*1*	*1/7*	*1/5*	0.32	0.04
EC4: Grasslands' area	*7*	*5*	*7*	*1*	*5*	4.15	0.55
EC5: Grasslands' Ecosystem services supply	*5*	*3*	*5*	*1/5*	*1*	1.72	0.23
Sum (B)	14.33	10.33	19.00	1.69	6.73	7.52	

the stakeholders agreed that these were important criteria to include, they had different opinions regarding the relationship between the values of each indicator and their contribution to the GCV. These discrepancies required prior agreement, as opinions on weighting depends on the direction in which each indicator contributes to the GCV. For 4 of the 5 criteria, the relationship was positive, while for SC1, it was negative: those cells with smaller median size of cadastral plots would have a higher GCV than those with larger median size. Therefore, this indicator was incorporated into the GCV estimation as its complement (1- SC1 scaled). More details on the criteria and indicators considered is presented as supplementary material (details of the indicators calculated for the ecological and socioeconomic criteria are shown in Supplementary Table S3 and Supplementary Table S4, respectively, while the indicators maps are shown in Supplementary Figure S2 and Supplementary Figure S3).

2.2.2 Weighting of criteria

The weighting of the criteria was based on a multi-criteria analysis method, the Analytic Hierarchy Process (Saaty, 1990, 2014). To establish the relative importance of each criterion, the participants make pairwise comparisons of each criterion with respect to the rest using the Saaty scale (Saaty, 1977). The assignment of preferences was established by comparing the importance of the criterion in each row with respect to the criterion in each column in a square matrix (Table 1) through the scale whose values range from 1 to 9 and establish the following priorities:

1 = Equally important
3 = Moderately more important (and conversely 1/3 is moderately less important)
5 = Strongly important (1/5 strongly less important)
7 = Very strongly important (1/7 very strongly less important)
9 = Extremely more important (1/9 extremely less important)

2, 4, 6, 8 correspond to intermediate values that can be used to resolve compromise situations.

The method provides a measure of the degree of weighting consistency called Consistency Ratio (CR), which indicates to what extent the preferences were assigned through an informed and coherent judgment (Saaty, 1990, 2014). To this, the comparison matrix must comply with 3 properties: reciprocity (e.g., if criterion A is moderately more important than B, then B must be moderately less important than A), transitivity (e.g., if criterion A is more important than B and B is more important than C, then A must be more important than C), and proportionality (e.g., if A is moderately more important than B and B is moderately more important than C, then A must be extremely more important than C). A matrix with CR ≤ 0.10 implies accepting up to 10% of the inconsistency that would have been obtained by chance. If the ratio is much higher than 0.1, the judgments are unreliable because they are too close to randomness (Saaty, 1990, 2014) (see supplementary material for details on consistency analysis).

Based on the hierarchical scheme proposed, the stakeholders made three comparisons (Figure 2). The first one took place during the second workshop, after we presented the results of the ecological indicators diagnosis. Each of the 12 participants compared the 5 ecological criteria with each other using the Saaty scale. Based on the individual preferences a consensus matrix comparison was agreed in a plenary session. This allowed us to calculate an individual weighting vector (anonymous) that summarizes the relative importance that each stakeholder assigned to the ecological criteria and a consensus weighting vector. We also calculated the consistency of each weighting. The second comparison was carried out in the third workshop, after we presented the results of the socioeconomic indicators diagnosis. Each of the participants compared the 5 socioeconomic criteria with each other using the Saaty scale. In this instance, due to the stakeholders' own dynamics during the workshop, we did not have the individual weightings, but they only registered the consensus weighting of the socioeconomic indicators as agreed in the plenary session. Finally, the relative importance of the ecological criteria with respect to the socioeconomic criteria was determined in plenary session and by consensus. Because at this hierarchical level there is only one pair of elements to compare, we asked them to directly assign a relative importance value. They had to distribute the 100% of the relative importance between the ecological and socio-economic criteria, ecological weighting (W_E) and socio-economic weighting (W_S), respectively.

2.2.3 Conservation value estimation and mapping

The area was divided into 1,217 cells of 5 × 5 km (Figure 3). Each of these cells represents the entity to which a conservation value will be assigned. The size of the cell was defined based on two criteria: 1) at this resolution (2,500 ha) basic attributes of the landscape (represented elements, configuration and structure) can be characterized (Baldi et al., 2006; Baldi and Paruelo, 2008), and 2) such grain is in between the resolution of coarser (e.g., faunal diversity, human population) and finer (e.g. remaining patches of grassland, supporting and regulating ecosystem services supply) available information. As some of the criteria (e.g., supporting and regulating ecosystem services supply, grasslands carrying capacity, functional diversity) were quantified from such spectral data derived from the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor on board the Terra satellite (Earth Observation System - NASA), the cells of the grid were adjusted to the pixels of the satellite images.

The GCV was determined by integrating the territorial diagnosis of ecological and socioeconomic indicators at the landscape level (5 × 5 km cells), with the weightings carried out by the stakeholders. To incorporate the diagnostic value of the indicators, stakeholders agreed on how each would contribute to conservation value. For 9 of the 10 indicators, a higher diagnostic value corresponded to a higher conservation value (e.g., Faunal diversity, presence of protected areas, carrying capacity, etc.). On the other hand, for the field size criterion, they agreed that higher median area of cadastral parcels would result in a lower conservation value. This was contemplated by performing an inverse scaling for this indicator (Equation 1). First, we determined: 1) the Ecological Value (EV) in each cell (Equation 2), which integrates the diagnostic value of the ecological indicators with the weighting of the ecological criteria by the stakeholders (12 individual weighting vectors and 1 consensus weighting vector) and 2) the Socioeconomic Value (SV) in each cell (Equation 3), which integrates the diagnostic value of the socioeconomic indicators with the weighting carried out in the group consensus. Finally, both values (EV and SV) were integrated together with their weighting (agreed upon in plenary) to obtain the Grasslands' Conservation Value (GCV) (Equation 4). The three values corresponding to group consensus (EV, SV, and GCV) and the 12 individual EV were mapped.

The EV of each cell (n = 1,217) was determined through the following equation:

$$EV_{i_1^{1217}} = \sum\nolimits_{j=1}^{5} EC_{ji} * W_{ECj} \tag{2}$$

Where, EVi corresponds to the Ecological Value of the cell i, j represents the ecological criteria, EC_{ji} represents the scaled diagnostic value of the indicator describing ecological criterion j for cell i obtained in the territorial diagnosis and W_{EC} represents the weighting of criterion j defined in the weighting vector of the ecological criteria.

The SV of each cell (n = 1,217) was determined through the following equation:

$$SV_{i_1^{1217}} = \sum\nolimits_{k=1}^{5} SC_{ki} * W_{SCk} \tag{3}$$

Where, SV corresponds to the Socioeconomic Value of the cell i, k represents the ecological criteria, SC represents the scaled diagnostic value of the indicator describing socioeconomic criterion k for cell i obtained in the territorial diagnosis and W_{SC} represents the weighting of criterion k defined in the weighting vector of the socioeconomic criteria.

Finally, the conservation value was determined by the weighted sum of EV and SV by their weights (higher hierarchical level) through the following equation:

$$GCV_{i_1^{1217}} = EV_i * W_E + SV_i * W_S \tag{4}$$

Where, GCV_i corresponds to the Grasslands' Conservation Value of cell i, W_E represents the ecological value of cell i, W_E its weighting value (upper level of the hierarchical scheme), SV corresponds to the socioeconomic value of cell i and W_s its weighting value (upper level of the hierarchical scheme).

2.3 Data analysis and synthesis

The degree of agreement among stakeholders was assessed through two complementary analyses. First, the degree of agreement in both the assessment of the criteria and the mappings was evaluated through correlation analysis (Pearson correlation coefficient, Sokal and Rohlf, 2009), and both analyses were compared to assess the extent to which dissent in the weightings translated into dissent in the maps. Second, from the 12 EV mappings, the Coefficient of Variation (EV_{CV}) was calculated in each of the cells and a map of the degree of agreement in the EV as a complement of the EV_{CV} ($1—EV_{CV}$) was obtained to identify spatially explicit consensus and disagreement.

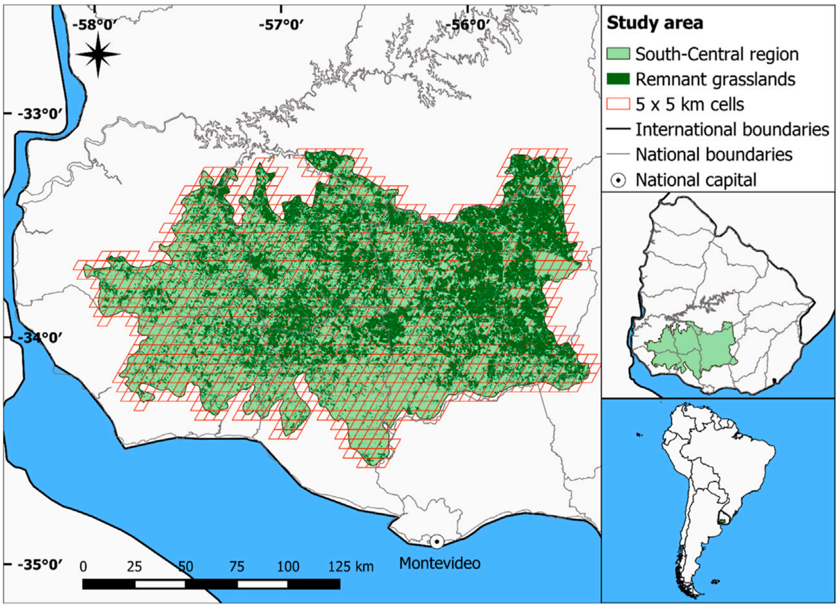


FIGURE 3
Study area. The conservation value has been determined for each cell of 5 x 5 km.

3 Results

3.1 Ecological value weightings and mapping

The ecological criteria most highly valued according to the group consensus weighting vector were, in decreasing order of importance, the proportion of grasslands (W_{EC4} = 0.55) and the level of supply of supporting and regulating ecosystem services (W_{EC5} = 0.23), followed by faunal biodiversity (W_{EC2} = 0.10), protected areas (W_{EC1} = 0.08) and finally functional diversity (W_{EC3} = 0.04) (Figure 4). The criteria comparison matrix, from which this weighting vector was derived, was consistent (CR = 0.10). As for the individual weights the most highly valued criteria were also the proportion of grasslands and the level of ecosystem services provided by the grasslands and were, in turn, those with the most variable weights among participants (W_{EC4}: mean = 0.44 and SD = 0.19; W_{EC5}: mean 0.26 and SD = 0.12) (Figure 4). Of the 12 individual comparison matrices, 6 were consistent (CR≤0.10 for participants 2, 5, 7, 9, 10, and 12); while of the remaining 6, 3 presented values close to the suggested threshold (CR = 0.17 for participant 1, CR = 0.11 for participant 6 and CR = 0.12 for participant 11) and the other 3 presented higher values (CR = 0.26 for participant 3, CR = 0.27 for participant 4 and CR = 0.41 for participant 8). The individual weighting vectors and their CR are reported in the supplementary material (Supplementary Table S5).

A total of 73% of the correlations between the individual priority vectors were positive, of which 75% presented correlation coefficients greater than 0.58 and 50% greater than 0.9 (Figure 5). In contrast, 27% of the comparisons presented negative correlation coefficients, of which 50% presented values lower than −0.58 (Figure 5). Higher positive correlation coefficients indicate that the criteria weighting ranking between two stakeholders is similar. More negative coefficients indicate opposite weighting rankings between two stakeholders, while those close to 0 represent different rankings. In this sense, stakeholders P6 and P8 presented negative correlation values with the majority of stakeholders, indicating the lowest degree of agreement (Figure 5). The degree of correlation between each priority vector and the consensus vector was greater than 0.92 for 8 of the 12 stakeholders, showing a high degree of similarity between their rankings and the one resulting from the group consensus (Figure 5). Two of the remaining stakeholders presented positive but lower values (P5 = 0.64 and P7 = 0.44) and the other two negative values (P6 = -0.19 and P8 = -0.63).

Regarding the degree of spatial agreement, the correlations between the 12 individual maps and the consensus map was higher or equal than 0.92 for 10 of the 12 stakeholders and for the remaining two it presented values of 0.61 (P6) and 0.66 (P8) (Figure 5). In all cases, the degree of agreement in the maps was higher than in the individual weigthings of criteria, even for the two stakeholders with a low degree of agreement in the individual weigthings of criteria. The dissent of these stakeholders in the weighting of criteria was not reflected in a dissent in the spatial

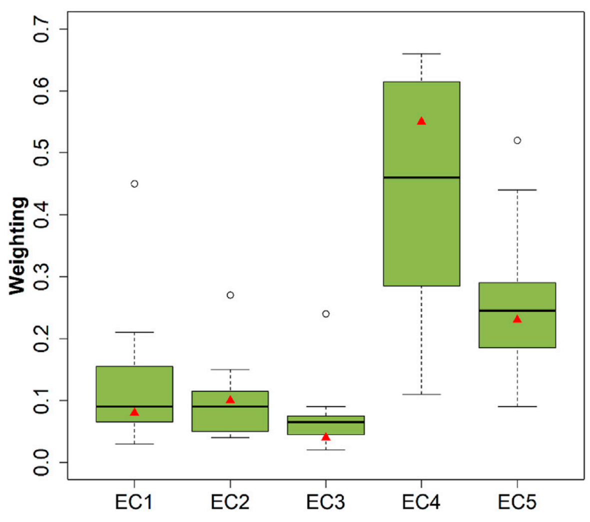


FIGURE 4
Distribution of the weighting values of the 12 individual stakeholders for each of the ecological criteria (EC1: Protected areas, EC2: Faunal diversity, EC 3: Functional diversity, EC4: Remaining grassland area, and EC5: Supporting and regulating ecosystem services supply). In each box, the horizontal black line represents the median, the extremes the quartiles (q1 and q3), the whiskers correspond to 1.5 of the interquartile range and the empty points are outliers. The red triangles represent the weights of the consensus vector.

ecological value. In turn, the cells with the lowest EV in the consensus map (Figure 6A), mostly coincide with those cells with the lowest degree of agreement in EV (Figure 6B).

3.2 Socioeconomic value weighting and grasslands conservation value mapping

The socioeconomic criteria most highly valued according to the group consensus weighting vector were, in decreasing order of importance, grasslands carrying capacity (W_{SC3} = 0.51) and grasslands on family farms (W_{SC2} = 0.25), followed by population (W_{EC5} = 0.12), farm size (W_{EC1} = 0.08) and finally infrastructure (W_{EC4} = 0.04). The criteria comparison matrix from which this weighting vector was derived was consistent (CR = 0.03). These results combined with the diagnosis of socioeconomic criteria determined the consensus mapping of socioeconomic value (SV, Figure 7B). The weighting of ecological criteria (W_E) to socioeconomic criteria (W_S), as determined by group consensus (top level of the hierarchical scheme, Figure 2), was 0.7 and 0.3, respectively. The consensus EV and SV maps weighted by these values determined the GCV map (Figure 7). The consensus EV ranged from 0.07 to 0.84 and the most frequent values were low (21.7% of the area had values between 0.1 and 0.2) (Figures 7A,D). The consensus SV varied between 0.002 and 0.65 and was more homogeneous than the EV, with 73% of the values between 0.3 and 0.5 (Figures 7B,E). The consensus GCV varied between 0.06 and 0.71 and the spatial pattern was similar to that of the EV, but with a higher frequency of average values, since 24.8% of the area had conservation values between 0.4 and 0.5 (Figures 7C,F).

4 Discussion

Participatory evaluation and decision-making processes face the challenge of incorporating all opinions considering the power relations established among stakeholders (Felipe-Lucia et al., 2015). In this article we presented the development and implementation of a method to quantify the conservation value of natural grasslands based on objective criteria and incorporating the participation of the stakeholders involved. The methodology allowed the incorporation of different perceptions not only in the definition of conservation criteria but also in their prioritization, in a transparent and auditable process. It also made it possible to evaluate the degree of agreement among participants both in the prioritization of criteria and in the grasslands' conservation value spatial variation.

An *a priori* and inclusive definition of the criteria to be considered and a critical evaluation of the quality of the data was essential to accommodate all views and interests. The inclusion or exclusion of a criterion in the construction of the conservation value was based on the one hand, on the perception and justification of its importance by the technical team and, at least, one of the stakeholders. On the other hand, the quality of the data was particularly considered. In this sense, spatially explicit data, based on documented sources and with access to metadata were privileged. The scale (extension and resolution) of the information was a key aspect in selecting the data. In this sense, only information that was larger than the area of study was included. Although we tried to include data with a more detailed resolution than that of the defined cells (2,500 ha) to carry out aggregation processes, this was not always possible. In the case of two criteria considered particularly important by some stakeholders (faunal diversity and population density) the basic information was at a coarser resolution. In these cases, we had to downscale the grain of the original information layers. To each cell we assigned the value of the object containing it or an area-weighted average in those cases where the cell overlapped with more than one unit. The lack of spatially explicit information or the availability of information with limited spatial detail highlights the need for the science and technology system to generate more detailed information for the criteria that are important to stakeholders.

The criteria selected to represent the biophysical dimension of the socio-ecosystems sought to cover, at the landscape level, the three dimensions of biodiversity proposed by (Noss, 1990).

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	C
P1	1	0.98	0.97	0.96	0.96	0.66	0.97	0.72	0.95	1.00	0.99	0.97	0.99
P2	0.95	1	1.00	0.93	0.93	0.55	0.90	0.61	0.98	0.99	1.00	0.99	1.00
P3	0.95	0.99	1	0.90	0.94	0.50	0.89	0.56	0.97	0.98	1.00	0.98	0.99
P4	0.93	0.91	0.89	1	0.87	0.82	0.93	0.83	0.94	0.95	0.94	0.95	0.95
P5	0.80	0.59	0.61	0.62	1	0.54	0.97	0.62	0.85	0.96	0.95	0.88	0.94
P6	-0.07	-0.24	-0.26	0.17	0.12	1	0.71	0.94	0.60	0.61	0.57	0.60	0.61
P7	0.64	0.38	0.38	0.48	0.95	0.28	1	0.78	0.84	0.95	0.92	0.87	0.92
P8	-0.74	-0.59	-0.60	-0.82	-0.72	-0.58	-0.66	1	0.64	0.68	0.63	0.64	0.66
P9	0.83	0.96	0.95	0.85	0.35	-0.30	0.11	-0.47	1	0.96	0.97	1.00	0.98
P10	0.98	0.97	0.95	0.90	0.71	-0.21	0.55	-0.60	0.87	1	0.99	0.97	1.00
P11	0.97	0.99	1.00	0.91	0.66	-0.18	0.45	-0.67	0.93	0.95	1	0.99	1.00
P12	0.90	0.98	0.98	0.91	0.47	-0.20	0.24	-0.59	0.99	0.91	0.97	1	0.99
C	0.97	1.00	0.99	0.93	0.64	-0.19	0.44	-0.63	0.94	0.98	0.99	0.98	1

Pearson correlation coefficient (r) up to										
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8	-0.9	-1

FIGURE 5
Below the diagonal: correlations between the weighting vectors resulting from comparing the ecological criteria among the 12 participants (P1 to P12) and the group consensus (C); values correspond to Pearson's correlation coefficient (white values indicate significant correlations, *p* value < 0.05). Above the diagonal: correlations between the Ecological Value (EV) maps of the 12 participants (P1 to P12) and the group consensus (C); values correspond to Pearson's correlation coefficient (white values indicate significant correlations, p value< 0.001).

Thus, aspects related to composition (EC2: potential species richness), structure (EC4: proportion of remaining grassland area) and functioning (EC3: diversity of ecosystem functional types) were included. Along with the biophysical aspects, two aspects related to the interaction between the biophysical and human dimensions were considered (Pacheco-Romero et al., 2020): the presence of protected areas and the change in the supply of regulating and support Ecosystem Services. The criteria associated with the human dimension partially captures the aspects pointed out by Pacheco-Romero et al. (2020). The influence of these criteria in defining conservation value was more controversial than in the case of biophysical aspects. In fact, for some of the criteria the participants disagreed not only on the weight but also on the direction of the influence (positive or negative) on the contribution to the conservation value of grasslands. These disagreements in the direction of influence of the indicators promote major changes in weighting. For example, if a certain stakeholder considered that infrastructure (SC4) was a particularly important criterion and in turn that those areas with a lower degree of infrastructure (SC4) should be those with a higher conservation value, when an inverse (positive) direction was agreed upon for this indicator, the weighting assigned to it was naturally reduced.

Although in study case presented, consensus weights were achieved in the absence of conflict, we consider that there are risks associated with reducing the opinions of multiple stakeholders in a single weighting. There is no consensus in the literature on how to reduce variability in the weights; and the commonly used reductions (some measure of central tendency such as average, median or mode), imply not only that information is lost but also that stakeholders whose weights are very different from the agreed weighting may no longer wish to participate in the process (Proctor and Drechsler, 2006). In this sense, we consider that the most valuable aspect of the method we presented is the possibility of assessing the degree of agreement among stakeholders both in the perception of the criteria (Figure 4, Figure 5) and in the spatial variation of the conservation value (in this case, the ecological value, Figure 6B). Moreover, these aspects were documented and are available to be consulted and discussed in an iterative process. Due to the particular characteristics and dynamics of the MGCN, we did not have the individual priority vectors for the socioeconomic criteria and therefore have not been able to generate individual maps of socioeconomic value (or conservation value), which would be very important to be able to document the degree of agreement on socioeconomic value and its impact on the final GCV. Where and why to conserve grasslands in South-Central region of Uruguay, was associated, according to the stakeholders of the MGCN, mainly, to two criteria. The GCV map resembles the distribution of remnant grasslands (Figure 3, Figure 7C). This is because among the ecological criteria, the area occupied by remanent grasslands was the most important according to group consensus (W_{EC4} = 0.55, Figure 4). The second most weighted criterion by consensus was Grasslands' supporting and regulating ecosystem services supply (W_{EC5} = 0.23, Figure 4), which takes positive values where there were grasslands and zero where there were no grasslands. At the same time, the weighting of the ecological criteria was higher than that of the socioeconomic criteria (W_E = 0.7). This implies that those landscapes with few remnant grasslands would not have conservation priority. In this sense, stakeholders raised the possibility of replicating the methodology to answer a different question, which are the areas with the highest restoration priority? In such case a lower proportion of native grasslands and its connectivity would have a greater importance.

Though the stakeholders involved in the processes included the academia, conservation NGOs and ranchers' associations, the focus was on conservation issues. In temperate and sub-humid grasslands, the exclusion of grazing does not necessarily lead to grassland

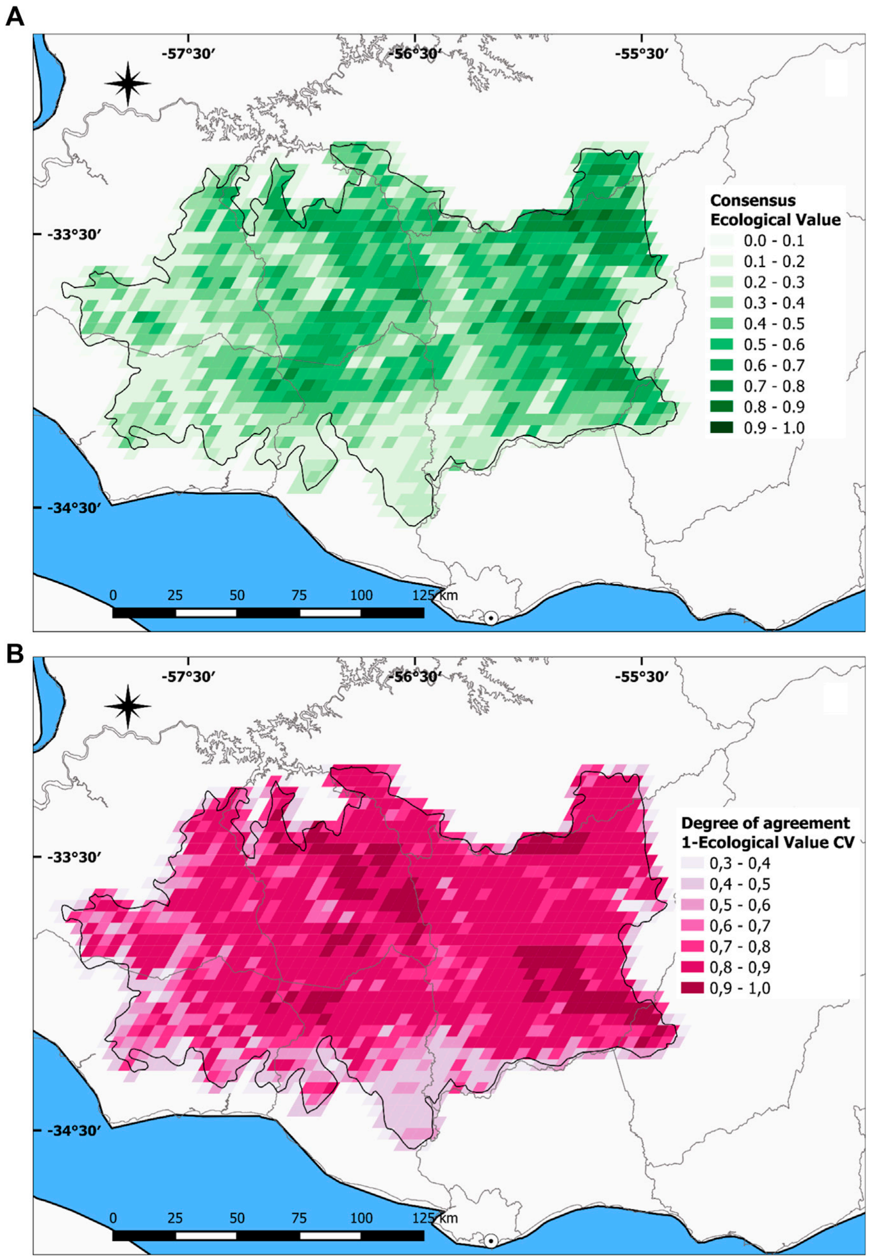


FIGURE 6
Consensus Ecological Value (EV) map **(A)**. Complement of the coefficient of variation of the 12 individual Ecological Value (EV) maps **(B)**.

conservation (Lunt et al., 2007; Cingolani et al., 2008; Gallego et al., 2020). In similar ecosystems, there is evidence that grazing prevents the accumulation of standing dead biomass, increasing light availability and consequently species richness and productivity (Rodríguez et al., 2003; Altesor et al., 2005; Overbeck et al., 2007). In turn, these compositional benefits are reflected in an increase in the supply of supporting and regulating ecosystem services (Gallego et al., 2020). Therefore, grasslands play a key role in supplying both provisioning (meat, wool, water supply) and regulating services (pollination, C sequestration, hydrologic regulation) (Yahdjian et al., 2015). In this sense, the participants weighted the criteria considering that a higher conservation value would imply a restriction for the transformation of grasslands to other land uses, but it would be compatible with cattle production. Thus, a high conservation value would not necessarily imply carrying out strict conservation activities. It is important to note that those stakeholders linked to activities that imply the replacement of grasslands (forestry industries, agricultural companies, for example) were not represented in the MGCN.

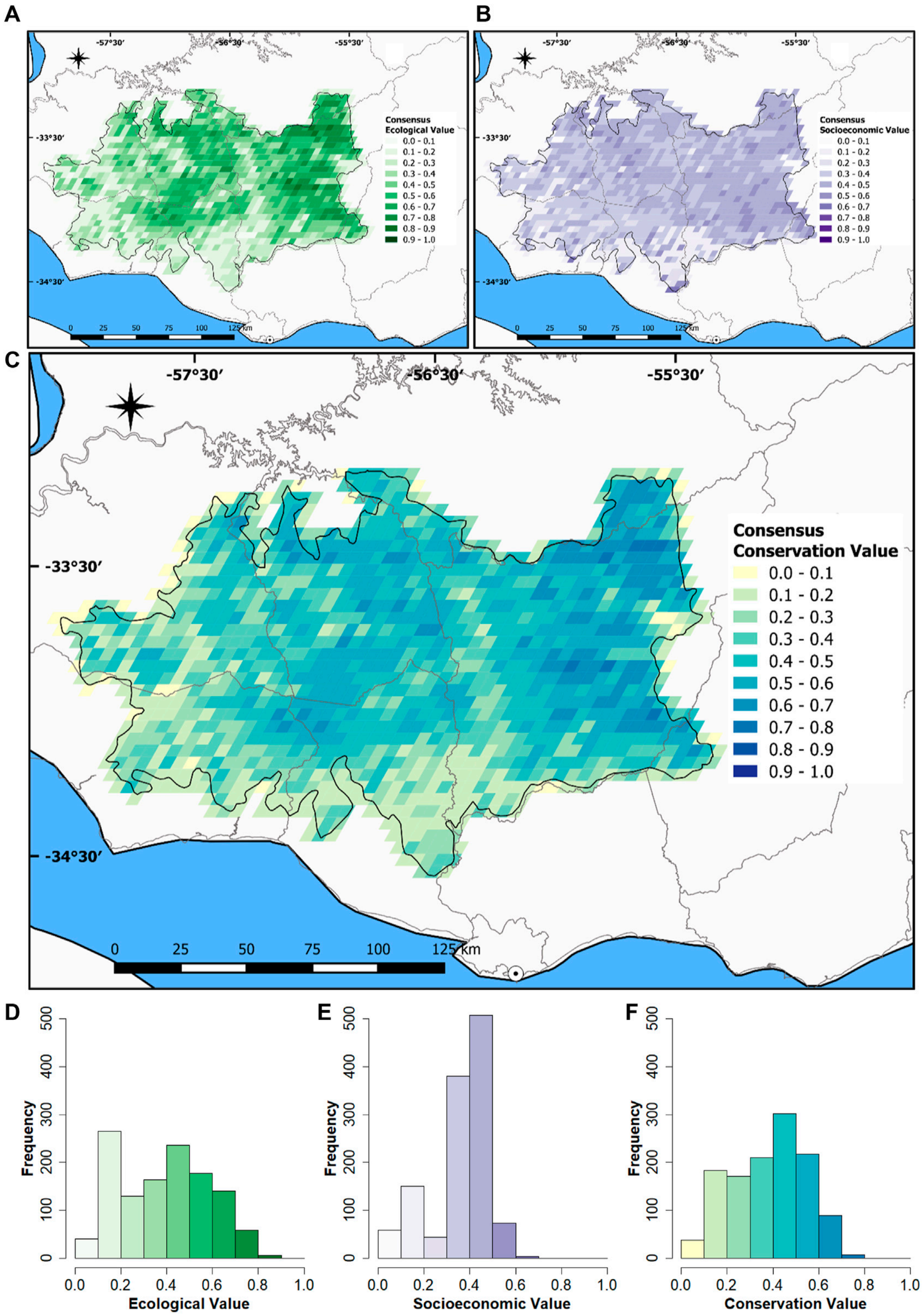


FIGURE 7
Consensus maps and histograms of Ecological Value (EV) **(A and D)**, Socio-economic Value (SV) **(B and E)** and Grasslands' Conservation Value (GCV) **(C and F)**.

The degree of agreement on the prioritization of conservation areas was greater than on the prioritization of criteria, even for participants with a low degree of agreement on the prioritization of criteria. This highlights an important emerging property of the process: the need to postpone the dispute of visions on particular criteria until the results are seen. Some stakeholders differed sharply in the weighting of the presence of protected areas in defining the conservation value. However, given the scarce presence of protected areas in the territory, marked differences in weighting had a low effect on the resulting conservation values. This underscores the importance of postponing discussions and consensus-building until a clear idea of the practical consequences (in this case the GCV assigned) is obtained. The effort to avoid conflicting positions on the importance of each of the criteria should be concentrated on those that have the greatest impact on the final result.

The territorial diagnosis process carried out set the basis to explore the consequences of different scenarios of conservation, transformation, and/or restoration of grasslands areas on critical dimension of the environmental footprint of human activities. Different scenarios of land-use and land-cover can be evaluated in terms of Ecosystem Services supply, natural habitat preservation, functional diversity, and economic output. Aside from its applications, the process was important in itself because it allows the stakeholders to have a clear idea of the dimensions involved in a zoning exercise and to identify gaps in data and conceptual models. Moreover, the methodology implemented not only make visible the range of visions on grassland conservation but also set a productive arena where to discuss alternatives. This could contribute to enrich the decision-making process in the implementation of future regulations restricting grasslands substitution, increasing the legitimacy of territorial planning processes.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

JP, LS, and AA contributed to conception and design of the study. LS and FG organized the database. JP, LS, AA, and FG carried out the field work (participative workshops). LS performed the statistical analysis and wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.820449/full#supplementary-material

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