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Incorporating Landscape Character in Cork Oak Forest Expansion in Sardinia: Constraint or Opportunity?

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Abstract: Cork oak (*Quercus suber*) is a declining woodland species across the island of Sardinia, despite its former economic importance for wine production and its significance for biodiversity. In particular, cork oak forests (COFs) on the island have seen a 29% decrease in the past 45 years. A spatial GIS model was developed to determine suitability for the expansion of cork oak forests on the island. The model uses a set of simple spatial decision rules based on principles of landscape ecology and expert opinion to assign a suitability score for pure cork oak forests to every land use parcel in Sardinia. These rules include the type of existing land parcel, its size, distance to existing cork oak forest, and the area of seminatural habitats in its neighborhood. This was coupled with a map of landscape types to assist with the development of policy for the protection of cork oak forests across Sardinia. The results show that there is an area of 116,785 ha potentially suitable for cork oak forest expansion in Sardinia, with the largest area of potential habitat on granitic mountains. There is a substantial overall agreement (Cohen's kappa = 0.61) between the suitability map produced and the historical reference map. The model is flexible and can be rerun to reflect changes in policy relating to agri-environmental targets for habitats and species.

Keywords: cork oak forest; GIS modelling; habitat dynamics; landscape character; Mediterranean; Natura 2000; Sardinia

1. Introduction

Ever increasing rates of global habitat destruction have attracted growing attention about the restoration of damaged habitats and the re-creation of lost habitats. Diverse spatial targeting approaches have been employed for the protection and creation/enhancement of specific habitats identified as important surrogate measures of biodiversity value [1,2]. Although these activities usually occur at the site level, the development of a strategy for habitat restoration needs to be applicable at the landscape scale. However, and despite the importance of a landscape context for ecological processes [3,4], most schemes for habitat creation, expansion, and restoration remain site-based. Furthermore, although some techniques do place emphasis on landscape processes, they tend to assume a uniform landscape without consideration of the physical and cultural diversity of landscapes (i.e., sensu landscape character) [5]. Firstly, this ignores the role of the spatial pattern of habitat patches within a landscape mosaic approach [6] for targeting potential sites for the creation of new habitats and the restoration of former habitats. Secondly, an aspect of spatial targeting lacking so far is the incorporation of landscape character as both a constraint and opportunity for habitat re-creation.

Cork oak sclerophyllous forests and sclerophyllous grazed forests in southern Europe have unique ecological roles since they host diverse animal and plant communities with high species richness [7–9] and many endangered species [10,11]. The economic role of these habitats arises from direct benefits derived from cork exploitation and/or parallel activities carried out under cork canopies (e.g., cropping, grazing), which are of considerable social importance as they are associated with traditional agrosilvopastoral practices in less favored areas of the European Union where other sources of income and employment are limited [12]. These traditional agrosilvopastoral systems represent a sustainable balance between human activities and natural resources [13]. Therefore, there is increasing recognition of the important contribution made by these agrosilvopastoral systems to the maintenance of valued seminatural habitats and landscapes in Europe [14].

Despite their important contribution to both biodiversity and "development" in Europe, concerns about the future of sclerophyllous grazed forests is growing. Agricultural intensification, extensification and abandonment in the case of sclerophyllous grazed forests [15] and ageing populations and poor regeneration in the case of sclerophyllous forests [16], have resulted in habitat loss and fragmentation [17] with a subsequent decrease of plant and animal diversity [13,18]. The island of Sardinia hosts one of the most extensive concentrations of cork oak habitats worldwide. Following the trend in other parts of Southern Europe, these habitats have deteriorated on the island in the last fifty years mainly through agricultural intensification, land abandonment, fire, and lower demand for cork [19–21].

Given the continuing concerns regarding the loss of species and their habitats [22], intensifying efforts for the identification of suitable sites for cork oak habitat expansion is a challenging and urgent task. The limited amount of time and resources available for such large scale operations calls for appropriate spatial planning. Spatial planning, i.e., identifying suitable sites for restoration based on the best available information, is a prerequisite for any concrete site action of habitat restoration or enhancement [23], whether the goal is habitat restoration per se or wildlife conservation [24] and ecosystem services provision [25]. The advances in spatial planning and targeting are increasingly suggested to inform nature conservation practice [26,27]. However, many of the techniques now being used are complex and daunting for practitioners [28,29]. In this paper, we have adopted a simple spatial overlay approach for two reasons: to develop a system that is easy to understand and can, therefore, be applied by local land managers, and secondly, to focus on an original aspect of this research, the incorporation of landscape character into the decision-making process.

Ecological restoration has a long history [30] and has gained an important role more recently in sustaining and enhancing the delivery of ecosystem services [31]. Historical reference has always been a key parameter to consider as a means to increase the chances of restoration success [32]. While the restoration techniques for cork oak forests have been dealt with extensively [13,33], landscape restoration or how to incorporate specific landscape-level processes in ecological restoration is less well understood [34]. Modelling efforts so far have placed emphasis on cork oak distribution [35,36], production, and optimization [37]. Moreover, efforts for cork oak habitat restoration/re-creation have been at the site level [13] with no regional scale examples incorporating a landscape context. The landscape context enables differences in both the natural and cultural patterns of differences in landscape character to be accounted for in any restoration strategy [5]. The aim of this paper, therefore, is to demonstrate and evaluate the role of spatial targeting in ecological restoration by employing cork oak forests (COF) in Sardinia as an example. The specific objectives are to: (a) develop a method for identifying suitable sites for cork oak forest expansion in Sardinia based on a set of ecological principles within a landscape context; (b) demonstrate the importance of the habitat's historical distribution in identifying sites for future habitat expansion.

2. Materials and Methods

2.1. The Study Area

In Sardinia, *Quercus suber* is mainly limited by precipitation and soils with nuclei of distribution from north to south in the areas of Gallura, Monti di Ala, Marghine and Goceano, Madrolisai, Iglesiente, Sulcis, and Sarrabus (Figure 1). In general, the species is neither drought- nor frost-tolerant. The distribution is confined by ca. 600 mm of annual rain and optimum temperature 16–19 °C, mainly siliceous substrates with good water availability, while only rarely can it be found on limestone [38]. Most extensive cork oak habitats are found in the range of 300–600 m, although the species can also be found above 600 m and in some places up to 1000 m. There are many diverse cork oak habitat types, including even and uneven mixed forests and wooded pastures where *Quercus suber* can be the dominant tree or as a mixture with, for example, *Quercus ilex* and *Olea europea.* According to the land use map for Sardinia [39] where cork oak forests (pure stands with cover >25%) were mapped separately, the area covered amounts to 84,700 ha, while according to [40], this figure was up to 119,500 ha in the past. Cork oak forests are identified as a distinct habitat type (9330) according to the European Habitats Directive and include west-Mediterranean silicicolous forests dominated by *Q. suber* with various subtypes usually in mixture with other species. In Sardinia, there are 24 Natura 2000 sites (c.f. Habitats Directive) where this habitat type can be found.

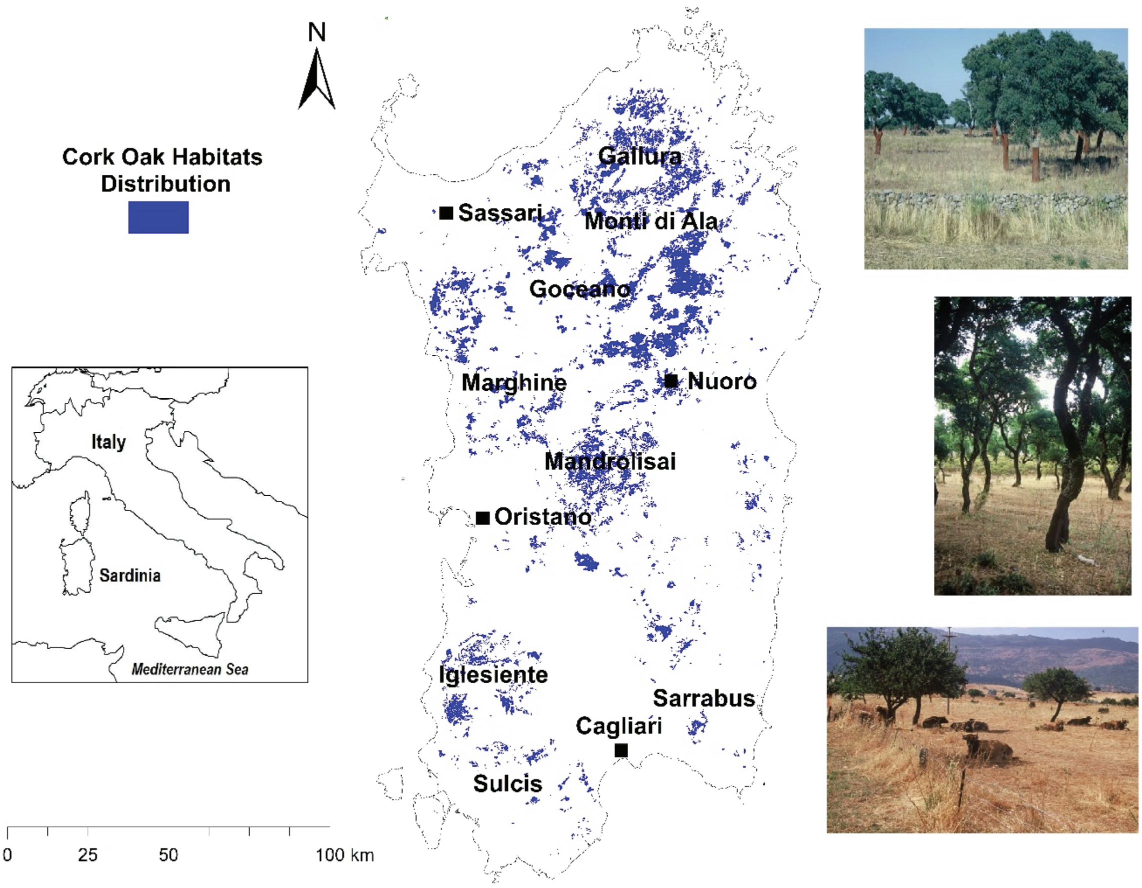

Figure 1. Historic distribution of cork oak habitats [40] and photos of typical habitat types with main place names cited in the text.

2.2. Spatial Model

We constructed a spatial decision model (rule-based overlay approach) to evaluate the suitability of land parcels for conversion to pure cork oak forest (referred to herein as the target habitat). We used the most recent land use map of Sardinia [39], which has a finer thematic resolution (level 4) compared to CORINE [41]. The cork oak forest formation is identified/mapped as a separate class in the land use map [39]. In addition, this land use map was the only one providing island-wide coverage. Pure cork oak forest is characterized on the land use map by a 25% canopy cover with limited or no understory, and where pastoral activities are limited or nonexistent [39].

A component-based spatial model was developed that uses four simple functions to assign a suitability score for the expansion of the target habitat, for every land parcel in the land use map. It includes the following functions: 'Existing', 'Area', 'Distance to', and 'Neighborhood' (Table 1), which were implemented within ArcGIS [42]. The suitability score for the target habitat is cumulative in the sense that the results from each function are summed on a land parcel basis. The rules/model components and their values were derived from a literature review of the most commonly employed landscape ecology related attributes [1,2,43]. This was followed by a number of consultative meetings and field visits with senior members of staff at the Stazione Sperimentale del Sughero (SSdS) in Sardinia (Tables 2 and 3), a research organization with collective experience in research and management of cork oak. Following earlier work by Griffiths et al. [43] and in order to avoid a complex scoring, every decision rule was assigned a categorical scoring system (A–E) to constrain the rank order to five categories (Table 2). The scores reflect current understanding, from the literature [1,2,43], of a spatially optimal pattern of habitats for enhanced biodiversity. Scoring was a derived from a consensus among research staff at the SSdS followed by field visits. The final score for each land parcel was calculated according to Equation (1):

$$\text{Total Score} = \text{Existing} + \text{Area} + \text{Distance To} + \text{Neighborhood} \quad (1)$$

Table 1. Spatial Functions used for the model.

Function	Description	Mapped Result
Existing	Returns a suitability score for the Active Land Parcel, based upon the existing land cover of that parcel. This tests whether the existing land cover type is appropriate for conversion into the Target Habitat. A score of zero indicates that the exiting land cover type is inappropriate for the creation of the Target Habitat. It may also be valid to convert one seminatural land cover type to another.	The mapped results for this spatial function demonstrate that the areas containing the most appropriate land cover types for conversion into the target habitat type are found east of Nuoro, east and west of Cagliari, in the area of Inglesiente and in the north around Goceano and Mandrolisai.
Area	Returns a suitability score for the Active Land Parcel, based upon the area of the parcel. This function allows targets to be set that will favor the creation of land cover type patches of a specific area (ha); for example, the creation of relatively larger land cover type patches with the potential for an increased complement of species.	Highly suitable areas, i.e., > 25 ha, seem to be widely distributed on the island with no specific pattern/concentration, i.e., areas which merit particular mention.
Distance To	Assigns a suitability code to the Active Land Parcel based upon the distance from the boundary of the parcel to a patch of land cover type of the target land cover type. Land Parcels that are close to seminatural land cover type of the same target land cover type will score higher, thus favoring the spatial concentration of land cover types of the same type.	The mapped results for this spatial function demonstrate that predictably highly suitable areas, i.e., < 20 m are located in the northern part of the island.
Neighborhood	Defines a fixed width buffer adjacent to the outside edge of the Active Land Parcel and measures the proportion of seminatural land cover within the buffer zone. This permits targets to be set that favor the creation of new land cover types in parcels that are surrounded by a high proportion of seminatural land cover types.	According to the mapped results for this rule, there are many areas with high suitability, i.e., > 50% cover of seminatural habitats within a 100 m buffer. Large parts of the island are still covered by seminatural habitats in the north east and south east, but also in the south west.
Calculate Scores	Calculates Suitability Scores for land cover type creation for each Active Land Parcel, based upon the Suitability Codes assigned by the individual functions and their numeric equivalents as shown in Table 2. This function then calculates a total score which is a simple sum of the results of the individual model functions.	Figure 2 shows the total suitability scores for conversion to cork oak forest for the study area. It is the sum of all model components according to Equation (1) (See text).
Intersect	Assigns a suitability code to the Active Land Parcel according to the landscape type that the parcel intersects with. This function permits the targeting of a land cover type to landscape types that are particularly suited to the creation of that land cover type.	The decision rules applied in the model so far assume an isotropic landscape, in which differences in physical and cultural patterns are unaccounted for. Therefore, we incorporated landscape character as an influence on the suitability of a land parcel to conversion to cork oak forest. The final result according to Equation (2) (See text) is given in Figure 3.

Table 2. Example parameters for the all the functions employed for cork oak forest expansion in Sardinia.

Functions	Parameter	Suitability Code *	Score
Existing Land cover type	Agriculture associated with cork oak	A	20
	Agroforestry areas, Deciduous forests, Maquis, Garigue, Transitional woodland/shrub	B	15
	Natural grassland, Plantations	C	10
	Vineyards, Olives, Complex cultivation systems, Land principally occupied by agriculture with significant areas of natural vegetation, Nonirrigated arable land, Permanently irrigated land, Coniferous forests, Riparian shrubs	D	5
	Construction sites, Bare rock, Sparsely vegetated areas, Urban, Industrial, Infrastructure, Sports parks, Beaches, Rivers, Water bodies	E	0
Area of Active Land Parcel	≥25 hectares	A	20
	5–25 hectares	B	15
	2–5 hectares	C	10
	<2 hectares	D	5
Distance to COF	≤20 m	A	20
	≤100 m	B	15
	≤250 m	C	10
	>250 m	E	0
Neighborhood (Percentage of Seminatural land cover type in 100 m Buffer)			
	>50%	A	20
	20%–50%	B	15
	5%–20%	C	10
	1%–5%	D	5
	≤1%	E	0
Landscape Type **	Granite Mountains	A	20
	Granite Hills	A	20
	Sedimentary Hills	B	15
	Volcanic Plateau and Hills	B	15
	Metamorphic Hills	C	10
	Alluvial Plains	C	10

* Generated following consultation meetings, field visits, and relevant literature (see text for details); **A**: Highly suitable, likely to result in a high quality habitat; **B**: Suitable and likely to result in a good quality habitat; **C:** Suitable and likely to result in a moderate quality habitat; **D**: Suitable, but only likely to result in a poor quality habitat; **E**: Unsuitable or lowest priority.
** [44]

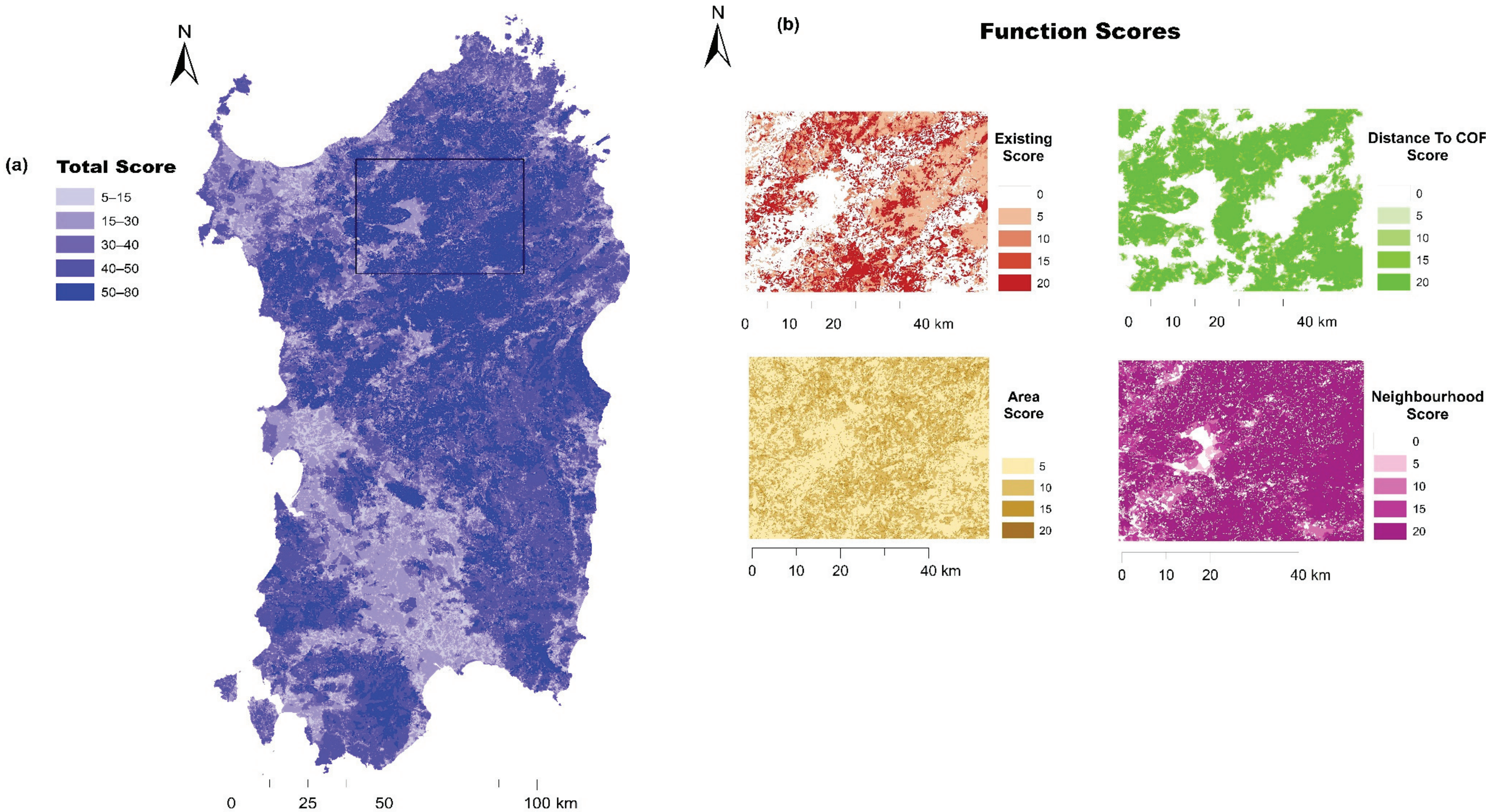

Figure 2. (**a**) Total suitability score and (**b**) individual function scores excerpt.

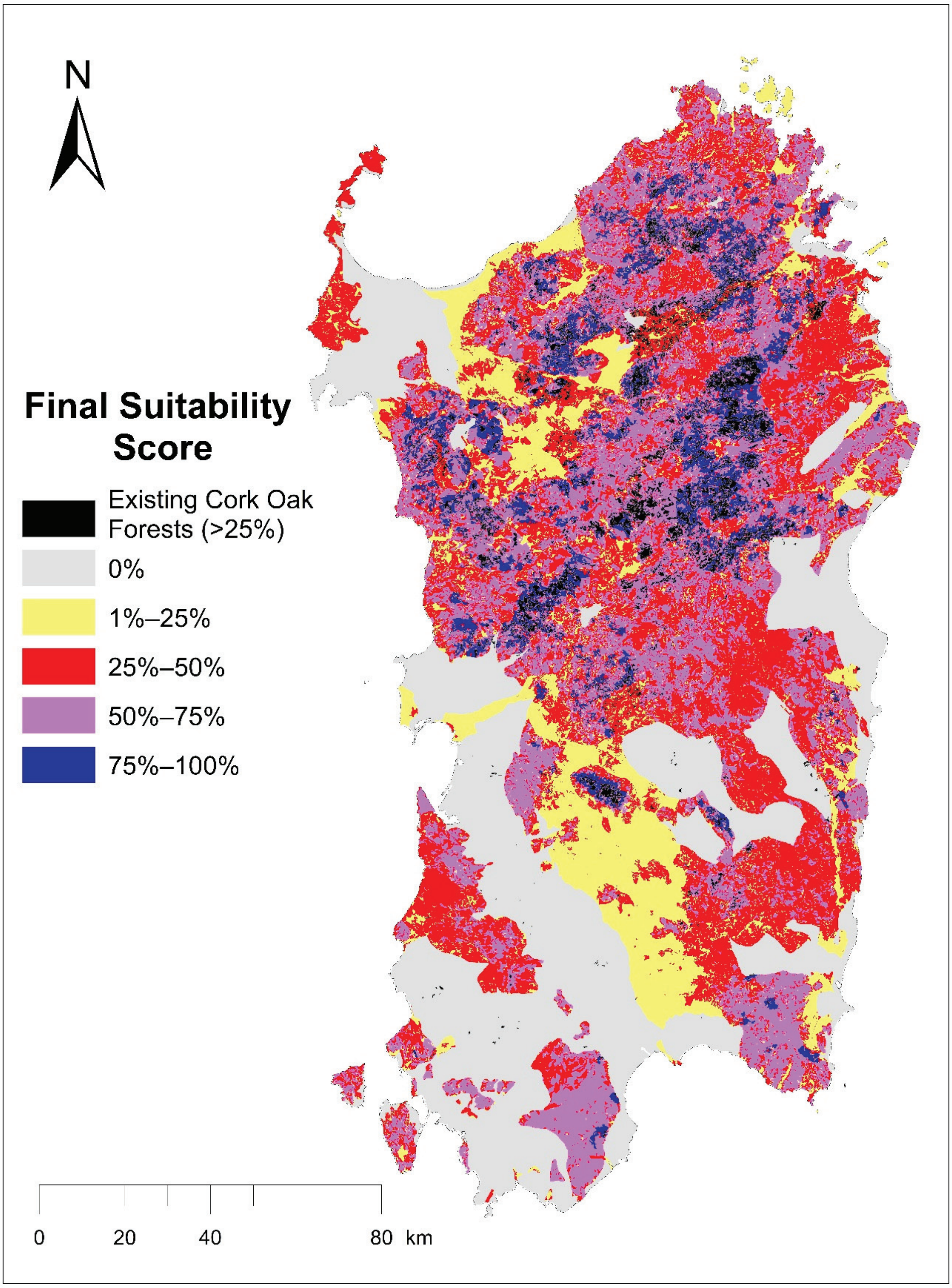

Figure 3. Final suitability map of cork oak forests' expansion potential.

Table 3. Agreement between suitability map and historical map.

Agreement Classes	Pixels	%Total
1. Included in both maps	520	52
2. Excluded in both maps	295	29.5
3. Included only in the suitability map.	90	9
4. Included only in the historical map	95	9.5
Overall Agreement = 81.5%	Cohen's Kappa = 0.61	

The maximum possible score for a land parcel is 80. Without any a priori reason for differential weighting between variables and mindful of the criticism that this aspect of spatial overlay modelling can often be subject to untested assumptions, all variables are equally weighted. We then incorporated a landscape component that "weights" the output from the spatial decision rules by differences in landscape type across the study area (see *Intersect Function*, Table 1). For this purpose, we employed the landscape typology developed by Ciancio et al. [44]. This is a spatial framework that comprises landscape units, i.e., relatively homogenous units of land that capture differences in the physical landscape based upon a set of attributes from a variety of digital map sources such as soil type, geology, landform, and vegetation. In order to decide on the suitability of each Landscape Type, we took into account the physiological requirements of the species from the literature [36,38] and existing and past mapped distribution [39,40]. Only six out of the twenty landscape types present in Sardinia [44] were deemed suitable (Table 2). These suitability levels were used to weight the final scores for every target land parcel by landscape type. The advantage of this method is that it identifies the landscapes that are particularly suited to the expansion of a habitat, and it preserves the relative suitability score for habitat expansion of parcels within each landscape type. The final suitability score was calculated as follows (Equations (2) and (3)):

$$Final\ Score = Total\ Score \times Landscape\ Type \quad (2)$$

$$Percentage\ Score = (Final\ Score \times 100)/Maximum\ Possible\ Score \quad (3)$$

The final suitability score is expressed as a percentage of the Maximum Possible Score that a land parcel may attain, with the higher percentages representing those land parcels that are considered most suitable for expansion of the target habitat.

2.3. Model Validation and Evaluation

We used the historic vegetation map [40] to validate our model results. Validation in this case aimed to determine whether the model results were within the species natural range as represented by cork oak forest formations mapped by Barneschi [40]. Ideally, we would have preferred to use the vegetation map as an input variable to the habitat expansion map. However, given that this is the only historic vegetation map covering the whole island, this would have excluded its use for validation. Since the land use map [39] employed as the main input for the spatial model and the vegetation map use different classification schemes, we used only the pure cork oak forests category for validation, which was clearly identified in both schemes Validation of COF distribution was by means of agreement between the habitat suitability map and the vegetation map [40] using Cohen's kappa [45] for 1000 random cells (Table 3). In addition, the results of the model were superimposed on Natura 2000 sites found on Sardinia, as well as the existing Landscape Types map for the island [44].

3. Results

In Figure 2, we can identify large areas for potential habitat expansion in the areas adjacent to the Orosei Gulf, north of Inglesias, and in the Sette Fratelli Mountains. These are away from existing large concentrations of the target habitat, but often close to remnant fragments. We can identify areas of potential habitat expansion that may serve as connectors between existing remnants of cork forests, for example, in the areas north-west of Nuoro and around Orgosolo and Mamoiada. However, some of these areas do not correspond with the historical distribution of the habitat according to [38,40]. Figure 3 presents the results of the model for potential CO Forests expansion when landscape types are considered. Areas with low score (25%–50%) indicate that expansion is not possible due to unfavorable conditions (according to the model) and cover 970,293 ha. Areas with low to moderate score (50%–75%) cover 679,152 ha and indicate that expansion is potentially feasible, and these cover 634,627 ha. Areas with moderate to high score (75%–100%) cover 116,875 ha and are those areas where future attempts at habitat expansion should be targeted. The inclusion in the model of landscape types provides a much better fit to the historical distribution of cork oak forest compared to the spatial model on its own. For example, the areas adjacent to the Gulf of Orosei mapped as potentially suitable in the unweighted spatial model (Figure 1) become nonsuitable. According to the model, the landscape type that has the largest area of potential habitat with moderate to high score 75%–100% is granitic mountains, followed by volcanic hills, and metamorphic mountains. The inclusion in the model of landscape types provides a much better fit to the historical distribution of cork oak forest compared to the spatial model on its own. For example, the areas adjacent to the Gulf of Orosei mapped as potentially suitable in the unweighted spatial model (Figure 1) become nonsuitable when the score is weighted by landscape type. There is a substantial overall agreement (Cohen's kappa = 0.61) between the suitability and the historical reference map (Table 3).

Most of the larger connected/contiguous areas (with a high score >75%) are in the North, which is expected, since this reflects the historical distribution of the species on the island [38]. In the south, large connected areas suitable for expansion of the target habitat are within designated Natura 2000 sites, while this is not the case in the north (Figure 4). According to the results, Monte Arcosu, Monte Arcuentu, and Sette Fratelli are listed among the Natura 2000 sites where significant habitat expansion could take place. In addition, there are areas where habitat expansion may provide links between existing nuclei of habitats; for example, the site at Catena de Goceano.

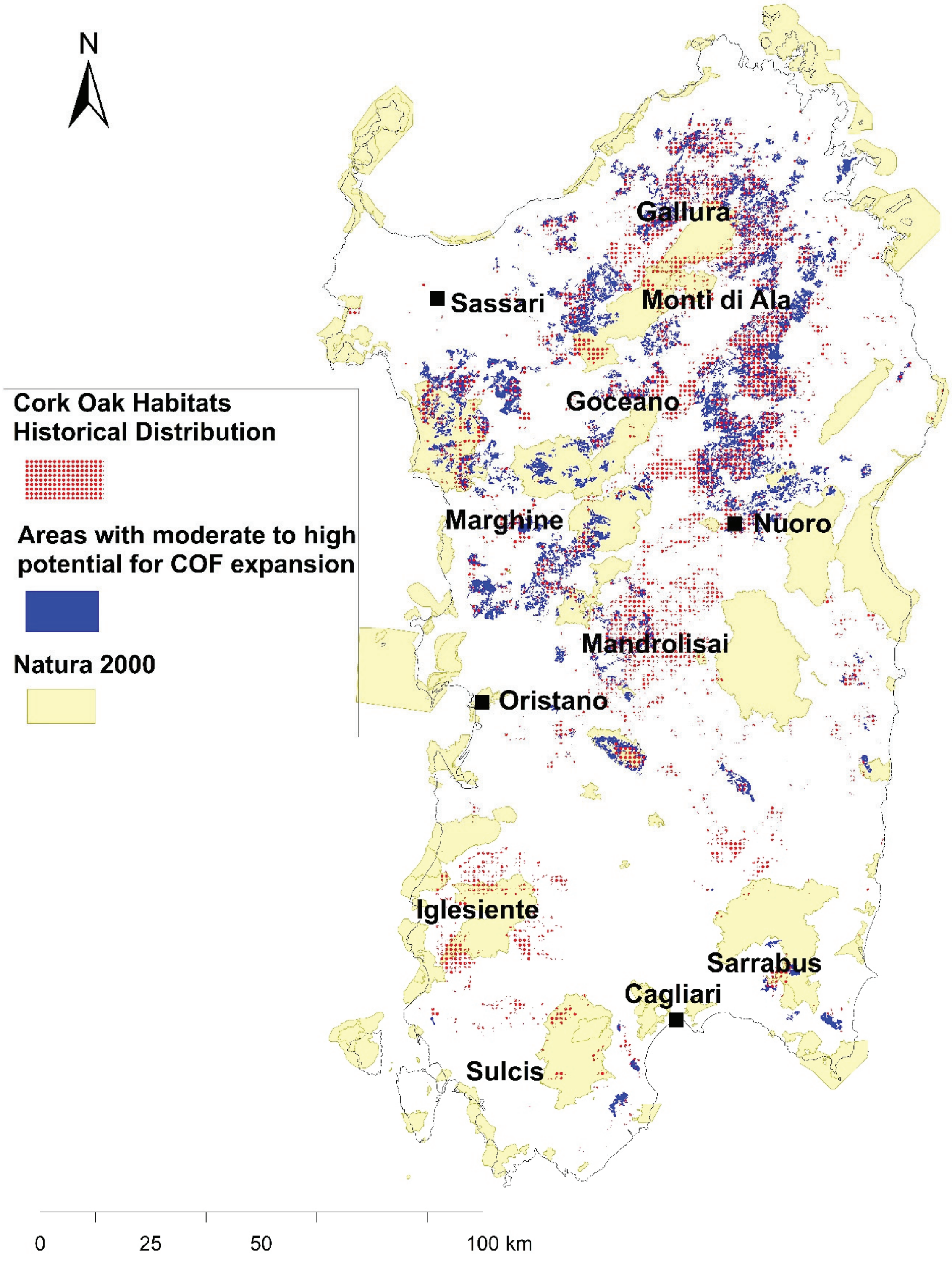

Figure 4. Potential expansion of cork oak forests compared to cork oak habitats historical distribution and Natura 2000 sites.

4. Discussion

4.1. Spatial Targeting and Model Functions

There is currently a plethora of applications of spatial targeting techniques in nature conservation, including reforestation [35], habitat creation [1], and habitat suitability [43,44], but also economic impact assessment [31]. In the case of cork oak, this type of landscape scale modelling is rare, but has been used in Spain to direct restoration efforts in burnt areas [35]. Landscape configuration has been considered when investigating cork oak recruitment [46]. The rule-based model developed in this study was successful in identifying parcels suitable for conversion to pure cork oak forests based on a set of agreed parameters and decision rules. In addition, model evaluation demonstrated the validity of the approach based on a comparison to historical patterns of COF distribution. However, there are several considerations that should be taken into account following its implementation.

GIS-based suitability modelling often employs landscape ecology principles to identify areas suitable for a given species or target habitat. Among the most commonly used model components, distance-related functions remain very popular [2,47], despite the fact that proximity alone does not equate with suitability. The function 'Distance' used in this paper may be sensitive to the presence of very small fragments of habitat. Ecologists have long used scoring systems and weighting for decision-making in nature conservation evaluation [48,49], often designed to reflect the opinion of managers and stakeholders [50] or based on complex algorithms [26]. The scoring system developed herein relied on ecological principles and was a result of a consultation exercise, an interactive process that included a series of discussions with experts knowledgeable about the ecology of the region and field visits. Similar scoring approaches have been employed in the past for spatial targeting [43,51]. These type of models do not consider vegetation dynamics; similarly, in this case, the model does not take into account that COFs may require active management to prevent the formation of a closed canopy holm oak forest [52].

Whilst the inclusion of landscape types proved to be an effective way to incorporate a landscape-scale dimension within the model, there are many alternative models for landscape-scale restoration. Depending on the purpose of restoration attempts these might include forest recovery indicators [53], reserve-selection framework at a spatial extent and resolution relevant to management [24], or multiscale approaches under different policy scenarios [25].

Landscape type in the study area had a noticeable effect on model output, thus demonstrating the potential importance of landscape character in determining the suitability of a land parcel for conversion to the target habitat type. A simple weighting system was developed to determine the favorability or otherwise for cork oak expansion within each landscape type, based on what is known about the species' realized niche. The present distribution of cork oak is restricted mainly to soils derived from siliceous rocks, including siliceous sandstone, granite, granodiorite, gneiss, schist, shale, slate, quartzite, basalt, and sand [13]. However, when it comes to habitat restoration/re-creation, from a strategic planning perspective, landscape types are an efficient way of integrating a range of factors (including cultural if mapped), which provides an overview of where to target effort.

Contrary to common practice in rule-based models for habitat restoration, which ignore differences in landscape character, our approach combines that character with landscape ecology to determine a land parcel's ecological suitability and desirability for habitat expansion, thus improving the likelihood for success in restoration efforts. Ideally, cultural patterns of land use, settlement, and agricultural system should also be incorporated into the landscape framework to improve the validity of the landscape as both a constraint and opportunity for habitat expansion modelling.

Simple overlay models are frequently criticized because inappropriate methods are often applied for standardizing suitability maps and with untested assumptions about the derivation of the weights assigned to the component maps [54]. The critique understandably focusses on the Boolean operations and weighted linear combination methods that may oversimplify the complexity of land use planning problems by focusing on the use of spatial data that can be represented in GIS rather than the optimal combination of facts and value judgments that are frequently impossible to represent in a GIS. However, in this case, we wanted to develop and demonstrate an approach that was easy to understand and apply by land managers across Sardinia with responsibility of land management and the protection/enhancement of the cork oak forests.

4.2. Validation

Results evaluation should be an integral part of any modelling exercise, although often this is not the case with spatial targeting, where validation is usually lacking. In this study, past mapped information [40] was used as a means for validating the results. Although the input land cover map used in modelling and the vegetation map used for validation were produced for different purposes and by different methodologies, this is a common problem in incorporating/integrating diverse sources of mapped information [55,56]. Inevitably there was not a one-to-one relationship between map classes, but this was resolved by examining the detailed reports produced for both maps [39,40] and then consulting local experts on the relationship between mapped classes. Since these maps were produced for different purposes, evaluation/validation took place between classes of the target habitat that had reasonable semantic confidence between maps to reduce ambiguity.

Historical information is an integral part of ecological restoration practice [32,57]. Although there have been concerns about its value [58], it is still incorporated in restoration frameworks [59] and cork oak habitats are no exception [59]. The value of historical cartography for providing essential information on the evolution of rural landscapes is discussed by Picuno et al. [60] and aligns with the rationale of the present study. In this case, the vegetation map [40] provided a reliable picture of cork oak distribution at the time, since it was derived from detailed regional field survey. The results confirmed that areas identified as suitable for cork oak forest habitat expansion are also those where the habitat was historically present (species/habitat natural range). Overall the model identified 116,875 ha suitable for COF expansion. This is significant area if we compare it to the actual area reported in [40] and [39] (119,498 ha and 83,970 ha, respectively).

The overall agreement of the expansion map resulting from the model and the historical reference map was very good (88%, see Table 3). However, there are occasions where the model failed to locate suitable areas with historical presence of forests even in the north of the island where historical distribution is concentrated (Figure 4). This is somewhat expected considering the numerous land use changes that have occurred in the last 40 years, altering the landscape configuration and creating new habitats, which, in their current form, are no longer suitable for expansion. In addition, some areas may have been overconstrained by the landscape typology intersection. The Italian national landscape typology [44] that was used in this study contains 20 landscape types for Sardinia. Although this might be adequate to describe the diversity of landscapes at the national level, a regionally developed typology with more detail would be preferable, particularly if this typology also includes cultural elements (e.g., settlement patterns and farming system) [61], which are inextricably linked with the presence of the species on the island [21]. On the other hand, there are areas identified as suitable that do not correspond with the historical presence of cork oak forests, such as the area north of Orosei (Figure 4). This is mainly due to a large afforestation program which took place during the 1990s, resulting in 10,000 hectares (an increase in COF surface of about 10%), above all located in Gallura. In model terms, this means that there are such changes in landscape configuration that allow neighboring areas to the recently planted ones to be considered as suitable for expansion.

4.3. Management and Policy Implications

From a planning and management perspective, what is feasible according to the model may not be desirable. There are areas which scored high, but at the same time support equally important habitats ecologically; therefore, their conversion might not be desirable. Examples include the sites of Sette Fratelli and Monte Arcuentu, which are designated Natura 2000 areas and already support healthy stands of cork oak. The same applies to other land uses outside protected areas, such as agroforestry areas or agricultural areas associated with cork oak; they were incorporated in the model, but restrictions or other priorities may cause potential conflicts with re-creation of the target habitat. Ownership, for example, may be another obstacle since the majority of COFs are privately owned, while there are no large areas on the island 'held in common' (i.e., lands allocated to community use) strictly regulated by local laws. These are decisions that the competent authorities (planning and forest departments) must take at the regional level.

Due to the socio-economic importance of cork oak habitats on the island, the habitat's persistence is not related to protected area designation. COFs in Italy (Annex I habitat type 9330) cover 10% of the Natura 2000 sites nationwide, but, according to the latest national report, its conservation status is unfavorable (all reporting parameters evaluated as such) [62]. In addition, there has been a 29% reduction in the habitat's extent in a forty-year period [39,40]. This is one of the reasons why the habitat has been included in the European Red List of habitats [22]. Targeted habitat expansion may increase areal extent within its historical range, enhance connectivity (as discussed herein and shown in Figure 4), and improve ecosystem function. This will lead to significant improvement of the habitat's conservation status in Sardinia and assist towards achieving national targets. In addition, the identification of suitable sites for expansion of cork oak forests in Sardinia may assist in the long term with evaluating the economic potential of the island in terms of cork production, and increase the opportunity for additional ecosystem services provision such as carbon sequestration [13], particularly if projections for land abandonment in southern Europe hold true [63]. Furthermore, it will give an insight to the consequences of past and future developments and help identify possible land use conflicts. Since habitat creation results in land use changes, any conflicts with other uses should be investigated (e.g., between habitat creation and agriculture) as dictated by other regional, national, or EU policies (for example, agrienvironment schemes) [64].

Spatial targeting should be part of a structured decision-making framework that includes the target audience/decision-makers, the goals and how these can be informed by the map, as well as any constraints of restoration activities [29,65]. Although the current attempt is not explicitly part of a formal existing framework, it has involved the competent authority on cork oak (SSdS) who had an interest in testing a methodology for spatial targeting given that they are often called to contribute to afforestation plans. As such, it can be part of the decision-making process for island-scale restoration plans.

5. Conclusions

This paper describes a method for identifying potential opportunities for habitat expansion at the landscape level. The approach is based on a rational, theoretically sound, and empirically tested set of spatial decision rules applied within the context of mapped differences in landscape character. Although landscape typologies have been increasingly employed in the Mediterranean [61,66,67], the validity of landscape character for ecological applications remains under-tested [68].

Landscape character can be seen both as an opportunity and a constraint. In spatial explicit rule-based models, landscape character can account for physical and, if necessary, cultural parameters in the modeling process; in this way, landscape character can act as a filter/sieve where no extra parameterization is needed. However, it can also be seen as a constraint since it might over- or under constrain the results where the resolution of landscape mapping is not sufficiently detailed to incorporate important attributes of a landscape's character. Nevertheless, the mapping framework underpinning any landscape typology, including scale and mapping components, can be improved, turning any constraint of the method to opportunity. Conservation priorities, particularly an assessment of the optimal area of habitat required, are dependent upon resources available within a policy context. Spatial targeting/planning may assist with making choices for ecosystem services delivery [18,31]. Strengthening of ecological networks is one of the important adaptation measures in the light of climate change [69–71]. Therefore, with appropriate parameterization adapted to local conditions and habitat of interest, the employed method can be applied to other terrestrial habitat types in the Mediterranean, including cork oak habitats.

Conservation assessment based on complex species distribution models, despite their potential, still suffer from several conceptual drawbacks when applied to setting conservation priorities [29,65]. Often the extent to which practitioners adopt scientific methods depends on the level of complexity and the tools involved. The approach developed herein, although involving GIS literacy/familiarity, does not require complex modelling, and was developed interactively with practitioners for practitioners. The rule-based model described in this paper uses a set of simple and easily understood ecological rules developed in consultation with local ecologists that are directly applicable to the local landscape. The advantage of the approach presented is that the decision rules can be adapted following stakeholders' consultation to accommodate the requirements of particular habitat expansion targets. This is a step towards bridging the research–implementation gap in conservation planning [28,72].

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References

1. Nikolakaki, P.A. GIS site-selection process for habitat creation: Estimating connectivity of habitat patches. *Landsc. Urban Plan.* **2004**, *68*, 77–94. [CrossRef]
2. Lee, J.T.; Bailey, N.; Thompson, S. Using Geographic Information Systems to identify and target sites for creation and restoration of native woodlands: A case study of the Chiltern Hills, UK. *J. Environ. Manage.* **2002**, *64*, 25–34. [CrossRef] [PubMed]
3. Turner, M. Landscape Ecology: What is the state of the Science? *Annu. Rev. Ecol. Evol. S* **2005**, *36*, 319–344. [CrossRef]
4. Dennis, P.; Hobbs, R.; Nassauer, J. *Issues and Perspectives in Landscape Ecology*; Wiens, J., Moss, M.R., Eds.; Cambridge University Press: Cambridge, UK, 2005; p. 412.
5. Warnock, S.; Griffiths, G. Landscape characterisation: The living landscapes approach in the UK. *Landsc. Res.* **2015**, *40*, 261–278. [CrossRef]
6. Neumann, J.L.; Griffiths, G.H.; Hoodless, A.; Holloway, G.J. The compositional and configurational heterogeneity of matrix habitats shape woodland carabid communities in wooded-agricultural landscapes. *Landsc. Ecol.* **2016**, *31*, 301–315. [CrossRef]
7. Grove, A.T.; Rackham, O. *The Nature of Mediterranean Europe. An Ecological History*; Yale University Press: New Haven, CT, USA, 2001; p. 384.
8. Leal, A.I.; Correia, R.A.; Granadeiro, J.P.; Palmeirim, J.M. Impact of cork extraction on birds: Relevance for conservation of Mediterranean biodiversity. *Biol. Conserv.* **2011**, *144*, 1655–1662. [CrossRef]
9. Ojeda, F.; Arroyo, J.; Maranon, T. Biodiversity components and conservation of Mediterranean heathlands in southern Spain. *Biol. Conserv.* **2000**, *72*, 61–72. [CrossRef]
10. Correia, E.; Freitas, H. *Drosophyllum lusitanicum*, an endangered West Mediterranean endemic carnivorous plant: Threats and its ability to control available resources. *Bot. J. Linn. Soc.* **2002**, *140*, 383–390. [CrossRef]
11. Suarez, S.; Balbontin, J.; Ferrer, M. Nesting habitat selection for booted eagles (*Hieraaetus pennatus*) and implications for management. *J. Appl. Ecol.* **2000**, *37*, 215–223. [CrossRef]
12. Commission of the European Communities. *Rural Developments. CAP 2000 Working Document*; European Commission DG VI: Brussels, Belgium, 1997; p. 74.
13. Aronson, J.; Pereira, J.S.; Pausas, J.G. (Eds.) *Cork Oak Woodlands on the Edge: Conservation, Adaptive Management, and Restoration*; Island Press: Washington, DC, USA, 2009; p. 315.
14. Pe'er, G.; Dicks, L.V.; Visconti, P.; Arlettaz, R.; Báldi, A.; Benton, T.G.; Collins, S.; Dieterich, M.; Gregory, R.D.; Hartig, F.; et al. EU agricultural reform fails on biodiversity. *Science* **2014**, *344*, 1090–1092.
15. Pinto-Correia, T. Future development in Portuguese rural areas: How to manage agricultural support for landscape conservation? *Landsc. Urban Plan.* **2000**, *50*, 95–106. [CrossRef]

16. Pausas, J.G.; Bladé, C.; Valdecantos, A.; Seva, J.P.; Fuentes, D.; Alloza, J.A.; Vilagrosa, A.; Bautista, S.; Cortina, J.; Vallejo, R. Pines and oaks in the restoration of Mediterranean landscapes in Spain: New perspectives for an old practice-a review. *Plant Ecol.* **2004**, *171*, 209–220. [CrossRef]
17. Costa, A.; Madeira, M.; Plieninger, T. Cork oak woodlands patchiness: A signature of imminent deforestation? *Appl. Geogr.* **2014**, *54*, 18–26. [CrossRef]
18. Bugalho, M.N.; Caldeira, M.C.; Pereira, J.S.; Aronson, J.; Pausas, J.G. Mediterranean cork oak savannas require human use to sustain biodiversity and ecosystem services. *Front. Ecol. Environ.* **2011**, *9*, 278–286. [CrossRef]
19. D'Angelo, M.; Enne, G.; Madraau, S.; Zucca, C. Land cover changes at landscape scale in Sardinia (Italy): The role of agricultural policies on land degradation. In *Land Degradation*; Conacher, A., Ed.; Springer: Dordrecht, The Netherlands, 2001; pp. 127–140.
20. Vacca, A. Effect of land use on forest floor and soil of a *Quercus suber* L. forest in Gallura (Sardinia, Italy). *Land Degrad. Dev.* **2000**, *11*, 167–180. [CrossRef]
21. Vogiatzakis, I.N.; Griffiths, G.H.; Bacchetta, G. Human impacts on *Quercus suber* woodland habitats in Sardinia: Past and present. *Botanika Chronika* **2005**, *18*, 277–284.
22. *European Commission European Red List of Habitats: Part 2*; Terrestrial and Freshwater Habitats Publications Office of the European Union: Luxembourg, 2016; p. 44.
23. Griffiths, G.H.; Vogiatzakis, I.N. Chapter 20: Habitat Approaches to Nature Conservation. In *Handbook of Biogeography*; Blumler, M., MacDonald, G., Millington, A., Schickhoff, U., Eds.; Sage Publications: New York, NY, USA, 2011; p. 624.
24. Thomson, J.R.; Moilanen, A.J.; Vesk, P.A.; Bennett, A.F.; Nally, R.M. Where and when to revegetate: A quantitative method for scheduling landscape reconstruction. *Ecol. Appl.* **2009**, *19*, 817–828. [CrossRef]
25. Vizzarri, M.; Sallustio, L.; Travaglini, D.; Bottalico, F.; Chirici, G.; Garfì, V.; Lafortezza, R.; La Mela Veca, D.S.; Lombardi, F.; Maetzke, F.; et al. The MIMOSE Approach to Support Sustainable Forest Management Planning at Regional Scale in Mediterranean Contexts. *Sustainability* **2017**, *9*, 316. [CrossRef]
26. Margules, C.; Sankar, S. (Eds.) *Systematic Conservation Planning*; Cambridge University Press: Cambridge, UK, 2007; p. 278.
27. Moilanen, A. Landscape zonation, benefit functions and target-based planning: Unifying reserve selection strategies. *Biol. Conserv.* **2007**, *134*, 571–579. [CrossRef]
28. Knight, A.T.; Cowling, R.M.; Rouget, M.; Balmford, A.; Lombard, A.T.; Campbell, B.M. Knowing but not doing: Selecting priority conservation areas and the research–implementation gap. *Conserv. Biol.* **2008**, *22*, 610–617. [CrossRef]
29. Villero, D.; Pla, M.; Camps, D.; Ruiz-Olmo, J.; Brotons, L. Integrating species distribution modelling into decision-making to inform conservation actions. *Biodivers. Conserv.* **2017**, *26*, 251–271. [CrossRef]
30. Margules, C.R.; Pressey, R.L. *Restoration ecology: A Synthetic Approach to Ecological Research*; Jordan, W.R., Gilpin, M.E., Aber, J.D., Eds.; Cambridge University Press: Cambridge, UK, 1990; p. 352.
31. Glenk, K.; Schaafsma, M.; Moxey, A.; Martin-Ortega, J.; Hanley, N. A framework for valuing spatially targeted peatland restoration. *Ecosyst. Serv.* **2014**, *9*, 20–33. [CrossRef]
32. Balaguer, L.; Escudero, A.; Martin-Duque, J.F.; Mola, I.; Aronson, J. The historical reference in restoration ecology: Re-defining a cornerstone concept. *Biol. Conserv.* **2014**, *176*, 12–20. [CrossRef]
33. Holl, K.D.; Crone, E.E.; Schultz, C.B. Landscape Restoration: Moving from generalities to methodologies. *BioScience* **2003**, *53*, 491–502. [CrossRef]
34. George, T.L.; Zack, S. Spatial and temporal considerations in restoring habitat for wildlife. *Restor. Ecol.* **2001**, *9*, 272–279. [CrossRef]
35. Hidalgo, P.J.; Marín, J.M.; Quijada, J.; Moreira, J.M. A spatial distribution model of cork oak (Quercus suber) in southwestern Spain: A suitable tool for reforestation. *For. Ecol. Manag.* **2008**, *255*, 25–34. [CrossRef]
36. Vessella, F.; Schirone, B. Predicting potential distribution of *Quercus suber* in Italy based on ecological niche models: Conservation insights and reforestation involvement. *For. Ecol. Manag.* **2013**, *304*, 150–161. [CrossRef]
37. Paulo, J.A.; Pereira, H.; Tomé, M. Analysis of variables influencing tree cork caliper in two consecutive cork extractions using cork growth index modelling. *Agroforest Syst.* **2017**, *91*, 221–237. [CrossRef]
38. Arrigoni, P.V. Fitoclimatologia della Sardegna. *Webbia* **1968**, *23*, 1–100. [CrossRef]

39. RAS (Regione Autonoma della Sardegna). *Carta Dell' Uso Del Suolo Scala 1:25 000. Note Illustrative*; RAS: Assesorato degli Enti Locali, Finanze ed Urbanistica: Cagliari, Italy, 2003.
40. Barneschi, L. *Carta Forestale della Sardegna. Stazione Sperimentale del Sughero*; Settore Forestale: Tempio Pausania, Italia, 1988.
41. Commission of the European Communities. *CORINE Biotopes: The Design, Compilation and Use of an Inventory of Sites of Major Importance for Nature Conservation in the European Community*; Commission of the European Communities: Luxembourg, 1991.
42. ESRI. *ArcMap, Version 10.1*; Environmental Systems Research Institute: Redlands, CA, USA, 2012.
43. Griffiths, G.H.; Vogiatzakis, I.N.; Porter, J.; Burrows, C. A landscape scale spatial model for semi-natural broadleaf woodland expansion in Wales, UK. *J. Nat. Conserv.* **2011**, *19*, 43–53. [CrossRef]
44. Ciancio, O.; Corona, P.; Marchetti, M.; Chirici, G.; Barbati, A.; Travaglini, D. *Carta Degli Aspetti Paesistici d'Italia. Relazione Tecnica Finale*; Università degli Studi di Firenze: Firenze, Italia, 2004.
45. Cohen, J. Weighted kappa: Nominal scale agreement provision for scaled disagreement or partial credit. *Psychol. Bull.* **1968**, *70*, 54. [CrossRef] [PubMed]
46. Store, R.; Kangas, J. Integrating spatial multi-criteria evaluation and expert knowledge for GIS-based habitat suitability modeling. *Landsc. Urban Plan.* **2001**, *55*, 79–93. [CrossRef]
47. Pons, J.; Pausas, J.G. Oak regeneration in heterogeneous landscapes: The case of fragmented Quercus suber forests in the eastern Iberian Peninsula. *For. Ecol. Manag.* **2006**, *231*, 196–204. [CrossRef]
48. Wilson, K.A.; Lulow, M.; Burger, J.; Fang, Y.C.; Andersen, C.; Olson, D.; O'Connell, M.; McBride, M.F. Optimal restoration: Accounting for space, time and uncertainty. *J. Appl. Ecol.* **2011**, *48*, 715–725. [CrossRef]
49. Tambosi, L.R.; Martensen, A.C.; Ribeiro, M.C.; Metzger, J.P. A framework to optimize biodiversity restoration efforts based on habitat amount and landscape connectivity. *Restor. Ecol.* **2014**, *22*, 169–177. [CrossRef]
50. Vogiatzakis, I.N.; Stirpe, M.T.; Rickebusch, S.; Metzger, M.; Xu, G.; Rounsevell, M.; Bommarco, R.; Potts, S.G. Rapid assessment of historic, future and current habitat quality for biodiversity around UK Natura 2000 sites. *Environ. Conserv.* **2015**, *42*, 31–40. [CrossRef]
51. Riedler, B.; Lang, S. A spatially explicit patch model of habitat quality, integrating spatio-structural indicators. *Ecol. Indic.* **2018**, *94*, 128–141. [CrossRef]
52. Dettori, S.; Filigheddu, M.R.; Deplano, G.; Molgora, J.E.; Ruiu, M.; Sedda, L. Employing a spatio-temporal contingency table for the analysis of cork oak cover change in the Sa Serra region of Sardinia. *Sci. Rep.* **2018**, *8*, 1–4. [CrossRef]
53. Altamirano, A.; Miranda, A.; Meli, P.; Dehennin, J.; Muys, B.; Prado, M.; Catalán, G.; Smith-Ramírez, C.; Bustamante-Sánchez, M.; Lisón, F.; et al. Spatial congruence among indicators of recovery completeness in a Mediterranean forest landscape: Implications for planning large-scale restoration. *Ecol. Indic.* **2019**, *102*, 752–759. [CrossRef]
54. Malczewski, J. On the use of weighted linear combination method in GIS: Common and best practice approaches. *Trans. GIS* **2000**, *4*, 5–22. [CrossRef]
55. Lengyel, S.; Kobler, A.; Kutnar, L.; Framstad, E.; Henry, P.Y.; Babij, V.; Gruber, B.; Schmeller, D.; Henle, K. A review and a framework for the integration of biodiversity monitoring at the habitat level. *Biodivers Conserv.* **2008**, *17*, 3341–3356. [CrossRef]
56. Tomaselli, V.; Dimopoulos, P.; Marangi, C.; Kallimanis, A.S.; Adamo, M.; Tarantino, C.; Panitsa, M.; Terzi, M.; Veronico, G.; Lovergine, F.; et al. Translating land cover/land use classifications to habitat taxonomies for landscape monitoring: A Mediterranean assessment. *Landsc. Ecol.* **2013**, *28*, 905–930. [CrossRef]
57. McDonald, T.; Jonson, J.; Dixon, K.W. National standards for the practice of ecological restoration in Australia. *Restor. Ecol.* **2016**, *24*, S4–S32. [CrossRef]
58. Millar, C.I.; Stephenson, N.L.; Stephens, S.L. Climate change and forests of the future: Managing in the face of uncertainty. *Ecol. Appl.* **2007**, *17*, 2145–2151. [CrossRef] [PubMed]
59. Plieninger, T.; Pulido, F.J.; Konold, W. Effects of land-use history on size structure of holm oak stands in Spanish dehesas: Implications for conservation and restoration. *Environ. Conserv.* **2003**, *30*, 61–70. [CrossRef]
60. Picuno, P.; Cillis, G.; Statuto, D. Investigating the time evolution of a rural landscape: How historical maps may provide environmental information when processed using a GIS. *Ecol. Eng.* **2019**, *139*, 105580. [CrossRef]
61. Vogiatzakis, I.N. Mediterranean experience and practice in Landscape Character Assessment. *Ecol. Mediterr.* **2011**, *37*, 17–31. [CrossRef]

62. Genovesi, P.; Angelini, P.; Bianchi, E.; Dupré, E.; Ercole, S.; Giacanelli, V.; Ronchi, F.; Stoch, F. *Specie e Habitat di Interesse Comunitario in Italia: Distribuzione, Stato di Conservazione e Trend*; ISPRA, Serie Rapporti, 194/2014; ISPRA: Roma, Italy, 2014.
63. Rounsewell, M.D.A.; Reginster, I.; Araújo, M.B.; Carter, T.R.; Dendoncker, N.; Ewert, F.; House, J.I.; Kankaanpa, S.; Leemans, R.; Metzger, M.J.; et al. A coherent set of future land use change scenarios for Europe. *Agric. Ecosyst. Environ.* **2006**, *114*, 57–68. [CrossRef]
64. Bryan, B.A.; King, D.; Ward, J.R. Modelling and mapping agricultural opportunity costs to guide landscape planning for natural resource management. *Ecol. Indic.* **2011**, *11*, 199–208. [CrossRef]
65. Guisan, A.; Tingley, R.; Baumgartner, J.B.; Naujokaitis-Lewis, I.; Sutcliffe, P.R.; Tulloch, A.I.; Regan, T.J.; Brotons, L.; McDonald-Madden, E.; Mantyka-Pringle, C.; et al. Predicting species distributions for conservation decisions. *Ecol. Lett.* **2013**, *16*, 1424–1435. [CrossRef]
66. Vogiatzakis, I.N.; Manolaki, P. Investigating the diversity and variability of Eastern Mediterranean Landscapes. *Land* **2017**, *6*, 71. [CrossRef]
67. Vogiatzakis, I.N.; Zomeni, M.; Mannion, A.M. Characterizing islandscapes: Conceptual and methodological challenges exemplified in the Mediterranean. *Land* **2017**, *6*, 14. [CrossRef]
68. Manolaki, P.; Zotos, S.; Vogiatzakis, I.N. An integrated ecological and cultural framework for landscape sensitivity assessment in Cyprus. *Land Use Policy* **2020**, *1*, 104336. [CrossRef]
69. Harrison, P.A.; Berry, P.M.; Butt, N.; New, M. Modelling climate change impacts on species' distributions at the European scale: Implications for conservation policy. *Environ. Sci. Policy* **2006**, *9*, 116–128. [CrossRef]
70. Hodgson, J.A.; Thomas, C.D.; Cinderby, S.; Cambridge, H.; Evans, P.; Hill, J.K. Habitat re-creation strategies for promoting adaptation of species to climate change. *Conserv. Lett.* **2011**, *4*, 289–297. [CrossRef]
71. Vos, C.C.; Berry, P.; Opdam, P.; Baveco, H.; Nijhof, B.; O'Hanley, J.; Bell, C.; Kuipers, H. Adapting landscapes to climate change: Examples of climate-proof ecosystem networks and priority adaptation zones. *J. Appl. Ecol.* **2008**, *45*, 1722–1731. [CrossRef]
72. Cook, C.N.; Mascia, M.B.; Schwartz, M.W.; Possingham, H.P.; Fuller, R.A. Achieving conservation science that bridges the knowledge–action boundary. *Conserv. Biol.* **2013**, *274*, 669–678. [CrossRef]