Chapter

Contributing to Healthy Landscapes by Sustainable Land Use Planning: A Vision for Restoring the Degraded Landscape of the Centre Region of Portugal

Selma B. Pena, Maria Luísa Franco and Manuela R. Magalhães

Abstract

The ecological-based methodologies are determinant to develop complete strategies in restoring the ecosystems at a landscape scale. Those methodologies start with comprehending ecological processes by mapping fundamental structures of the territory (water, soil, biodiversity), also called green infrastructures. The adequate land use planning and its forthcoming implementation will guarantee a multifunctional landscape, better ecosystem services provision, and a possibility of developing new economies. The intervention of Landscape Architecture at the landscape scale will also provide information about the place and the type of restoration actions to be implemented. The Centre Region was the most affected by rural fires from 2017, representing 15% of the total region area (416 thousand hectares). These events reflect the high importance of rethinking the territory with more suitable land uses, considering the concepts of sustainability, resilience, and ecological integrity. This work proposes a Landscape Transformation Plan for the Centre Region of Portugal, applying the FIRELAN model. The results show that about 35% of the Centre Region should have restoration action towards a more sustainable landscape.

Keywords: fire resilience, green infrastructure, ecosystem restoration, landscape transformation

1. Introduction

The first Portuguese Landscape Architect, Francisco Caldeira Cabral, reflected on how nature conservation should not be seen from a museology perspective, where Man is external to the object of protection. He defended that every person is an integral part of nature conservation by actively participating in protecting natural resources and constructing the landscape.

> *(…) a campaign of general mentalization began for the need as a condition of urban and rural life, to maintain in congruent form the essential elements of the*

> *natural landscape, conserving or even reconstituting its continuity and functionality. Thus became aware of maintaining the " continuum natural " and the " continuum cultural [1].*

Since our existence, humankind has established interactive and empirical relationships with the Landscape [2], searching for defensive systems at higher elevations and safeguarding the fertile valleys as food producers essential for survival. But the interaction between Man and the ecosystems is bidirectional, where an action of Man on a particular ecosystem will imply a reaction and an adaptation of the ecosystem [3].

Landscape and land-use planning are intended to plan human interventions that maintain or promote the landscape's dynamic stability. The stability of the landscape is associated with slow landscape evolutions (pedogenesis), while instability is characterized by rapid changes (morphogenesis) [4]. The balance between morphogenetic and pedogenetic processes is a natural process of the landscape, which can be intensified towards instability by an incorrect action in the territory. The planning of human intervention in the territory in harmony with ecological systems has resulted in preserving natural resources and nature conservation.

The understanding of the functioning of natural systems, or ecosystems, as a support for decision making [5] emerged after the foundation of ecology as a science, in the mid-nineteenth century, by Ernest Haeckel. The evolution of knowledge about the ecological processes in a given territory allowed the development of ecology-based landscape planning methodologies.

Following the Convention on Biological Diversity [6], one of the decisions taken at the fifth Conference of the Parties to the Convention on Biological Diversity [7] was that biodiversity conservation objectives could only be achieved through an ecological-based approach:

> *(...) a strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way. It is based on the application of appropriate scientific methodologies focused on levels of biological organization that encompasses the processes, functions and interactions among organisms and their environment. It recognizes that humans, with their cultural diversity, are an integral part of ecosystems [7].*

Ecological-based methodologies start from the knowledge and spatialization of natural processes that occur in a given territory [8]. With this approach, the most significant areas for ecosystem functioning are identified in the landscape, with various potentialities, and actions are planned without compromising the stability and balance of the landscape. This approach is related to the concept of ecological suitability to the various human activities that do not compromise the proper functioning of ecological processes [9].

The concept of ecological suitability was used in the United States of America and the United Kingdom, using the manual overlay of transparent supports, whose methodologies were refined throughout the 1960s [10]. Other landscape architects followed, such as the work done by Philip Lewis, in 1964, to classify all the environmental resources of the State of Wisconsin, with the purpose of delimiting the areas where building should not be done [11]. The concept of ecological suitability was also considered in McHarg's [12] and Steiner [13] methodologies with the study of environmental processes and cultural integration in the choice of the best use, according to the intrinsic characteristics of the systems. In Portugal, contemporary with McHarg's methodology, the Algarve Plan was completed by landscape architects A. Barreto, A. Castelo-Branco and A. Dentinho, with methodologies based on ecological suitability of the Landscape [11].

The adequate planning of the landscape, according to the ecological processes that occur in it, impacts not only the ecological balance but also on the economic and social balance. This type of intervention has the ability, in a cost–benefit analysis, to be the best way to prevent future costs arising from natural disasters (flood prevention, fire risk reduction, mass movement), maintain water quality, ensure greater agricultural productivity, and contribute to the enhancement of urban areas [14]. Of this last point, the study done [15] in the case study of Cologne (Germany) concluded that increasing urban parks by 1%, about 500 meters from housing, leads to the growth of housing sales prices by 0.1%. With a priori protection of natural resources, engineering solutions are less, and the cost is lower [14].

The economic valuation of ecosystems was developed with the emergence of the ecosystem services concept [16] and spread at the beginning of the 21st century with the publications of the Millennium Ecosystem Assessment. Different local scientific and political communities started raising awareness of the importance and benefits of ecosystem services. Several initiatives and methodologies have emerged to quantify these services in monetary value. However, there are sometimes limitations in quantifying an ecosystem service [17].

Ecological-based planning has the added advantage of helping to increase the number or quality of services provided by ecosystems. Inherent in the concept of ecological-based planning is the continuity and ecological network [18]. In fact, landscape connectivity is a component of landscape structure that facilitates or impedes the flows of natural cycles [19]. Those authors believe that it is more critical to establish connectivity than the proximity of areas studied in "island biogeography" [20].

Like nature conservation, the ecological continuity of ecosystems is a broad concept that involves the need to promote continuity between plant and animal species and that of all ecological cycles: water, nutrients, carbon, etc. For this, the planning of these continuities (ecological structures or networks) cannot be disconnected from the function and its "congruent form", as defined by the landscape architect Francisco Caldeira Cabral [1]. The land-use planning approach advocated, plans the landscape from a biophysical and not only biological perspective [11, 21], where the continuous structures of the landscape are identified and planned according to their function and coherent form.

The importance of connecting nature protection areas, establishing a network or infrastructure has been reinforced [22]. According to this publication, this type of infrastructure, designated by green infrastructure, can mitigate fragmentation and promote the various benefits of maintaining and restoring ecosystems and their services, not only inside Natura 2000 areas.

However, as mentioned above, nature conservation should be understood as a comprehensive and integrative concept of Man and ecological processes, not limited to classified areas (RAMSAR Areas, Biogenetic Reserves, Natura 2000 Network, etc.). Nature conservation will emerge from the correct occupation and use of the Landscape by Man, both in terms of building, forest, woodland and/or agriculture. Therefore, the incorporation of ecological processes in the nature conservation strategy is necessary [23], not forgetting that: (1) ecosystems are spatially and temporally dynamic; (2) ecosystem components interact with each other contributing to biodiversity; (3) ecological processes act as species-selective forces; (4) in highly modified sites ecosystem restoration is a conservation priority.

2. Integration between green infrastructure, ecosystem services, and ecosystem restoration

The concept of structure in landscape architecture is necessarily related to spatialization. In this structure, relationships between ecosystems or elements are expressed [24]. The structure integrates the landscape system's objective and subjective components, articulating significant features that relate to each other [11]. Infrastructure is a structure that serves as the base for something to be developed. Thus, when we refer to green infrastructure, we are talking about a planned network of structural spaces rather than a network of spaces disconnected from the biophysical structure of the territory. The concept of green infrastructure is broad and varied, but it is considered the one summarized by Naumann [25], whose definition is frequently used:

> *Green infrastructure is the network of natural and semi-natural areas, features and green spaces in rural and urban, terrestrial, freshwater, coastal and marine areas, which together enhance ecosystem health and resilience, contribute to biodiversity conservation and benefit human populations through the maintenance and enhancement of ecosystem services. Green infrastructure can be strengthened through strategic and coordinated initiatives that focus on maintaining, restoring, improving and connecting existing areas and features as well as creating new areas and features [25].*

Green infrastructure planning involves an assessment of the types of natural and cultural resources available and a prioritization of the resources most important to present and future needs [14]. Therefore, a green infrastructure strategy includes the process of identifying, assessing, and prioritizing areas that are critical to preserving a healthy community. In addition to prioritizing areas, there is also a need to implement actions to ensure their conservation [14]. Mapping natural resources are thus the first step in building a green infrastructure map to inform which areas need conservation actions and which need restoration actions.

The European Biodiversity Strategy for 2020 [26] highlighted the importance of using green infrastructures in landscape planning since it can ensure the "best functional connectivity between ecosystems within and between Natura 2000 areas and in the wider countryside" ([27]: 6). The indication in a European document of the importance of ensuring functional connectivity between ecosystems, even outside protected areas, through landscape planning was a crucial step towards elevating nature conservation to a more comprehensive status than protecting particular species. Recently, the European Biodiversity Strategy for 2030 [28], as a core part of the European Green Deal, defines an action plan towards protecting nature and reversing the degradation of ecosystems.

Green infrastructure is also a tool to achieve economic and social benefits through natural solutions. This concept of natural solutions (or nature-based solutions) was further developed by the working groups of the European Commission [27] as a solution inspired, supported or copied from nature. The green infrastructure strategy itself states that "Green infrastructure can make a significant contribution to the effective implementation of all policies where some or all of the desired objectives can be achieved in whole or in part through nature-based solutions." ([29]: 3).

The scientific community widely refers to ecosystem services as benefits that a population acquires, directly or indirectly, from ecosystem functions [16]. Ecosystem services result from flows of materials, energy, and information from natural capital stocks capable of producing human well-being [16]. Their monetary quantification [30], with specific units [31] or measured through indicators [32] as well as a qualitative assessment [33] has been addressed in the last decades.

These services were categorized into several typologies by the Millennium Ecosystem Assessment [34]: supporting (services required to produce all other ecosystem services); provisioning (products obtained from ecosystems); regulating (benefits obtained through the regulation of ecosystem processes); and cultural (non-material benefits obtained from ecosystems). The landscape is intended to be one where ecosystem services are provided in balance with the physical structure that supports them, so the various actors dealing with land-use planning must understand the support structure of the landscape.

To contribute to a consistent definition of ecosystem services, Fisher [35] introduces the importance of ecosystems' structure and their processes and functions. In this approach, ecosystem services are characteristics of ecosystems used directly or indirectly by humans to produce well-being. Accordingly, ecosystem structure is itself a service because it provides a platform for ecosystem processes. Related to this idea, the same authors say that the configuration of ecosystem structure and processes is necessary for the healthy functioning of ecosystems and their services, relating them to the concept of (green) infrastructure. The spatial characteristics of ecosystems are also a way to classify their services, so it will be important in planning to know what services are available and how they flow through the landscape. In this way, it is important to understand the relationships between the production of the service and the place where the benefit occurs, recognizing the dynamic characteristics of ecosystems. In this regard, [35] propose a system for classifying ecosystem services into three categories: (1) in situ (services produced and benefits provided occur at the same location); (2) Omni-directional (where services are provided at a single location, but the benefit occurs in the landscape surrounding the service production with no defined direction); (3) directional - where service provision benefits from a specific location due to the direction of flow.

The Ecosystem services were also an integral part of the European Biodiversity Strategy for 2020 [26]. According to this strategy, ecosystems and their services would be maintained and enhanced by creating green infrastructure and restoring at least 15% of degraded ecosystems. Ecosystem services were then identified through indicators associated with each ecosystem, assessed according to the Common International Classification of Ecosystem Services [36]. The European methodologies followed for mapping ecosystems [36] use the interpretation of different land use and land cover classes and relate them to the European Habitat Classification (EUNIS). As a result, the analysis of ecosystem services while assessing land-use mapped ecosystems tends to present itself transformed into an "in situ" category, in the sense of [36], where the production of the service and the benefit are located in the same place. Another consequence of a methodology based on current land use mapping is to assess the use and service regardless of whether it is in an area of greater ecological suitability. Such is the example of forests that are all converted into ecosystems capable of producing the same services regardless of the type of forest species. This is an incorrect approach since it is well known that different forest trees or stands provide different ecosystem services. In Portugal, this is very relevant since most of the forest stands are not native (maritime pine, eucalyptus) providing poorer ecosystem services when compared with native stands (oak).

It is essential to consider that the landscape has different capabilities to provide specific ecosystem services [33], being of a more profound complexity than just an assessment by current land use. The structure of the ecosystem assumes a vital role in supporting the very functioning of the ecosystem. Interestingly, authors such as Burkhard [33] consider that the typology of supporting ecosystem services (defined in the Millennium Ecosystem Assessment), is understood as those that ensure ecological integrity. However, supporting services are considered difficult to map [37], and it is considered that the link between supporting services and human well-being occurs indirectly [34]. Therefore, supporting services have received much less attention among four types of ecosystem services. Despite European recommendations to map ecosystems and their services, recent publications have failed to include supporting services [38].

In this sense, it is considered that by mapping green infrastructure, the supportive services are provided in conjunction with other ecosystem services. Incorporating structural components of ecosystems also allows for a complete approach to mapping ecosystems and their services by encompassing the various relationships between the area of production of the service and the site of benefit from that service.

Including ecosystem services in landscape planning will need to go through defining the goal of achieving multiple ecosystem services [39]. However, the function of an ecosystem must be ensured in planning regardless of the benefit it may provide [40]. Maximizing one ecosystem service may jeopardize the balance of all other ecosystem services, as exemplified by Dosskey [39] in the US Green Belt region, where agricultural productivity was put as a priority at the expense of water quality and wildlife. It should be desirable for public policy to seek a degree of multifunctionality across cultural landscapes and to achieve the greatest degree of multifunctionality in green infrastructure [40]. The same author considers that monofunctional landscapes will require greater inputs to continue to provide values and functions and are likely to become unsustainable and require restoration.

Ecosystems are naturally multifunctional, making available services determined by landscape structure [39]. Modifying landscape structure can rebalance the services available. Thus, the landscape planning process will need to include an understanding of the current functioning of the landscape and an assessment of whether changing the landscape structure can affect the ecological functions and services provided [39]. Ecologically based planning aims to define the best use which implicitly includes the best use of natural resources without compromising their existence and their stability in the system [41]. This applies both to landscapes dominated by native vegetation, forming a dense woodland, and to agricultural or production forest areas properly integrated into the landscape and its structure with good management practices and appropriate design.

Ecosystem restoration is often focused on the recovery of a particular plant or animal community, often appearing related to landscape fragmentation [42]. The restoration of an ecosystem, which is itself a complex system, will involve the recovery of the ecological functions of the system. The functions that are easily altered by the degradation of an ecosystem are soil structure, nutrient flow, and water cycling [43]. The restoration of an ecosystem will mainly involve the recovery of the lost functions, because this loss has also contributed to its own degradation:

> *When a reintegrated landscape is achieved, it will be a landscape that is a mosaic of agricultural, natural, and semi natural systems, which together maximize biodiversity and economic returns by maintaining the landscape amenity function (minimizing the loss of landscape qualities through soil salinization of water and wind erosion) and so make possible a sustainable agriculture and a functional diverse natural system [43].*

The ecosystem restoration will involve the recovery of its ecological integrity. The integrity of an ecosystem includes the integrity of the system's structure and function, the maintenance of its components and its dynamic interactions [44]. From this perspective, any loss of system components leads to a loss of system integrity. According to Forman [45] and Thorn [46] a system with ecological integrity exhibits natural conditions of productivity, biodiversity, soil and water conservation, which are the goal of any sustainable environment [47]. The integrity of an ecosystem includes an adequacy of uses to the ecological characteristics of the system, meeting the dynamic stability of the landscape, making it resilient.

Ecosystem restoration is defined by the Society for Ecological Restoration as the process of supporting the recovery of an ecosystem that has been degraded, damaged, or destroyed [48]. These last three states can be equated to various states of morphogenesis, where an imbalance of landscape stability occurs. A morphogenesis ecosystem can be at different levels of imbalance from degradation to complete destruction. When ecosystems are being overexploited or degraded the health of the ecosystem goes into decline as well as its integrity and resilience [49]. This state of decline can be reversed with recovery actions, which in turn lead to ecosystem rebalance in Tricart's [3] interpretation of dynamic equilibrium. An ecosystem in equilibrium provides a greater number or a higher quality of services.

A Landscape-scale ecosystem restoration involves restoring a set of ecosystems to recover natural and cultural values and ecosystem service flows [49]. Hobbs [50] argues that the recovery of ecosystems should not focus on replicating the conditions prior to disturbance, but should be managed in a future perspective, not forgetting that the landscape is temporally and spatially dynamic. Besides, there are two types of recovery [51]: one in which the goal is the recovery of biotic continuity, and another, corresponding to more severe situations of degradation, will involve the physical recovery of the ecosystem. An example of the latter is the case of the obstruction of a river, where the goal will be to recreate the continuity of water flow. According to those authors, there are thus two thresholds that, if crossed, imply different interventions, the biotic threshold, and the abiotic threshold. The least severe situation of degradation of an ecosystem will thus imply changes in land use.

The ecosystem restoration can integrate cultural values, for example, an agricultural area located on productive soils and with good management practices (including compartmentalization hedges, contour farming) contributes to increased productivity, biodiversity, and soil and water conservation. Designing green infrastructure with planned land uses, consistent with its different ecological characteristics, guarantee the ecosystem's integrity and allow it to assess restoration needs.

3. The need for a restoration solution: centre region of Portugal

The absence of an ecological-based landscape and land-use plan can have severe consequences in the increase of soil degradation and floods, decrease of biodiversity, and increased fire risk. This landscape degradation is present in several areas of Portugal. Also, a consequence of the set of policies followed since the beginning of the 20th century. In the 1930s, Portugal went through a wheat campaign that destroyed the fertility of the soil. Later, the monoculture campaigns of maritime pine and eucalyptus continue the degradation of the soil and the destruction of the landscape, which we still see happening, especially in the north of the Tagus river, in the Centre and North regions.

The Centre Region (**Figure 1**) corresponds to a Statistical Territorial Unit (NUT) and comprises about 2,819,936 hectares. This region includes different landscape typologies, such as the southwest western zone with fruit productivity, the coastal zone with low and high coastlines, and an inland zone dominated by maritime pine and eucalyptus in formations of schist and granite. This area is characterized by a rugged relief in the most central location, such as Serra da Estrela, where Rio Mondego begins, the Serra da Lousã and the Serra do Açor. The Natura 2000 network includes 21 Special Areas of Conservation.

In an evaluation of land use from the 1990s to the present, it was possible to understand the evolution of the different land uses (**Figure 2** and **Table 1**).

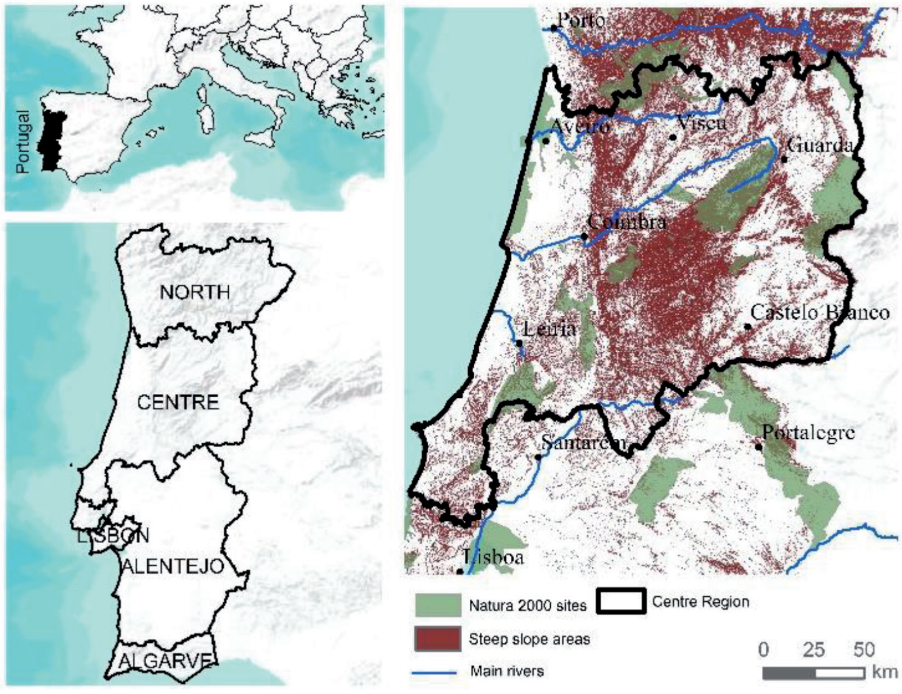

Figure 1.
Location of the Centre region in Portugal.

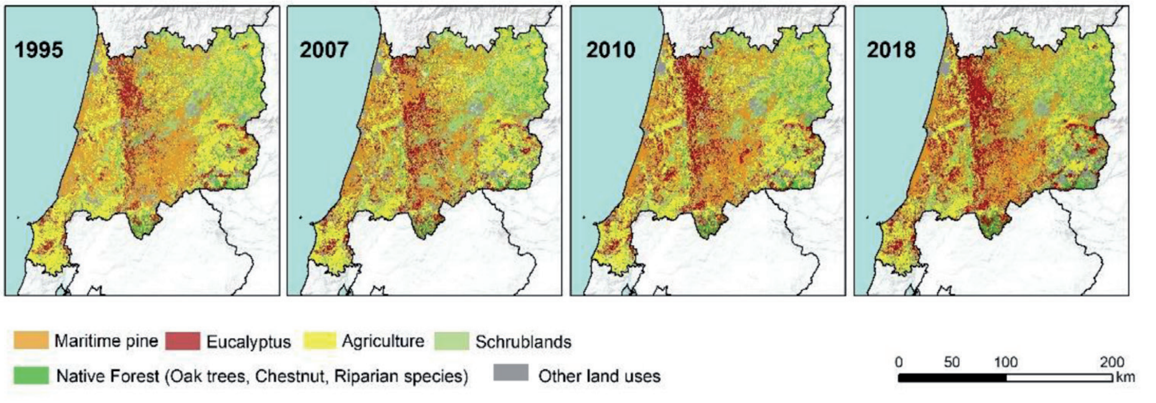

Figure 2.
Evolution of the main land use classes in the Centre region, between 1995 and 2018 (data base: DGT, land use and land cover map).

Main Land Uses in Centre Region	% in 1995	Variation	% in 2007	Variation	% in 2010	Variation	% in 2018
Maritime pine	26,7%	↘	20,0%	↗	22,5%	↘↔	22,3%
Eucalyptus	9,7%	↗	10,9%	↗	13,5%	↗	17,2%
Schrubland	11,7%	↗	16,4%	↘	12,3%	↗	13,3%
Agriculture	31,3%	↘	25,5%	↘	26,2%	↘	23,3%
Native	7,6%	↘	5,8%	↘	6,4%	↗	9,3%

Table 1.
Evolution of the main land uses in the Centre region, between 1995 and 2018.

This analysis was done with the interpretation and reclassification of the Land-Use and Land Cover maps produced by DGT (1995, 2007, 2010, 2018) [52]. In this period of 24 years, there is an oscillation of maritime pine, which tends to stabilize at 22%. The percentage of eucalyptus in the central zone has increased since 1995, from

9.7% of the total area, to 17% in 2018, i.e., it has practically doubled. On the other hand, the area occupied by agriculture has decreased since 1995. Native species include cork oak, holm oak, other oaks and also chestnut stands (archaeophyte), and oscillate between the years analyzed, with occupations between 6 and 9%.

There is in fact a very serious problem of inappropriate land uses that lead to the destruction of landscapes with negative consequences for those who live there, but also for those who live further away, for example, the impacts derived from water quality. Since the end of the 19th century, the oaks and chestnut trees and the traditional pastures, were replaced, first by maritime pine, which were planted on the community lands ("Baldios"), and then by eucalyptus. Land property fragmentation and, consequently, the landowners' increase also aggravated the land management problem.

A balanced landscape constituted by agriculture on the best soils, mixed woodland complementing agriculture and all its by-products, pastoralism in articulation with woodland and agriculture, villages, towns, and cities strategically located in situations of greater comfort and proximity to the food and materials produced was replaced by a landscape ecologically degraded, humanely depopulated and which burns extensively and repeatedly.

Fire frequency (number of times between 1990 and 2017)	Area (ha)	%
1 time burnt area between 1990 and 2017	698 775	24.8
2 times burnt area between 1990 and 2017	321 099	11.4
3 times burnt area between 1990 and 2017	93 965	3.3
4 times burnt area between 1990 and 2017	16 105	0.6
5 times burnt area between 1990 and 2017	2 882	0.1
6 times burnt area between 1990 and 2017	327	0.012
7 times burnt area between 1990 and 2017	224	0.008
No burned area between 1990 and 2017	1 686 559	59.8

Table 2.
Fire frequency between 1990 and 2017, area and percentage of case study.

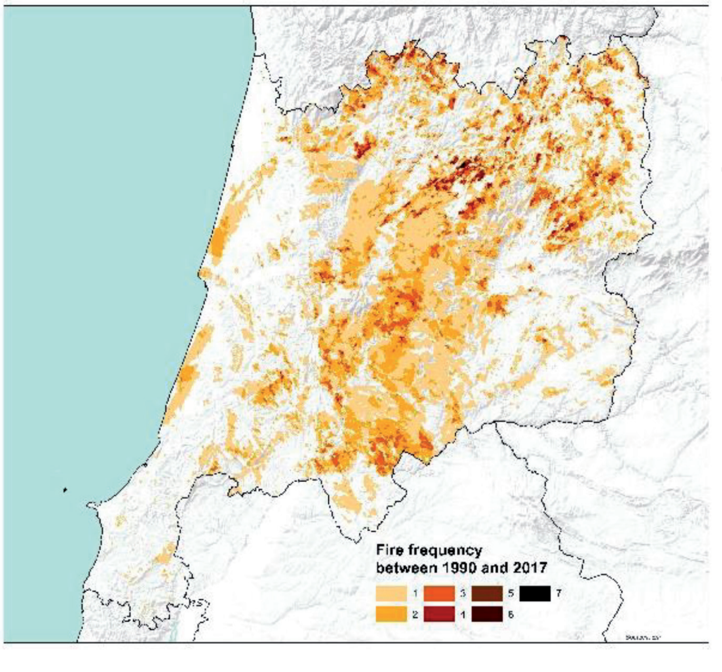

Figure 3.
Fire frequency between 1990 and 2017.

The policies disconnected from the ecological capacity of the land, led to the current situation of mega-fires, with loss of life and property and land abandonment. Analyzing the centre region in terms of burnet areas, 40% of the region was burned between 1995 and 2017. About 25% of the Centre Region burned once (**Table 2**), but 11% burned twice (**Figure 3**). In the megafires from 2017, the Centre Region was the most affected, representing 15% of total region area (416 thousand hectares). It is very urgent to develop adequate land-use plans for the rural areas.

The creation of a healthier landscape implies the conservation of natural resources, the creation of a balanced, multifunctional system with landscape recovery using native species. This will lead to creation of different economies, where ecosystem services payment can also take place.

4. The solution for healthier landscape – centre region of Portugal

The solutions developed to attain a healthier landscape involve the creation of a multifunctional landscape, with native or archaeophytes species, agriculture, and pastureland. The planned landscape will allow to create businesses, generate employment (landscape recovery companies, native species nurseries, forest management companies, reactivation of native wood business), and unique products (non-wood products, such as flour from oak acorns, chestnut, walnut, honey and mushroom production) capable of attracting nature tourism as well.

This landscape will then provide better ecosystem services, such as water quality, soil conservation, and biodiversity improvement, among others. Together, it will develop a fire resilient landscape, which is the landscape's capacity to absorb the disturbance caused by rural fires without losing its function, structure, and identity and ultimately weakening fire frequency and intensity or magnitude [53].

The vision for a healthier landscape of the Centre Region was developed by the application of FIRELAN [53], which is an ecologically based model that integrates different principles related to landscape fire resilience and ecological sustainability into a land-use plan, using the river basin as a landscape unit. The FIRELAN pretends to provide a multifunctional landscape (**Figure 4**) with benefits to the environment, but also developing economies and rural communities.

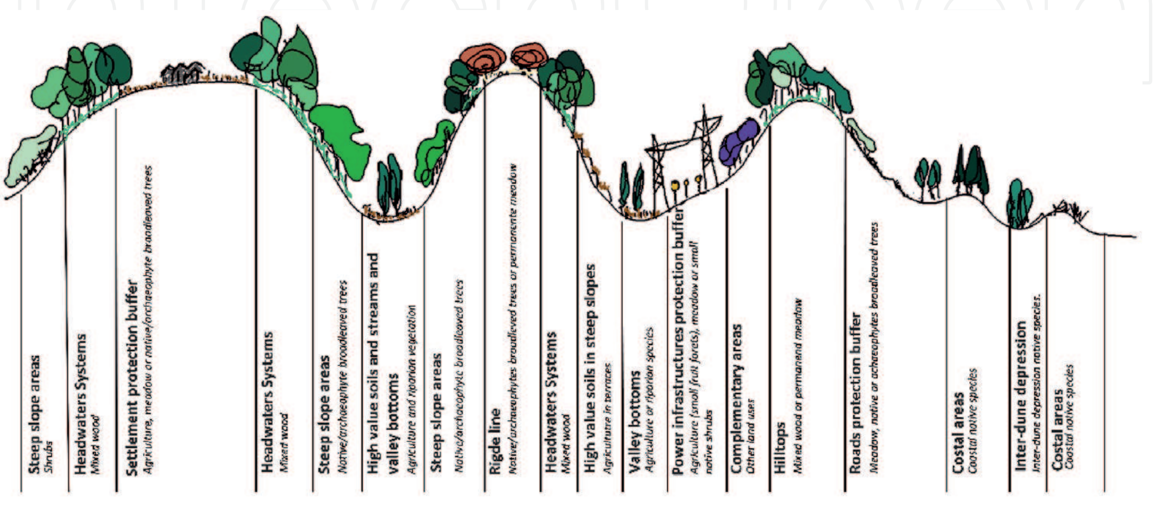

Figure 4.
Ecological and cultural system and land use potential from FIRELAN model.

The different components of the FIRELAN network for the Centre Region are mapped in **Figure 5**. The FIRELAN network is the main landscape structure with physical, biological, and cultural elements (**Table 3**). For each component there is a set of adequate land uses that should be promoted. Those land uses are identified in **Figure 6** and in **Table 4**. In the interstices of the FIRELAN network, also called Complementary Areas, the land use possibilities are wider.

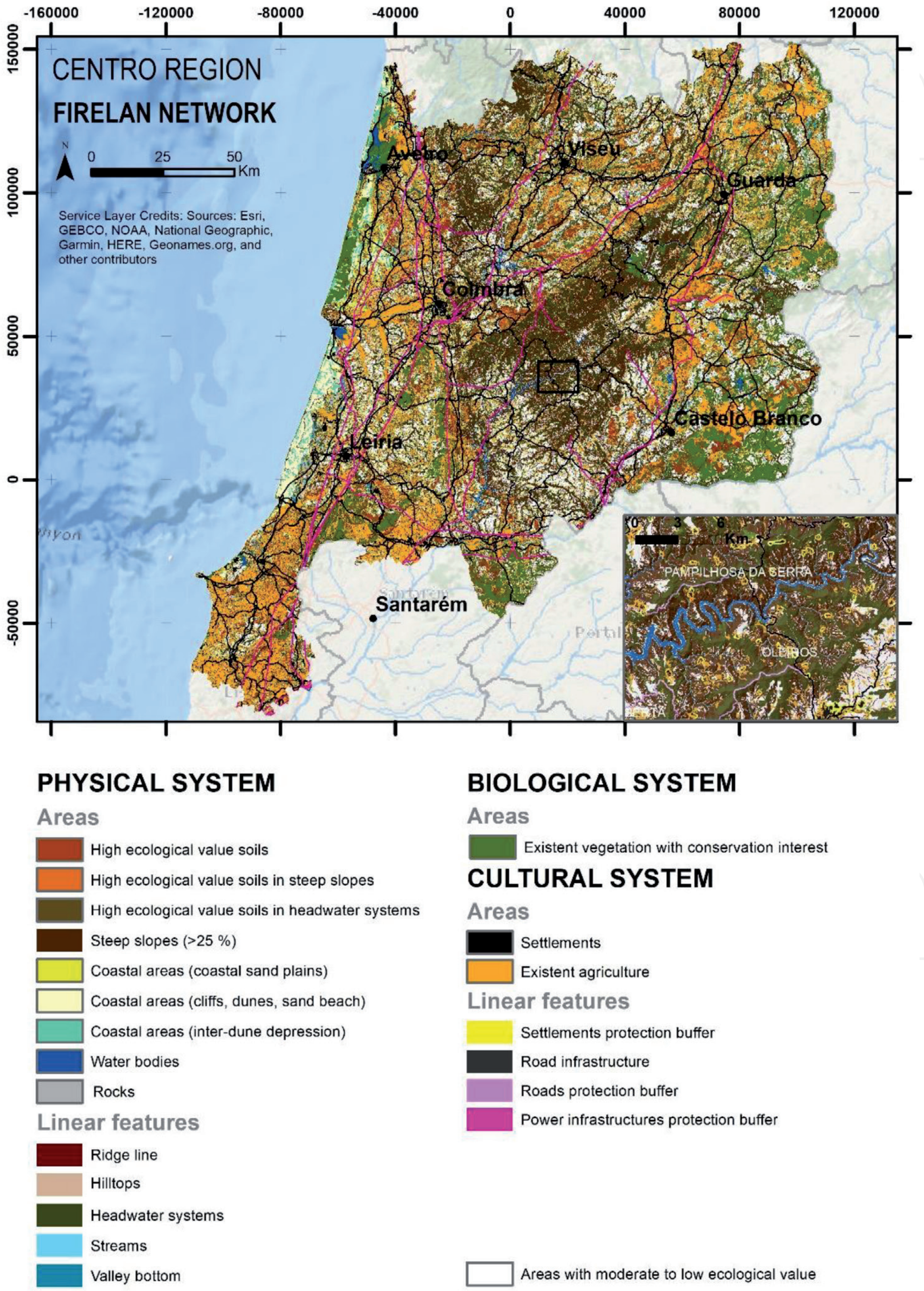

Figure 5.
FIRELAN network components in the Centre region of Portugal.

Firelan network component			**Data Source**
Physical System	Areas	Soils with high and very high ecological value	[54–56]
		Steep slopes (>25%)	[56, 57]
		Coastal area	[56, 58]
		Wetlands	[53]
		Water bodies	[53]
	Linear	Ridge line	[56, 57]
		Hilltops	[56, 57]
		Headwater systems	[56, 59]
		Streams and Valley bottoms	[56, 57]
Biological System	Areas	Existent vegetation with conservation interest	[52, 56, 60]
Cultural System	Areas	Settlements	[52]
		Existent agriculture	[52]
	Linear	Settlement protection buffer	—
		Roads	OpenStreetMap©
		Roads protection buffer	—
		Power infrastructures buffer	[61]

Table 3.
Components of FIRELAN and sources for the Centre region of Portugal.

The potential land uses plan (**Figure 6**, **Table 4**) highlights that:

- Native and archaeophytes species (including agroforestry systems), which represent 11% of the study area, can expand into further 31%.
- The agriculture can be increased in about 12% of the case study area, in addition to existing agriculture (23%).
- Existent vegetation with conservation interest is present in 14% of the Centre region.
- Complementary areas (areas with moderate to low ecological value) represent 16% of the study area.

Comparing potential land use and current land use map allows defining a Landscape Transformation Plan with conservation and restoration actions. According to the developed plan (**Figure 7**, **Table 5**): 35% of the Centre region should have restoration actions, and 57% should be maintained and conserved. Also, according to the results:

- The eucalyptus can be kept in 5% of the case study area, only in complementary areas, and with environmental measures.
- The maritime pine can be kept in 6% of the case study area, only in complementary areas, and with environmental measures.
- About 0,8% of the case study area should have recovery of the riparian vegetation.

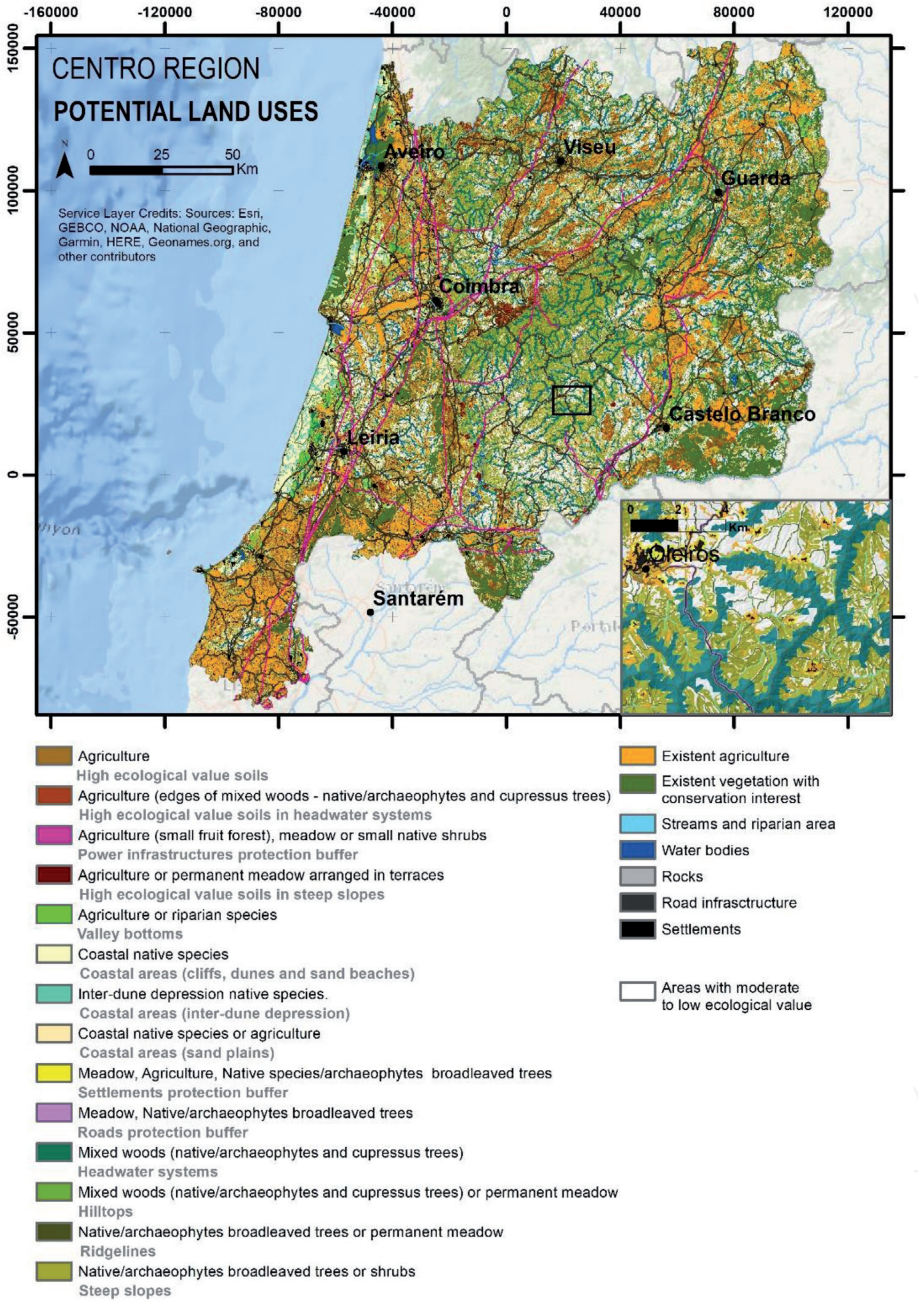

Figure 6.
Potential land uses in the Centre region of Portugal.

5. Conclusions

The United Nations General Assembly proclaimed the Ecosystem Restoration decade between 2021 to 2030, aiming to halt the degradation of ecosystems and restore them to achieve healthier landscapes. Landscape Architecture is an interdisciplinary discipline helpful in attaining those goals through planning and design

Firelan network components	Potential land uses	Area (ha)	%
High ecological value soils	Agriculture	131627	4.67
High ecological value soils in headwater systems	Agriculture (edges of mixed woods - native/ archaeophytes and cupressus trees)	52733	1.87
Power infrastructures protection buffer	Agriculture (small fruit forest), meadow or small native shrubs	5545	0.20
High ecological value soils in steep slopes	Agriculture or permanent meadow arranged in terraces	14408	0.51
Valley bottoms	Agriculture or riparian species	24395	0.87
Coastal areas (cliffs, dunes and sand beach)	Coastal native species	35653	1.26
Coastal areas (inter-dune depression)	Inter-dune depression native species	14178	0.50
Coastal areas (coastal sand plains)	Coastal native species or agriculture	5147	0.18
Settlements protection buffer	Meadow, Agriculture, Native species/ archaeophytes broadleaved trees	105883	3.76
Roads protection buffer	Meadow, Native/archaeophytes broadleaved trees	27454	0.97
Headwater systems	Mixed woods (native/archaeophytes and cupressus trees)	314469	11.15
Hilltops	Mixed woods (native/archaeophytes and cupressus trees) or permanent meadow	42221	1.50
Ridgelines	Native/archaeophytes broadleaved trees or permanent meadow	86392	3.06
Steep slopes	Native/archaeophytes broadleaved trees or shrubs	248223	8.80
Existent agriculture	Existent agriculture	646346	22.92
Existent vegetation with conservation interest	Existent vegetation with conservation interest	381180	13.52
Streams and riparian area	Streams and riparian area	22309	0.79
Water bodies	Water bodies	26709	0.95
Rocks	Rocks	3310	0.12
Road infrastructure	Road infrastructure	50764	1.80
Settlements	Settlements	132965	4.72
Areas with moderate to low ecological value	Areas with moderate to low ecological value	447731	15.88

Table 4.
Potential land uses for the Centre region of Portugal, area and percentage.

restoration in different contexts and scales, from rural to urban, from inland to coastal. The ecological-based planning methodologies contribute to better landscapes by starting from the knowledge and spatialization of natural processes. As part of an ecological-based planning methodology, working with green infrastructure allows the ecological integrity of the landscape, increasing the number or quality of services provided by the ecosystems and defining restoration actions and locations.

The Centre Region of Portugal has a severe problem of inappropriate land use. Since the end of the 19th century, the oaks and chestnut trees were replaced by

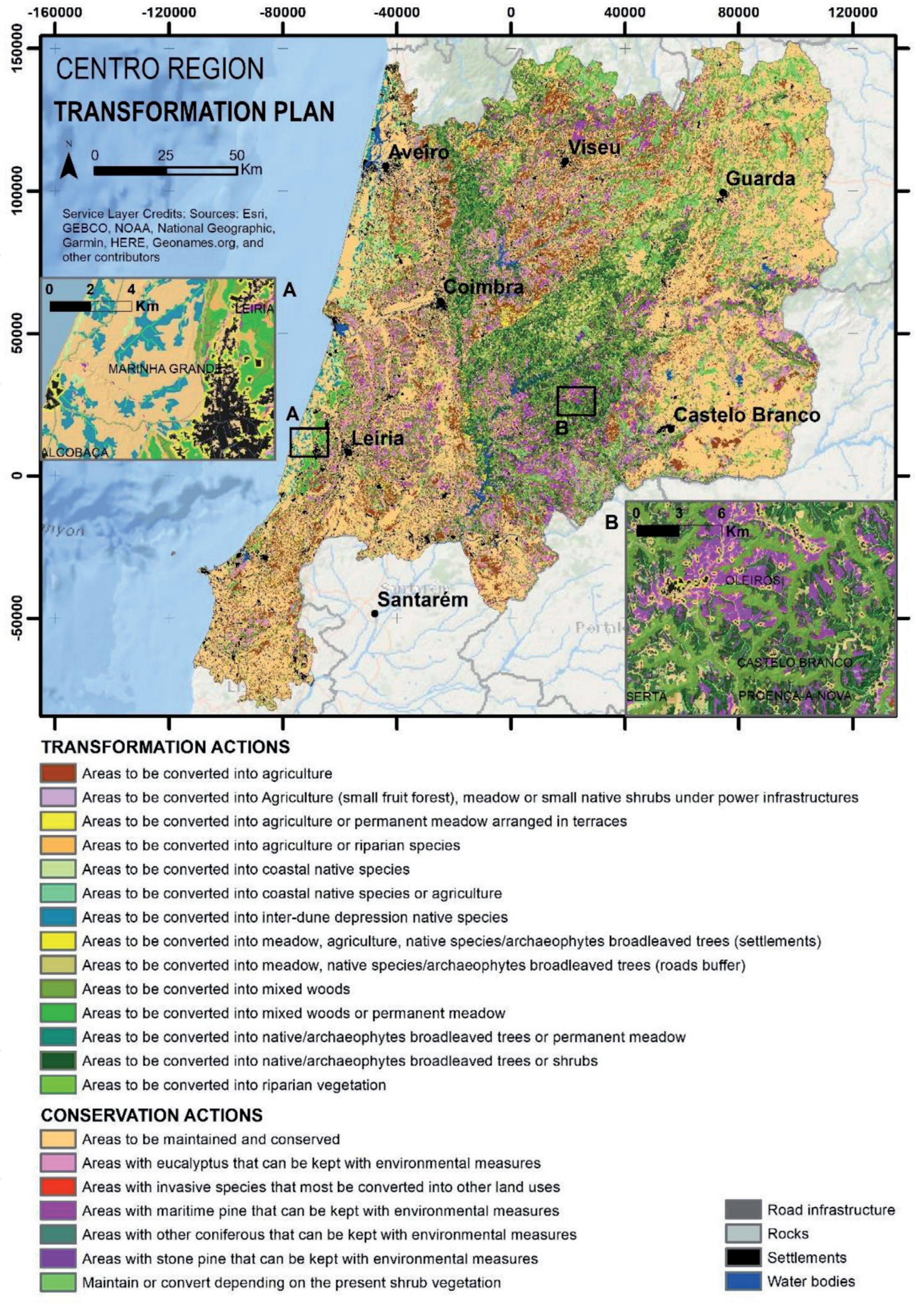

Figure 7.
Landscape transformation plan for the Centre region of Portugal.

maritime pine and eucalyptus. The number of fires and their severity increased, the land is continually degrading, and biodiversity loss increases. Applying an ecologically based landscape plan to prioritize restoration actions at the landscape scale is necessary to reverse this situation. The FIRELAN model was applied to the Centre Region to establish a vision for a healthier landscape. According to the results, 35% of the Centre Region should have restoration actions.

Landscape Transformation Actions		Area (ha)	%	Area (ha)	%
Restoration	Areas to be converted into agriculture	157670	5.59	980608	34.78
	Areas to be converted into Agriculture (small fruit forest), meadow or small native shrubs under power infrastructures	4332	0.15		
	Areas to be converted into agriculture or permanent meadow arranged in terraces	13938	0.49		
	Areas to be converted into agriculture or riparian species	18149	0.64		
	Areas to be converted into coastal native species	7840	0.28		
	Areas to be converted into coastal native species or agriculture	2786	0.10		
	Areas to be converted into inter-dune depression native species	14125	0.50		
	Areas to be converted into meadow, agriculture, native species/archaeophytes broadleaved trees (settlements)	96844	3.43		
	Areas to be converted into meadow, native species/archaeophytes broadleaved trees (roads buffer)	24944	0.88		
	Areas to be converted into mixed woods	314469	11.15		
	Areas to be converted into mixed woods or permanent meadow	35461	1.26		
	Areas to be converted into native/archaeophytes broadleaved trees or permanent meadow	80508	2.86		
	Areas to be converted into native/archaeophytes broadleaved trees or shrubs	185648	6.58		
	Areas to be converted into riparian vegetation	22309	0.79		
	Areas with invasive species that most be converted into other land uses	1584	0.06		
Conservation	Areas to be maintained and conserved	1212952	43.02	1625284	57.64
	Areas with eucalyptus that can be kept with environmental measures	142909	5.07		
	Areas with maritime pine that can be kept with environmental measures	161113	5.71		
	Areas with other coniferous that can be kept with environmental measures	3283	0.12		
	Areas with stone pine that can be kept with environmental measures	2951	0.10		
	Maintain or convert depending on the present shrub vegetation	102077	3.62		
—	Road infrastructure	50764	1.80	—	—

Landscape Transformation Actions		Area (ha)	%	Area (ha)	%
—	Rocks	3310	0.12	—	—
—	Settlements	132965	4.72	—	—
—	Water bodies	26709	0.95	—	—

Table 5.
Transformation action, area and percentage of Centre region case study.

Subsequently, the eucalyptus area must drop from 17% of the Centre Region area to 5%, and the maritime pine from 22–6%. The results also show that agriculture could increase from 23–35% of the Centre Region. In the restoration actions, the native species should be used in more than 24% of the case study, especially in the headwaters systems and streams where mixed woods and riparian galleries should be developed.

The landscape transformation plan contributes to the definition of adequate policies to tackle ecosystem restoration through landscape and land use planning.

Acknowledgements

This work was supported and financed by the Portuguese Foundation for Science and Technology (FCT) under the project SCAPEFIRE PCIF/MOS/0046/2017. This work was also under the research unit Linking Landscape, Environment, Agriculture and Food Research Centre (LEAF) UID/AGR/04129/2020.

Author details

Selma B. Pena*, Maria Luísa Franco and Manuela R. Magalhães
Linking Landscape Environment, Agriculture and Food (LEAF), Instituto Superior Agronomia, Universidade de Lisboa, Lisboa, Portugal

*Address all correspondence to: selmapena@isa.ulisboa.pt

References

[1] Cabral FC. O "Continuum Naturale" e a Conservação da Natureza. (The "Continuum Naturale" and nature conservation.) Proceedings of the seminar Conservação da Natureza, Lisboa: Serviços de Estudos do Ambiente, 18 e 19 de Abril de 1980. p. 35-54

[2] Telles GR. 1992. A conservação das Paisagens Históricas e Rurais. Correio da Natureza 17. 1992 p. 53-55

[3] Tricart J. Ecodinâmica. Rio de Janeiro, IBGE, Diretoria Técnica, SUPREN. 1997. Available from: https://www.docdroid.net/D8HPCLd/jean-tricart-ecodinamica-pdf [Accessed: 2016-05-02]

[4] Tricart J. Morphogènese et pédogenèse, géomorphologie et pédologie. Science du Sol 1, 1965. P. 69-85

[5] Odum EP. Fundamentals of ecology. Saunders College Publishing, Philadelphia, PA (US), 1971. 574 pp.

[6] ONU. Convention on biological diversity. 1992. Available from: https://www.cbd.int/doc/legal/cbd-en.pdf [Accessed: 2015-09-01]

[7] COP 5. Fifth Ordinary Meeting of the Conference of the Parties to the Convention on Biological Diversity, 15 - 26 May 2000 - Nairobi, Kenya. Available from: https://www.cbd.int/decisions/cop/?m=cop-05 [Accessed: 2015-09-01]

[8] Magalhães MR, Abreu MM, Lousã M, Cortez N. Estrutura Ecológica da Paisagem. Conceitos e delimitação – escalas regional e municipal. ISAPress, Lisboa, 2007. 361pp.

[9] Magalhães MR, Cunha N, Pena S. The Ecological Land Suitability in the Land-Use Plan. In Proceedings of the 7th International Conference on Virtual Cities and Territories, Nova University, TULisbon, October 11-13, 2011, Portugal. 2011. p. 307-312

[10] Collins MG, Steiner FR, Rushman MJ. Land-use suitability analysis in the United States: historical development and promising technological achievements. Environ. Manage. 2001; 28 (5), 611-621. DOI: 10.1007/s002670010247

[11] Magalhães MR,. A Arquitectura Paisagista. Morfologia e Complexidade. Editorial Estampa, Lisboa, 2001. p.525.

[12] McHarg IL. Design with Nature. NHP, New York (US), 1971. 197 pp.

[13] Steiner FR. The Living Landscape, Second Edition: An Ecological Approach to Landscape Planning, Island Press. 2008.

[14] Firehock K. Strategic Green Infrastructure Planning. A multi-scale approach. Island Press. 2015. 138pp.

[15] Kolbe J, WUstemann H. Estimating the Value of Urban Green Space: A hedonic Pricing Analysis of the Housing Market in Cologne, Germany. J. Chem. Inf. Model. 2014. 5, 45-61. DOI:10.1017/CBO9781107415324.004

[16] Costanza R, d'Arge R, De Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P, Van Den Belt M, The value of the world's ecosystem services and natural capital. Nature 1997. 387, 253-260. DOI:10.1038/387253a0

[17] Hermann A, Schleifer S, Wrbka T. The Concept of Ecosystem Services Regarding Landscape Research: A Review. Living Rev. Landsc. Res. 2011. 5, 1-37. DOI:10.1177/0170840609104565

[18] Bennett G, Mulongoy KJ. Review of experience with ecological networks, corridors and buffer zones. 2006. Secretariat of the Convention on Biological Diversity, Montreal, Technical Series No. 23.

[19] Taylor PD, Fahrig L, Henein K, Merriam G. Connectivity is a vital element of landscape structure. Oikos. 1993. 68, 571-573. DOI:10.2307/3544927

[20] MacArthur Rh, Wilson EO. The theory of island biogeography. Princeton Univ. Press. Ed., Princeton. 1967.

[21] Cunha NS, Magalhães MR. Methodology for mapping the national ecological network to mainland Portugal: A planning tool towards a green infrastructure. Ecological Indicators 2019. 104C: 802-818. DOI: 10.1016/j.ecolind.2019.04.050

[22] EEA. Green infrastructure and territorial cohesion. 2011. Technical report No 18/2011

[23] Bennett AF, Haslem A, Cheal DC, Clarke MF, Jones RN, Koehn JD, Lake PS, Lumsden LF, Lunt ID, Mackey BG, Nally RM, Menkhorst PW, New TR, Newell GR, O'Hara T, Quinn GP, Radford JQ, Robinson D, Watson JEM, Yen AL, Ecological processes: A key element in strategies for nature conservation. Ecological Management & Restoration, 2009. 10: 192-199. DOI: 10.1111/j.1442-8903.2009.00489.x

[24] Forman RTT, Godron M. Landscape ecology. John Wiley, New York. 1986. 619p.

[25] Naumann S, McKenna D, Timo K, Mav P, Matt R. Design, implementation and cost elements of Green Infrastructure projects. Final report to the European Commission, DG Environment, 2011. Contract no. 070307/2010/577182/ETU/F.1, Ecologic institute and GHK Consulting.

[26] EC. Our life insurance, our natural capital: an EU biodiversity strategy to 2020. COM(2011) 244 final. 2011.

[27] EC. Towards an EU Research and Innovation policy agenda for Nature-Based Solutions & Re-Naturing Cities. 2015. DOI:10.2777/765301

[28] EC. EU Biodiversity Strategy for 2030 Bringing nature back into our lives COM/2020/380 final. 2020.

[29] EC. Green infrastructure (GI): enhancing Europe's natural capital COM(2013) 249 final. 2013.

[30] De Groot R, Brander L, van der Ploeg S, Costanza R, Bernard F., Braat L, Christie M, Crossman N, Ghermandi A, Hein L, Hussain S, Kumar P, McVittie A, Portela R, Rodriguez LC, ten Brink P, van Beukering P. Global estimates of the value of ecosystems and their services in monetary units. Ecosyst. Serv. 2012. 1, 50-61. DOI:10.1016/j.ecoser.2012.07.005

[31] Boyd J, Banzhaf S. What are ecosystem services? The need for standardized environmental accounting units. Ecol. Econ. 2007. 63, 616-626. DOI:10.1016/j.ecolecon.2007.01.002

[32] Müller F, Burkhard B. The indicator side of ecosystem services. Ecosyst. Serv. 2012. 1, 26-30. DOI:10.1016/j.ecoser.2012.06.001

[33] Burkhard B, Kroll F, Müller F. Landscapes' Capacities to Provide Ecosystem Services – a Concept for Land-Cover Based Assessments. Landsc. Online 2010, 1-22. doi:10.3097/LO.200915

[34] Alcamo J. Ecosystems and human well-being, Ecosystems. ISLAND PRESS, Washington, D.C., USA. 2003. p. 245.

[35] Fisher B, Turner RK, Morling P. Defining and classifying ecosystem

services for decision making. Ecol. Econ. 2009. 68, 643-653. doi:10.1016/j.ecolecon.2008.09.014

[36] EU. Mapping and assessment of ecosystems and their services in the EU. Indicators for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020, 2nd Report. 2014. DOI:10.2779/75203

[37] Benis E, Drakou E, Dunbar MB, Maes J, Willeman L. Indicators for mapping ecosystem services: a review. 2012. DOI:10.2788/41823

[38] EEA. European ecosystem assessment— concept, data, and implementation Contribution to Target 2 Action 5 Mapping and Assessment of Ecosystems and their Services (MAES) of the EU Biodiversity Strategy to 2020. 2015. DOI:10.2800/629258.1.

[39] Dosskey MG, Wells G, Bentrup DW. Enhancing ecosystem services: Designing for multifunctionality. J. Soil Water Conserv. 2012. 67, 37A – 41A. DOI:10.2489/jswc.67.2.37A

[40] Selman P. Planning for landscape multifunctionality. Sustain. Sci. Pract. Policy, 2009. 5, 45-52. DOI: 10.1080/15487733.2009.11908035

[41] Ndubisi F. Managing change in the landscape: a synthesis of approaches for ecological planning. Landscape Journal. 2002. University of Wisconsin Press. EBSCO Publishing. p. 138-155

[42] Jaeger JAE, Soukup T, Madriñán LF, Schwick Chr, Kienast F. Landscape fragmentation in Europe. EEA-FOEN Report. 2011. ISBN 978-92-9213-215-6

[43] Main AR. Landscape Reintegration: Problem Definition. In: Richard J. Hobbs, Denis A. Saunders (editors) Reintegrating Fragmented Landscapes. 1993. Springer New York. p 189-208.

[44] Regier HA,. The Notion of Natural and Cultural Integrity. In: Woodley, S., Key, J., Francis, G. (editors) Ecological Integrity and the Management of Ecosystems. USA. St. Lucie Press. 1993. p3-18

[45] Forman RTT. Land Mosaics. Cambridge University Press, Cambridge, 1995. p. 632.

[46] Thorne JF. Landscape ecology. A Foundation for greenway design. In Paul S.Smith & Paul Cawood Hellmund (editors) "Ecology of greenways" University of Minnesota press. 1993. p 23-42

[47] Cook EA. Landscape structure indices for assessing urban ecological networks. Landsc. Urban Plan. 2002. 58, 269-280. DOI: 10.1016/S0169-2046(01)00226-2

[48] SER, 2004. The SER International Primer on Ecological Restoration, in: Www.ser.org & Tucson: Society for Ecological Restoration International.

[49] Clewell AF, Aronson J. Ecological Restoration. Principles, Values, and Structure of an Emerging Profession. 2ª edition. USA. ISLANDPress. 2013

[50] Hobbs RJ, Hallett LM, Ehrlich PR, Mooney H a,. Intervention Ecology: Applying Ecological Science in the Twenty-first Century. Bioscience, 2011. 61, 442-450. DOI:10.1525/bio.2011.61.6.6

[51] Hobbs RJ, Harris JA. Restoration Ecology : Repairing the Earth ' s Ecosystems in the New Millennium. Restor. Ecol. 2001. 9, 239-246. DOI:10.1046/j.1526-100x.2001.009002239.x

[52] DGT, Land Use and Land Cover Maps from different years: 1995, 2007, 2010, 2018. Available from: https://snig.dgterritorio.gov.pt/ [Accessed: 2020-09-01]

[53] Magalhães MR, Cunha NS, Pena SB, Müller A. FIRELAN—An Ecologically

Based Planning Model towards a Fire Resilient and Sustainable Landscape. A Case Study in Center Region of Portugal. Sustainability 2021. 13, 7055. DOI:10.3390/su13137055

[54] Leitão M, Cortez N, Pena SB. Solo (Soil). In Magalhães, M.R.M. (editor) Estrutura Ecológica Nacional. Uma Proposta de Delimitação e Regulamentação (National Ecological Network. A Delimitation and Regulation Proposal). ISAPress, Lisboa. 2013. p. 83-104, ISBN 978-972-8669-53-9.

[55] Pena SB, Abreu MM, Magalhães MR, Cortez N. Water erosion aspects of land degradation neutrality to landscape planning tools at national scale. Geoderma, 2020. 363, 114093. DOI: 10.1016/j.geoderma.2019.114093.

[56] EPICWebGIS (http://epic-webgis-portugal.isa.ulisboa.pt/)

[57] Cunha NS, Magalhães MR, Domingos T, Abreu MM, Withing K. The land morphology concept and mapping method and its application to mainland Portugal. Geoderma, 2018. 325: 72-89. DOI: 10.1016/j.geoderma. 2018.03.018.

[58] Silva JF, Cunha N, Lopes AM, Abreu MM, Magalhães MR. Litoral (Coastal area). In: Magalhães, MRM (editor), Estrutura Ecológica Nacional. Uma Proposta de Delimitação e Regulamentação (National Ecological Network. A Delimitation and Regulation Proposal), ISAPress, Lisboa. 2013. p. 67-82ISBN 978-972-8669-53-9.

[59] Pena SB, Magalhães MR., Abreu MM. Mapping headwater systems using a HS-GIS model. An application to landscape structure and land use planning in Portugal. Land Use Policy 2018. 71, 543-553. DOI: 10.1016/j. landusepol.2017.11.009

[60] Mesquita, S. (2013). Vegetação (Vegetation). In: Magalhães MRM (editor), Estrutura Ecológica Nacional. Uma Proposta de Delimitação e Regulamentação (National Ecological Network. A Delimitation and Regulation Proposal), ISAPress, Lisboa. 2013. p. 105-120. ISBN 978-972-8669-53-9

[61] REN. Rede nacional de transporte de electricidade (National electricity transport network), 2012, Portugal. Escala 1:1.000.000. REN - Rede Elétrica Nacional, S.A. Lisboa