Chapter

Spatial and Temporal Variability Regarding Forest: From Tree to the Landscape

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Abstract

Spatial and temporal variability in forest has become a topic attracting great attention regarding the role of the forest ecosystems in biogeochemical cycles, climate change and biological diversity and in human society. Advances in the natural sciences have brought insights into and a better understanding about the patterns and processes at different spatial and temporal scales. At the same time, this supports a better management of the forest ecosystems and landscapes. Variability from the tree level to the landscape is addressed. Tree characteristics and functions, forest stand dynamics and ecological succession to forest landscape ecology are put together, considering their interrelations and dependencies. Managing forest stands and variability at different scales is described and discussed, including the scope of sustainability. An evaluation of forest and landscape characteristics in Portugal is performed with propositions considering these different elements.

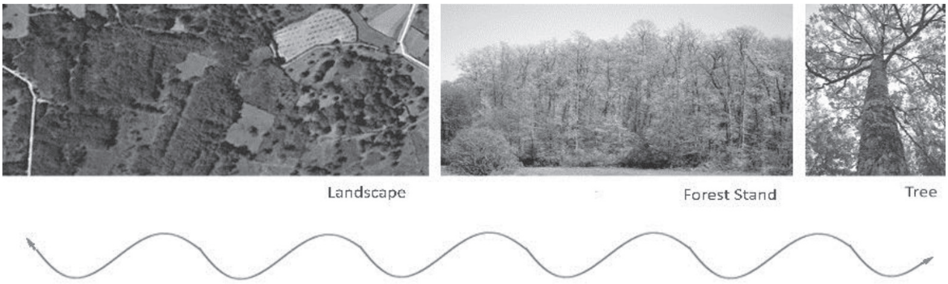
Keywords: forest ecosystems, forest management, landscape

1. Introduction: variability at different spatial and temporal scales

A given forest ecosystem is part of a landscape ecology matrix that develops as a whole and in which several processes operate in variable spatial and temporal scales. Forest dynamics and spatial variability are closely linked, involving the effects of biologic processes and external factors, which occur at a wide range of spatial scales. In turn, spatial variation of environmental conditions creates variable abiotic templates where forest communities develop. In the forest ecosystem, many aspects change in time and space, whether as a result of its own process or influenced by disturbances. The ecosystem functioning, in its various expressions, emphasizes the internal dynamics of the system in a particular state [1–3].

At the landscape level, different characteristics are involved, such as the amount of *habitat,* patch size, the landscape mosaic and connectivity, which are under the scope of biological conservation, ecological restoration, forest management, landscape ecology and land management [4]. Different management levels may be more or less dependent or related. In turn, different spatial scales can also be considered (local, regional and national).

The spatial pattern of forest patches involves elements such as size, quantity, type, proportion, shape and connectivity [5]. The landscape pattern may affect the



Spatial scale	Main characteristics
Landscape ↕	Mosaic of soil use. Spatial variation of site conditions. Different forest ecosystems. Different forest stands and interventions. Interaction of ecosystem processes.
Forest stand ↕	Characteristics of the forest stand. Site conditions and management options considering ecosystem functions and level of integration.
Tree	Tree origin, age or size and species. Tree characteristics and functions.

Figure 1.
Forest management considering different spatial scales: tree, forest stand and landscape. Fluxes and interconnections occur among these spatial scales.

ecological processes and the disturbances regime [6]. The spatial heterogeneity in forested landscapes may derive from different causes, including changes in ecological conditions, biotic interactions, developmental stages, land uses and disturbances.

In this chapter, the forest is assessed considering the variability at different spatial scales: the landscape, the forest population and the tree (**Figure 1**). A forest, of different size, is viewed as a part of the landscape, which might be structured according to a physiographic or natural model. A forest stand is considered a management unit that can be differentiated with a certain number of site and vegetal characteristics.

The understanding of the forest ecosystem's functioning and dynamics has improved over the past decades [7–13]. A better knowledge of their dynamics is important to forestry, providing a better decision support of the most appropriate practices to achieve certain objectives.

2. Disturbances and forest ecosystems dynamics

A better understanding of the forest ecosystem dynamics has allowed a broader comprehension about the influence of disturbances in the development of the forest stands and the landscape, therefore supporting the most appropriate forest management decisions.

All forest ecosystems are subject to disturbances, which may be of a different type and affect their characteristics and functioning. Natural disturbances are part of the dynamics of a forest ecosystem. The role of different disturbances, both spatial and temporal, is recognized as part of the forest development. Not only small disturbances are considered, but also major disturbances and even climate change, with their specific characteristics and occurrence.

A disturbance is any event that affects or disrupts a particular ecological process or ecosystem development; modifies the population structure; and changes the availability of a particular resource or the physical environment [6, 10, 14, 15]. A disturbance may be essentially described according to its type, frequency, magnitude or severity, extent and return period. The relative importance of each disturbance varies according to their characteristics and the type of forest.

The disturbance *type* is one of the most important characteristics of a disturbance regime. Disturbances may be biotic or abiotic, natural or anthropogenic, as well as endogenous or exogenous. Endogenous disorders are an integral part of the autogenic ecosystem development process. The potential to create endogenous disturbances varies with the species, the forest stand and development. The control and intervention on destabilizing forces are important for the development and stability, and the ability to minimize certain effects can be assessed, such as loss of water and nutrients.

The *magnitude* may affect more or less the existing plant mass. Some disturbances may destroy all vegetation, while others may leave some trees or other vegetation, which will influence the recovery process, depending on the number of remaining trees, species and position in the canopy. Major exogenous disturbances (fire, storm and clearcutting) result in a reduction or elimination of primary production and have different consequences in terms of biomass and export nutrients. A major disturbance may have an appreciable effect on the subsequent development of the forest ecosystem. For example, a fire may destroy a large part or all of the biomass and suppress primary production. At the same time, nutrients removed by volatilization and leaching can increase soil erosion. A clearcutting also removes a significant amount of nutrients present in the exploited material. A storm with the loss of many trees affects also the primary production; however, the biomass may remain in the system. Soil erosion, which can occur as a result of intensive logging, soil tillage or fire, has a strong negative impact on the ecosystem. A clearcutting or fire leads to the destruction of important hydrological, nutritional and biological soil properties. A clearcutting, particularly on steep slopes and thin soils, may lead to long-time changes on soil structure and the ecosystem biogeochemistry.

The disturbances *frequency* can be relatively variable and depend on the influence of various factors, both natural and anthropogenic. Typically, larger scale natural disturbances occur over longer periods of time. Disturbances may occur regularly or irregularly in time and space, which will be reflected in the stand characteristics and development. The *time* and *duration* of a disturbance are also important characteristics that may affect the ecosystem response.

The disturbance *extent* influences on the composition and structure of the stand, affecting the microclimatic conditions and colonization capacity from the surrounding areas. A disturbance may intervene at wide range of spatial scales (tree, stand and landscape).

Other relevant elements to consider in stand development are related to the initial conditions after a disturbance, the residual material and stand structural characteristics. A disturbance can create gaps of different size and shape, which may affect stand characteristics and dynamics. A given disturbance may affect different tropic and biological levels. The ecological effects due to disturbances and vegetation development vary with species. The resilience and the community type that are established after a disturbance are highly dependent on the ecosystem characteristics, the site conditions and the species that survive after a disturbance. Plants have different anatomical and physiological characteristics, with different adaptation and regeneration mechanisms, which allow them to face and survive certain disturbances.

A group of trees that develops after a disturbance is designated in some literature as *cohort* [9, 16]. The age range of the cohort may vary according to the extension temporal occupation. The cohort may also be referred to as singular or multiple if it results from one or more disturbance events. At the landscape level, different forestland uses may occur depending on the disturbance regime, the species, site conditions and objectives. A mosaic can be established with different compositions and structures formed by cohorts with different characteristics. Small stands do not behave like large stands since the edge is very much influenced by the adjacent area.

The direct and indirect effects of human disturbances on ecosystems and biological diversity are subject of debate and concern at various levels [7, 17–19]. Human activity has been affecting deeply forest and landscape characteristics for centuries or millennia (e.g., Ellenberg [20]). Patterns of land and forest use by man are also forms of spatial influence on ecosystems affecting various aspects such as connectivity or the edge effect on habitats. In many situations, we are witnessing a deterioration of habitats and destruction of biological balances at various territorial scales. Any effect on the ecological balance, or on any of its components, has repercussions on the entire ecological system.

3. The forest ecosystem in space and time

3.1 General forest stand spatial characteristics

There are three main forest stand characteristics that have a strong influence on spatial stand features. They are stand origin, structure and composition. Stand structure relates to the vertical stratification with different tree heights occupying

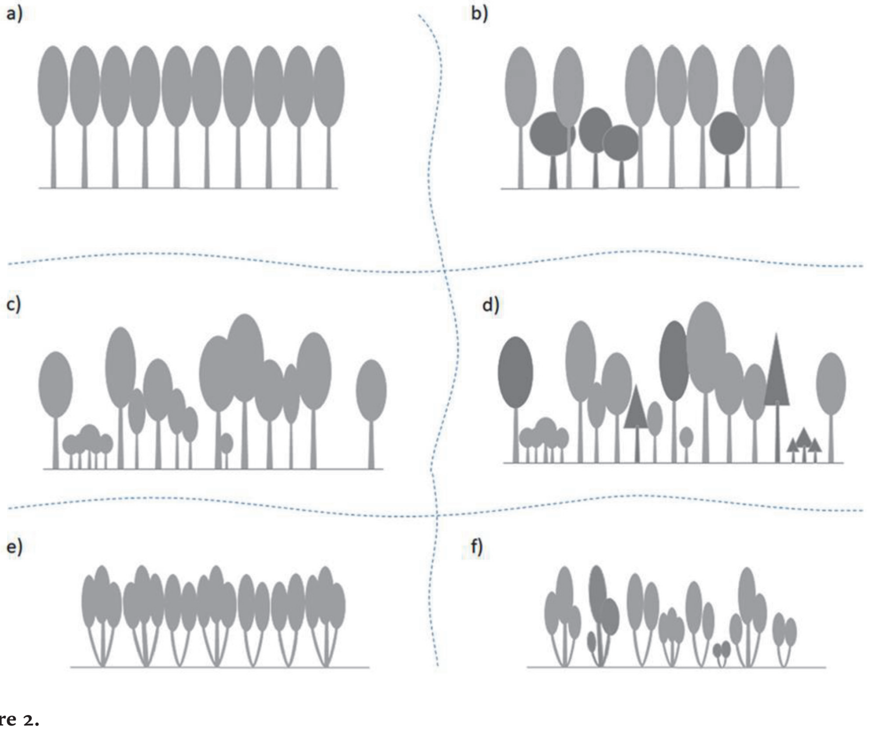


Figure 2.
Forest stand origin, structure and composition have an important role on stand characteristics, influencing many functional attributes of the ecosystem. Different combinations may lead to different silvicultural systems; some are represented here: (a–d) high-forest; (e–f) coppice; (a) pure even-aged; (b) mixed two-storied; (c) pure uneven-aged; (d) mixed uneven-aged; (e) simple coppice; (f) mixed uneven-aged coppice. The figure shows the vertical and horizontal distribution (spatial pattern) of the trees within the stand.

different canopy layers. Tree origin (seminal or vegetative) and species composition (pure or mixed) will also affect the stand stratification because of their different tree height and growth pattern. The combination and levels of stand origin, structure and composition lead to different silvicultural systems. These different forest stand components have a strong influence on the ecosystem functional processes that operate on both spatial and temporal scales (**Figure 2**). They affect stand yield, as well as forest ecologic and social functions. This also means that they have different silvicultural importance. Furthermore, their natural dispersion pattern within the stand also plays an important role and may introduce additional spatial variability (**Figure 3**).

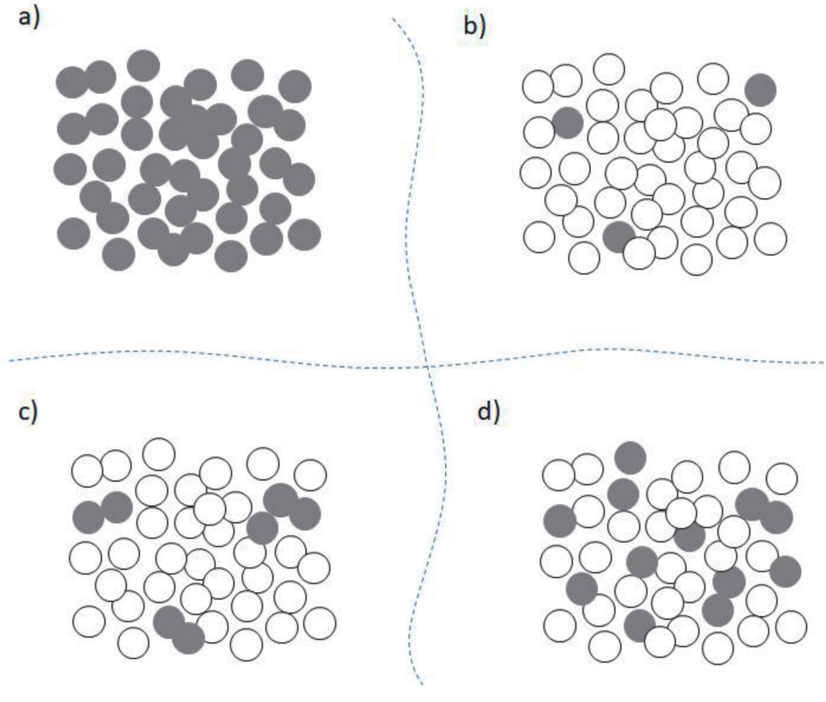


Figure 3.
*Natural tree horizontal dispersion patterns in forest stands, seen from above. A circle may represent a tree-unit of a different origin, size or species (white and gray circles represent different tree-units). Illustrated cases of stands with 1 and 2 combination of trees. Some trees and species tend to dominate stand composition and coverage appearing in large spatial groups (a), for a certain period of time. Others tend to naturally appear scattered with an isolated pattern (b) or in small groups (c) across the stand, while others may occur with a larger coverage in the stand (d). Besides a horizontal dispersion pattern, there is also a vertical canopy or stand stratification (**Figure 2**) according to the species, site conditions, tree size, stand dynamics and silviculture. These different vertical and horizontal tree and species occurrences and dispersion patterns introduce possibilities for spatial variability.*

3.2 Ecological succession: the forest ecosystem in time and space

The initial concepts concerning the ecological succession were guided to relatively predictable developmental stages of the ecosystem in general, and of plant communities in particular, in a succession of stages to a certain climax state [21]. Through ecological succession, with temporal changes in the vegetation, with biotic interaction processes, facilitation and inter- and intraspecific competition, as well as changes in habitat itself, are reached at a given time, a state of equilibrium with the climate, which results in a more stable condition and functional evolution. In this classic model of Clements, the succession consists of a predictable temporal sequence of plant communities, each modifying the environment and creating conditions for subsequent communities. This notion would be contrasted with an interpretation made by Gleason [22] where the plant communities are the result of processes of adaptation and individual development to environmental conditions, shaping the ecological continuous concept of vegetation. On the other hand, in several situations, the succession is greatly influenced by the initial plant species composition. In addition to the facilitation, other biotic processes are involved such as colonization, competition, tolerance, inhibition and survival, as well as other biotic interactions like herbivory and mutualism, which may lead to different dynamics [10, 23]. Later, other authors showed that plant communities did not behave in a simplistic way as postulated by Clements, but where the environment factors could give rise to different pathways and climax states in a given climatic region [7, 10, 17, 24–26]. On the other hand, the climax state was seen as a relatively stable equilibrium condition. Currently, the succession is mostly understood as a dynamic process of re-equilibriums and adaptations, in response to external disturbances and as a result of internal development processes of the ecosystem. The concept of succession has thus become more complex, where the prediction on the vegetation and ecosystem dynamics requires local specific information about the site characteristics, the type of disturbance, the composition and biology of the species. Many of the initial concepts included equilibrium characteristics related to the flows of energy and matter, tropic interactions and population dynamics. Complementary and alternative approaches developed concepts related to the temporal and spatial variability, the nonlinear dynamics and complex systems. On the other hand, the ecosystems are subjected to changes and adaptive processes of wider temporal scales as well as related with climate variations [11].

In addition to the temporal aspects, successional processes at the landscape scale with mosaic dynamics are also important to be considered [4, 6, 27]. In this sense, both the community and the ecosystem are landscape properties responding to changes in environmental gradients. One feature is the occurrence of successional stages across the landscape and time, gaps and patches of different sizes and trees of different growing stages within a stand.

The concept of *forest ecosystem dynamics* covers several notions, namely: the ecosystem is an open system; the ecosystems and landscapes are dynamic; the disturbance is a critical element of the system; the ecosystem is controlled by biotic and physical processes that occur at different spatial and temporal scales with levels of biological hierarchy; the succession does not necessarily follow the same pathway and ends at the same point of equilibrium; the spatial pattern is important for biological diversity; the interaction between ecosystem processes and landscape dynamics is important for biodiversity; past and recent human activities have an impact on ecosystems currently perceived as natural [3, 6, 19, 28].

The dynamics of the forest ecosystem and the temporal and spatial heterogeneity are related. The successional processes, disturbances and changes in the site factors create a complex of situations where forest communities develop (dynamic patches), which can be more wide and not necessarily in equilibrium [14, 15, 29]. Biotic interactions are also important, as are results from herbivores or pathogens and may in some cases be crucial in the development of the forest stand. The spatial pattern of the forest can itself have a strong influence on population dynamics and ecosystem processes. For example, habitat connectivity has a major effect on the abundance and persistence of certain species [30]. Therefore, besides the attributes of a certain forest, it is also important to consider the stand landscape context.

More recently emerged notions related to complex systems linked to the ecosystem dynamics. Profound changes may occur from small variations of the initial conditions. In sensitive systems, small changes to the initial conditions can result in large changes as the system evolves [10, 11]. The disturbances and heterogeneity are interdependent factors, creating opportunities for recolonization.

The different vegetation components of a forest stand are important for the ecosystem functioning. Feedback processes are also involved, which allow the development of self-regulation mechanisms. For example, less visible organisms (e.g., fungi) play important functions such as the formation of a good soil (decomposition, recycling of nutrients and formation of humic compounds), in a variety of biotic relationships indispensable for the ecosystem functioning. The temporal and spatial fluctuations, as well as the connections, are important aspects of the forest ecosystem dynamics.

The resistance and resilience concepts are related to the ecosystem dynamics, with their ability to absorb disturbances and recover to a given state. Some studies show that complexity offers greater stability to the ecosystem [10, 31–33]. The multiple interrelationships between a population and the community contribute to stability situations. The complex adaptive systems take into account the diversity and heterogeneity. They promote self-regulation, in which the reciprocal interactions within the system between the structure and processes contribute to the regulation, organization and dynamics. Different initial conditions are directed for a stable situation, becoming relatively robust for certain disturbances, where the system components adapt. On the other hand, in simplified or unstable systems, small disturbances may have a destabilizing and destructive effect.

3.3 Forest stand development stages

The forest development stages provide an idea about the changes that operate on a forest stand as regards the structure, composition and ecosystem processes associated with the dynamics of a population of trees. These stages seek to provide a general framework in which certain conditions and procedures are more prevalent. They occur successively and may also involve processes that operate at different sizes and moments in the stand. These variations are related to the concept of dynamic equilibrium of the forest ecosystem. The ecosystem functionality will be linked to structural, compositional and population dynamics characteristics.

Several authors (West et al. [7]; Oliver and Larson [9]; Spies [34]) recognized the following stages in the development process of a forest stand:

- Establishment, initiation or re-organization stage
- Stem exclusion stage
- Transition or understory re-initiation stage
- Old-growth or shifting mosaic stage

Figure 4 shows the evolution of total biomass at different development stages, after a clearcutting. In the re-organization stage, a loss of total biomass occurs, where growth and living biomass accumulation begin. In the stem exclusion stage, the ecosystem accumulates biomass to a certain point. In the transition stage, the total biomass decreases slightly until it stops in a fluctuating way in the old-growth or durable mosaic stage. The biomass reaches a maximum at the beginning of the transition stage, decreasing and stabilizing subsequently as a result of mortality of dominant trees that are replaced by smaller trees. Carbon retention in the living and dead components of the ecosystem may also reach a maximum at this stage. Throughout these stages, a development of the stand structure occurs through

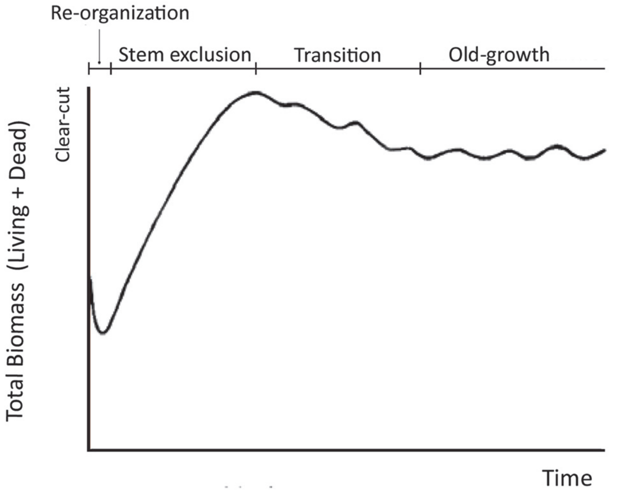


Figure 4.
Evolution of total biomass at different stages of stand development, after a clearcutting (adapted from Bormann and Likens [35]). Stages are delimited by changes in total biomass (living and dead biomass), assuming a natural development without exogenous disturbances.

different ways depending on the species, site conditions and the dynamics of the stand itself.

Old-growth stands receive a special attention from the point of view of ecology, conservation and forestry, addressing aspects related to biocenosis, genetics, ecosystem, management and the landscape. The various definitions on this stage or stand type show the diversity of interest. In its definition, structural elements as well as the state of the development process should be considered. According to Spies [34], it is a forest ecosystem distinguished by the presence of very old trees for the particular soil and climate conditions in which it occurs, showing certain morphological and growth characteristics.

The first phase occurs after the occurrence of a disturbance in which new individuals are established. The structural complexity varies depending on the type of disturbance and the present biological elements. Relative fast changes occur on the forest environment, the competition level, the species dominance and the population structure. At this stage, there is a great diversity of species, which may decrease as the space is being colonized by trees [36]. A severe disturbance leads to a regression of the forest ecosystem to an earlier stage of ecological succession. The development pattern after this event is also greatly influenced by the present floristic composition. The relative importance of species can vary in time and space according to the reproduction and growth strategies, and modifications of species dominance may happen.

At this stage, as a result of the disturbance, there is a loss of biotic regulation of the system. Hydrological and biogeochemical parameters are changed and deregulated. In turn, there is a temporary increase in the availability of resources, as well as an increase in solar radiation at the soil surface. The clearcutting has a strong effect on many ecosystem processes and greatly modifies the regulation ability of radiation energy flow as well as the hydrological and nutrient cycles. With the removal of the forest cover, the microenvironment is affected, with an increase of the soil temperature as well as various processes such as the absorption of nutrients and water, transpiration, the absorption and reflection of solar radiation, the primary production and the production of litter. The system's ability to store water and nutrients is greatly affected. The decomposition of organic matter is accelerated. There is a loss of soil organic matter and an increase of soil acidity.

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The restoration of vegetation leads to a progressive reduction of soil erosion. Nevertheless, some studies show that even several years after clearcutting, having attained a full canopy coverage, which may extend for 15 years or more, may still register important decrease in the soil organic matter and nutrients until full control is restored [35, 37, 38] which in turn affect attributes such as soil water holding capacity and carbon storage (**Figure 5**). A reduction in soil thickness may also occur, which may extend for a long time after a clearcutting as a result of the effects in many ecosystem processes [39, 40].

The reduction of transpiration and soil water holding capacity has a pronounced effect on the hydrological cycle. There are frequent situations where rainfall produces flooding. Situations involving the transport of particles and soil erosion become more problematic. This stage ends when the living and dead biomass are accumulated in the ecosystem and end the decline of organic matter, and the restoration of biotic regulation of the hydrology and nutrient exportation occurs.

In the stem exclusion stage, a progressive reduction of tree density typically occurs as a result of the intense competition among the trees. The more evident characteristic is a rapid accumulation of biomass with a competitive exclusion of many individuals where mortality is very much dependent on the population density. The net primary productivity can be very high and some characteristics of the population, such as leaf area, can reach a maximum. The loss of nutrients at this stage is lower due to intensive use of existing resources. The stand instability against unfavorable atmospheric events may be higher due to a high population density. The tree mortality is more intense particularly in the lower and intermediate classes of light-demanding species, so there may be a reduction of the species diversity compared to the first stage. At this stage, the canopy is relatively uniform and there are few gaps. Canopy openings as a result of death of individual trees are of small size. Variations in the growing space, the species, tolerance, age, genetics, competition, site characteristics and external factors influence the growth pattern. The density of the dominant trees decreases as its size increases. Compared to the previous stage, there is a better regulation capacity of the energy flow, hydrological and nutrients through the biotic and abiotic components of the ecosystem. Another important feature is the regulation of the chemical composition of the drain water.

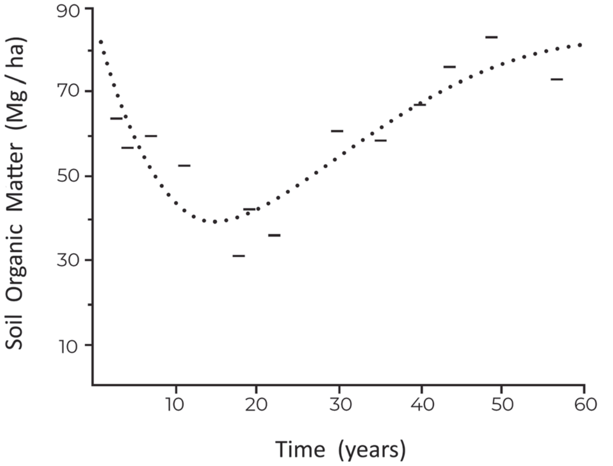

Figure 5.
*Following a clearcutting, on a broadleaved stand (*Acer, Betula, Fagus, Fraxinus *and* Prunus*), a degradation of the soil organic matter occurs that extends up to 15 years and a loss of 51% of the initial content. The recovery to initial values may take nearly 40 years (adapted from Covington [39]).*

In the transition stage, some authors recognize that in some types of forest there may be steps or sub-stages (understory release, maturation, early transition, and old-growth and late-transition old-growth) [41]. Two major steps may occur: a transition phase and a steady-state or shifting gap phase. Gradual changes occur in the population, the structure and development process, which together may have a very variable duration. The living biomass and diversity of forms reach a maximum. The initial group of trees disintegrates gradually, the mortality of lower trees increases, and a new group of trees may gradually grow in gaps. Some authors such as Oliver and Larson [9] recognize a stage of re-initiation, where a new group of trees grows in the understory. A transitional phase to an old-growth is developed where initial trees are also present. Compared to the previous stage, a progressive decrease of total biomass up to a more or less stable level occurs. The amount of dead wood tends to be more or less stable, fluctuating around a certain value. Species diversity increases where endogenous disturbances become more important. The death of trees leads to changes in microclimate conditions and resources. Canopy gaps promote the availability of resources, which are used by pre-existing or new regeneration. The occupation that occurs will promote stand stratification. This stage presents a great stability and resilience of the ecosystem to destabilizing events.

The old-growth or shifting mosaic stage is characterized by a pattern of relatively small disturbances, resulting in gaps of different sizes, which create conditions for the establishment of new trees and growth of trees from the lower and middle layers. The aggregation and dynamics of these small disturbances, and tree response from a larger spatial scale, result in a very small change state. Hence, some authors also designate this stage as a durable state or dynamic mosaic [7, 35]. A longer period of time is required for the establishment and development of this stage. In most cases, it is not present or occurs incompletely as a result of logging activities or frequent disturbances. The disturbance pattern, climate fluctuations and other external factors affect also the stand development. Some structural features are present in this stage, such as old and large trees, dead standing and down trees, trees of variable size and age, and a diverse understory. According to several authors, the total biomass remains relatively stable with little fluctuations over time. Slight variations of biomass occur between different parts of the ecosystem, the living biomass, dead wood, floor organic matter and the soil organic matter, with development interactions and balances. The environment conditions do not differ much from the last transition stage.

At this stage, there is a progressive elimination of old dominant trees and the development of dominant trees of different ages. These processes may lead to the formation of a population with a high degree of differentiation and structure. The stand may contain different tree species, which develop in different microclimate conditions. The stand may present a considerable biological diversity. At this stage, there is also a horizontal diversification, with different structural units.

The diversity of habitats increases as the ecosystem includes various states of development. Certain species have a greater abundance and development at this stage, due to their low rate of colonization and growth, as with certain lichens, fungi and tree species. Many species are dependent for their survival of dead wood or other structural features of the stand only present in this development stage.

Regarding the hydrological and biogeochemical cycles, dynamic oscillations occur as a result of occasional disturbances. Nevertheless, the ecosystem taken as a whole is relatively stable and resilient through different processes. There is a stabilization of the total biomass and storage capacity, regulating the export of nutrients. This stage corresponds to a relative equilibrium condition in relation to growth and mortality, the hydrological and biogeochemical state. The forest ecosystem has a great resilience, able to absorb disturbances and persist within certain limits.

4. Tree-level variability

Trees have various attributes such as the species, age, size, anatomical features and the dispersion or occurrence pattern (**Figure 3**). Another dimension is related to the function that a given tree may have depending on its characteristics, location and silvicultural options (**Figure 6**). This aspect introduces an additional element of variability. These functions may be related to aspects such as: production; protection; education; regeneration; biodiversity; and aesthetics. In turn, different species present distinct natural dispersion patterns. Certain species occur on an aggregate pattern, while others are more scattered.

The presence of certain trees with particular biodiversity objectives and providing tree-related microhabitat structures is also an important aspect to consider (*habitat trees*). These are living or dead trees with singular anatomical characteristics or providing ecological niches of interest to a wide range of various life forms including rare and endangered species. Anatomical features such as tree size, snags, branching variations, broken top, dead branches, stem cracks, fork crack, rotten wood and stem cavities are of interest. In some cases, these might be remarkable and monumental or veteran trees. Different studies have shown that the presence of large trees, cavernous and dead trees, standing or down, has an important contribution to biodiversity [13, 42]. These microhabitats support a complex biological network, providing food, shelter and reproduction space, contributing to the ecosystem functioning. Certain species are particularly associated with these habitats, being important conservation components (e.g., saproxylic fungi and insects).

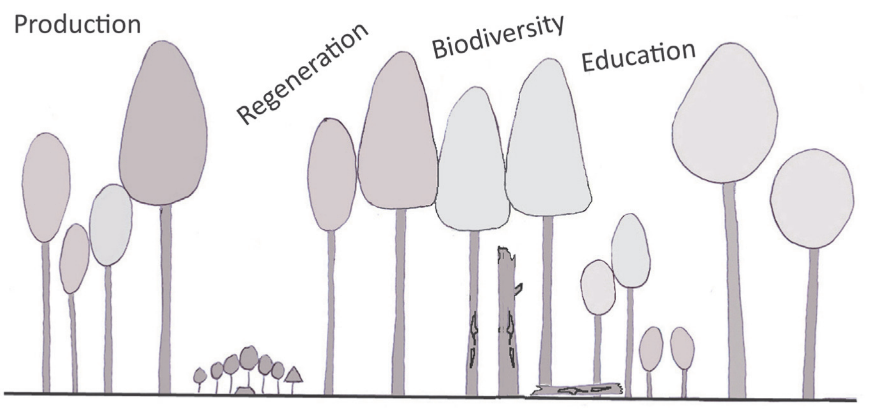

Figure 6.
Representation of some functions attributed to trees. Diverse tree characteristics may provide different functions and variability.

5. Forest ecosystems in the landscape

The forest has vital importance at the landscape scale, going far beyond the production of materials and energy, called *tradable goods*. The other functions of the forest in the landscape are the conservation of water, soil and biodiversity. These supporting ecosystem services are interrelated with other forest-related ecosystem services, such as climate regulation, bioclimatic comfort and other cultural services (landscape contemplation, recreation and cultural heritage). The quality of the ecosystem services provided depends on the principles of landscape planning, followed by the technicians and policy-makers, which will also determine the sustainability of the forest.

The adequate provision of forest ecosystem services, without disturbing the landscape equilibrium, depends on the understanding of the ecological and cultural landscape context. For this, the forest planning needs to be defined in articulation with other uses considering the river basin context. The river basin is a fundamental landscape unit of planning because everything flows in it: water, sediments, nutrients, air, through the local breezes (mountain and valley), and even man and goods. This flow of energy and materials depends on the land morphology of the river basin [43], but also ecological components, invisible or unnoticeable to an ordinary observer, such as the lithology, the characteristics of soil and the land cover types existing in the basin with different behaviors in the rainwater infiltration. This last aspect of the land cover is also crucial in the thermal and water balance of the atmosphere, because if there is a change on the land cover and land use, there is a changing of the planetary albedo, meaning a change on the reflection coefficient for solar radiation. Albedo is a crucial climate factor. Thus, climate change should be discussed in an integrated way [44] concerning the impact of land use and land cover changes.

The location of the forest and the type of species used should, therefore, be planned to take into account all these aspects, through a landscape design that articulates them in patterns of occupation (mosaics) capable of also ensuring other functions previously described, such as continuity and stand fragmentation.

The methodology that has been developed considering the integration of different components of the landscape system is being studied in the SCAPEFIRE project (**Box 1**). The conceptual approach is to include layers by objectives and then develop their spatial integration. In order to ensure the ecological sustainability of the landscape, the layers considered are (i) water conservation, (ii) soil conservation and (iii) biodiversity conservation. To these is added one more layer concerning the sustainability of the forest by itself: (iv) the prevention of rural fires. The areas from (i), (ii) and (iii) are included in the landscape ecological network [43, 45, 46] and need to be carefully planned.

The overarching goal of the SCAPEFIRE Project is to propose a landscape planning model that contributes to the prevention of rural fires, considering the ecological, economic and social sustainability of the landscape. Some Portuguese landscapes are highly combustible due to the last four decades of inadequate policies. Despite the importance of spatial planning as a core component in the rural fire prevention, mentioned in the media and the political discourse, its definition and implementation are still to be accomplished. The proposed project is based on the assumption that a paradigm shift in the land use is needed in favor of a lesser "fire-prone" and a more sustainable model. Acknowledging the current economic importance of the most fire-prone species, the aim is to create a landscape protection structure against rural fires that ensures soil, water and biodiversity conservation and socio-economic viability. This structure will be adapted to each type of landscape. In addition to the proposal for a new land-use planning model, the economic evaluation of multifunctional agroforestry systems will be carried out. Moreover, by improving and valuating native broadleaved species by their multiple goods and services, they provide with higher comparable profitability. Therefore, this project aims to integrate the sectoral themes in a landscape/land-use plan. Its main innovation lies in the transdisciplinarity that has not been usual, either in the field of rural fire research or in public and political discussion. The core project team consists of a permanent group of researchers based at LEAF/ISA/ULisbon, where coordination is located. This team will bring together researchers across several Portuguese research centers and other national institutions and the Pau Costa Foundation with extensive knowledge on fire ecology and operational fire management at landscape level. Stakeholder participation will be present throughout the Project, through a group of researchers, public entities linked to land-use planning, at national level (Directorate General of the Territory), and local (municipalities), but also owners and the Portuguese Federation of Local Development Associations (MINHA TERRA).

Box 1.
Species movement.

5.1 Water conservation

The main objective regarding water conservation in a river basin is to maximize its concentration time, meaning to increase its retention as long as possible before arriving into the sea through the rivers. This objective is most important in the Mediterranean climate, as in the case of Portugal, where precipitation occurs in the cold season when plants are at vegetative rest, so there is an imperative need to store rainwater in winter so that it can be used in summer. The best storage is underground, that is, in aquifers, because this prevents evaporation losses and provides better water quality due to the effects of filter and buffering capacity of the soil. In order for water to get to aquifers, it must be retained so that it has time to infiltrate.

Infiltration can be achieved in two ways: a natural mode and a forced mode, that is, with active measures in that direction. Natural infiltration requires knowledge of the combined permeability of lithology, soil and slope degree [47].

At the river basin scale, it is also essential to address the areas where infiltration is ensured, even at low permeability. It is vital to infiltrate and retain water in the headwater systems [48] and, as much as possible, in the upper third of the basin. In this regard, Molchanov [49] indicates a minimum size of 40% of the basin's afforestation area, ensuring a convenient full water flow.

Another measure to achieve water retention is the selection of vegetation species that can contribute to good soil that has water retention capacity and also to produce a highly absorbent organic layer of soil (leaf litter and humus). In this regard, Molchanov recommends a combination of hardwoods and *Cupressaceae*. The species to be used must be autochthonous, meaning that, in each case, research is needed on the best leaf litter to obtain. As for soil capable of better retaining water, it will be developing in the following point, which is a common feature of all landscape-system layers.

Other areas of the river basin where water conservation is required are the streams, their banks, and floodplains, and also the springs. The banks and springs should be lined with vegetation from the riparian gallery, from various strata, from aquatic herbaceous plants to the tree layer. Floodplains, depending on the time of year, are wetlands, or even subject to flooding. They should be reserved for suitable crops or riverside trees and never have buildings (other than small irrigation or other support infrastructures). Depending on their situation in the river basin (upstream or downstream), these areas usually do not infiltrate water, especially in the rainy season, when the lower section has already depleted the infiltration capacity. Floods that occur downstream of the basin, depending on conditions, can to a large extent be controlled or mitigated by basin planning, especially in the upper third, either with appropriate coverings or with forced measures.

5.2 Soil conservation

Soil plays a crucial role in the capacity to retain water. This capacity depends on the texture of the soil (coarser textures seep more water, while the finer textures retain it until the soil reaches field capacity, after which it begins to shed water and needs to be drained to support the plants) and depends on the soil structure. Only a well-structured soil can retain water through the clay-humic complexes and for that it has to have organic matter, including lignin, and a balanced microbial life, in which all microorganisms play an essential role, including fungi due to mycelia and their role in improving the conditions of nutrient use by plants.

These characteristics are usually ignored by people, but also by technicians who advocate soil-destroying cultural practices. These include soil loss by building or compaction, but also by soil tillage or tillage techniques, contributing to water evaporation and erosion, especially as the slope increases. Also, the practice of prescribed fire and the use of biocides are severely detrimental to soil quality due to the destruction they cause of their biome. The issue of erosion should be addressed in the presence of soil erosion maps [50] in order to propose the best land cover to provide pedogenesis and water infiltration. In the absence of these maps, it is well known that, among the factors involved in erosion, the slope is decisive, so depending on the soil types and the evidence of erosion, it is necessary to evaluate which slopes from which erosion control techniques should be programmed. However, on slopes greater than 25%, those soil erosion control techniques should always be considered.

5.3 Biodiversity conservation

Concerning the conservation of biodiversity, much has already been mentioned. With regard to the landscape, aspects that still need to be considered, apart from those for water and soil conservation, are the fragmentation and continuity necessary for the conservation of life flows (plants and animals) (**Box 2**). Continuity should be ensured in the main structural lines of the landscape (ridges and waterlines), creating links with existing forest areas. Where there is no forest, both in rural and urban areas, continuity should be achieved by partitioning the landscape through linear biodiverse structures (hedges) consisting of shrubs and tree species, depending on the functions to be obtained, in addition to biodiversity (wind protection, reduced evaporation, shading, field or path delimitation, etc.).

An important aspect about the variability and biodiversity is related to the landscape and fragmentation of the forest habitat. Many studies, including in the Mediterranean region, have shown that an excessive forest fragmentation is another element of fragility and vulnerability of the forest with adverse effects on biodiversity, economic and landscape values [51–54].

As the forest is gradually fragmented, with patches of reduced size and increasing distance, the habitat became increasingly more isolated. This has a major impact on habitat loss, on the different biotic communities, the population dynamics and processes of the forest ecosystem. Habitat connectivity has an important effect on the persistence and abundance of different species [55, 56]. The gradual fragmentation may also lead to the extinction of species of different biological groups that are more sensitive to this process. The colonization of a species results from the combination of dispersion and recruitment. Certain species of slow dispersion are affected by excessive fragmentation. For certain species, with a narrow ecological niche or limited dispersal ability, habitat reduction leads to risk of extinction of local populations. On the other hand, small fragments are more susceptible to degradation factors. In smaller fragments, the edge effect is larger.

Habitat destruction leads to biodiversity loss not only in the affected areas but also in the fragments due to the population size reduction, the disruption in the movement and interactions [52]. The functional connectivity is a crucial factor in the viability of certain populations, the dynamics and interspecific interactions (e.g., Tilman and Kareiva [57]). Species movement and dispersal, genetic exchange and other ecological flows in a given area are important for the survival and viability of many species [19]. Some studies show that as the proportion of a given habitat reduces, the colonization possibilities of the remaining fragments decrease (e.g., With et al. [42]). Fragmentation has also effects on the stand genetic variability [58]. Recovery after a disturbance will be heavily influenced by the availability of seedlings and the connectivity to existing nearby populations.

Box 2.
Fragmentation of Forest Habitat.

5.4 Conservation of the forest itself: prevention against rural fires

The occurrence of mega-fires in recent decades, not only in Portugal (since the 1980s), but in other countries, introduces another problem to solve in landscape planning: rural fires. Admittedly, landscape management cannot solve all occurrences, especially when they are of criminal or negligent origin. Nevertheless, it can reduce the size of the fire, curb its progression and even promote its self-extinguishment.

One of the critical components of fire behavior is known to be basin morphology, including slope, aspect and altitude [59–61]. The slopes exposed to the north, with slopes >25%, are the least burning [62]. The speed of fire progression doubles for each 10° increase in slope [63] and is reduced when it reaches the top, due to the local wind from the opposite slope. When it reaches the ridge, if it does not progress in the opposite slope, the fire begins to plow toward the lower slope, more slowly than when the slope rises. Given this pattern of fire behavior, it is essential to create a landscape fire-prevention network directly related to the watershed morphology that contains or extinguishes the fire. Agee et al. [64] propose the installation of shaded fuel breaks as low-fuel vegetation strips or areas (note that they do not correspond to the fuel management strips provided for in Portuguese law, with no vegetation and bare soil). These authors propose that these shaded fuel breaks be networked, according to the site, and say they are more efficient if they are wide and have surface fuel control bands.

The key areas of the river basin in which to intervene for this purpose are the structuring lines of the landscape-the streams and the ridges. According to Povak et al. [65], the waterlines and associated valley bottoms are more important for this purpose than the ridges. If the slope is too long, one or more fire retardant strips should be introduced downhill along the slope to avoid top-down and down-up fire [61]. To complete the structure, it is also necessary to create strips transverse to the slope. In the hillslope, the streams and the secondary ridges alternate, so it is in these secondary lines that these fire-retardant strips should be created [66].

Concerning the species to be used, there is a considerable debate about the higher or lower combustibility of species. In Portugal, *Eucalyptus globulus* Labill. and *Pinus pinaster* Aiton. have occupied the country and are currently the two species with the present main commercial value, since the industries related to the transformation of autochthonous species have practically disappeared, which discourages the owners for their use. The simple empirical observation of fires and their consequences, as well as the analyses carried out on the species that burned the most, allows to say that these two tree species are more combustible than the autochthonous tree species. From the available literature, Silva et al. [67] verified a tendency toward fire, in decreasing order of: pinewood, eucalyptus forests, broadleaf forests, unspecified coniferous forests, cork oak forests, chestnut orchards and holm oak. They also concluded that stand composition is the most important variable to explain the probability of fire. Calviño-Cancela et al. [68] also state that autochthonous species are more fire-resistant, as well as the studies concerning leaf litter combustibility [69]. In this context, it has to be admitted that species are not equally combustible and that, as might be expected, hardwoods other than eucalyptus are more fire-resistant and therefore can be regarded as fire-retardant. The landscape fire-prevention network should, therefore, be planned with different tree species, always avoiding monocultures. In this network, it is also possible to have the agricultural fields, pastures and, ultimately, voids (without shrub or tree vegetation) that, however, should be covered with herbaceous plants so as not to leave the soil uncovered and prevent its erosion.

6. Evaluation of the forest condition in Portugal: analysis and results

Different characteristics and variables concerning the forest of Portugal were evaluated to provide an overview of their status and condition. Data were collected considering different sources and analyzed, taking into consideration the main features related to the sustainable forest management goals and including the forest landscape features in relation to the habitat mosaic and connectivity.

An analysis considering the patch size by forest type and the land morphology was performed.

Table 1 presents several characteristics of the forest in Portugal and its comparison with Europe.

Variables and indicators	EU-27	Trend	Portugal	Trend	Evaluation
Forest area – 2010 *(x 1000 ha)*	177,757	+2%	3164	−2.5%	🟠
% land area (average)	38.0	1990–10	35.5	1995–15	
(range)	(10.8–76.6)				
Growing stock (*M* m^3)	805.6	+12%	154	−27%	🟠
(*average and range*)	(13–3466)	1990–10		1990–10	
Coppice forest (*% forest area*)	9.8		27.4		🟠/🟢
(*average and range*)	(0–48)				
Irregular stands *(% f. area)*	25.8		3.0		🟠
(*average and range*)	(0–95)				
Tree species composition					
(*% forest area*)					
1 species	29		50		🟠
2–3 species	51		44		
≥4 species	20		6		
Introduced species *(% f. area)*	5.0	+0.7%	28.0	+14%	🟠
(*average and range*)	(0–70)	2000–10		1995–2015	
Regeneration *(% f. area)*					
Natural regeneration	56		53		🟠/🟢
Planting	34		25		
Coppice	10		22		
Carbon stock – above gr (*M t C*)	292	+26.8%	102		🟠
(*average/country and range*)	(23–1405)	1990–10			
(*average t C/ha*)	44		32		
Forest functions *(% f. area)*					
(*primary function*)					
Production	61.9		64.7		🟠/🟢
Protection soil and water	9.7		7.5		
Conservation biodiversity	12.2		5.5		
Social services	2.0		<1		
Protection area	14.2		22.3		
Fellings (*M* m^3) (*average*)	16.9	+19%	9.6		🟠/🟢
(*average/forest area,* $m^3\ ha^{-1}$)	2.6	1990–10	3.0		
Products (*sum & average*)		−9%			🟠/🟢
Roundwood (*M* m^3)	405 (15.0)	1990–10	9.6		
Mushrooms (*M kg*)	429 (15.9)		n/a		
Fruits (*M kg*)	376 (13.9)		23.7		
Cork (*M kg*)	169 (6.3)		140		
Honey (*M kg*)	242 (8.9)		7.8		
Soil condition (*C/N*)					🟠/🟢
Organic floor	25.3		31.6		
mineral 0-10 cm	17.4		16.4		
Desertification (*% f. area at risk*)	n/a		60		🟠
Forest damage (*% f. area*)		+2.5%			
Insects and diseases	2.8	1990–10	9.2		🟠
Grazing and wildlife	2.2		38.0		
Invasive trees	0.05		0.17		
Fire	0.2		4.2		
Storms	1.7		n/a		

Variables and indicators	EU-27	Trend	Portugal	Trend	Evaluation
Naturalness (*% f. area*)					
Undisturbed by man	4		n/a		🟠
Semi-natural	88		62		
Plantations	8		38		
Deadwood (*m^3 ha^{-1}*)	10		1.0		🟠
(*average and range*)	(2–41)				
Forest connectivity index	0.75		0.7		🟢
(average normalized connectivity/ landscape unit)					
Threatened species (*n°*) – 2005					
(*average and range*)					
Trees	6 (0–30)		22		🔴
Birds	30 (1–248)		103		
Mammals	14 (3–31)		19		
Other vertebrates	15 (1–81)		n/a		
Other invertebrates	97 (4–476)		n/a		
Vascular plants	194 (7–1196)		144		
Fungi	300(77–1284)		n/a		
Protected forests –		+0.8%			
Biodiversity C.I & Landscape		2000–10			
C.II (*% f. area*)	18.1 (5–45)		5.5	−0.2%	🟢
Natura 2000 (*% f. area*)	21.1		23.3	1995–2015	
Forest w/management plan (*% f. area*)	77 (10–100)		44		🟠/🟢
Certified forest SFM (*% f. area*)	62		15.3		🟠/🟢
Contribution GDP (*%*)	1.0 (0.2–5.0)		1.6		🟢/🟠
Export – Import (*M euros*)	2106		1036		🟢

Reference year 2010 [70–73]. 🟢 *Good/Fair;* 🟠 *Need improvement;* 🔴 *Bad/At risk.*

Table 1.
Status and condition of the forests in Portugal, and comparison with Europe (EU-27).

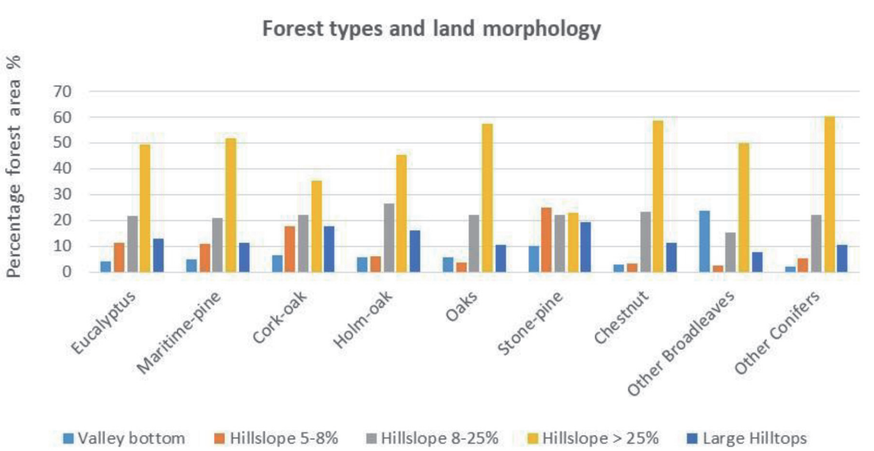

Figure 7.
Different forest types in relation to the land morphology (percentage in relation to each forest type) (collected data using [74]). In Portugal, forest land use covers 3.2 million ha (36.2% of land area) (2015, [71]). The forest and agroforest types and land percentage cover are eucalyptus, mostly Eucalyptus globulus *Labill. (26.2%), maritime-pine* Pinus pinaster *Aiton. (22.2%), cork-oak* Quercus suber *L. (22.3%), holm-oak* Quercus rotundifolia *Lam. (10.8%), other oaks* Quercus *spp. (2.5%), stone-pine* Pinus pinea *L. (6.0%), chestnut* Castanea sativa *Mill. (1.5%), carob* Ceratonia siliqua *L. (<1%), acacia* Acacia *spp. (<1%), other broadleaves (5.9%) and other conifers (1.6%).*

Figure 7 shows the relation between each forest type and its location in land morphology, using categories defined by [75]: valley bottoms, hillslopes and large hilltops. The location of the forest in the Portuguese landscape not always fulfills the best soil and water conservation goals. Most forest species and the two species with the higher occupation and use (eucalyptus and maritime-pine plantations) are mostly located in slopes above 25%, which normally represent the less suitability for forestry production, due to the high susceptibility to soil erosion and other issues, considering the silvicultural practices that have been applied.

The study of the dimension of the forest stand also shows that the current landscape has extensive areas of fire-prone eucalyptus and pine plantations and monocultures, with patches over 100 ha (**Figures 8** and **9**) (collected data using [74]). The large amount and contribution to the total forest cover of these forest areas are mainly eucalyptus (18%) and maritime-pine (17%) (**Figure 8**).

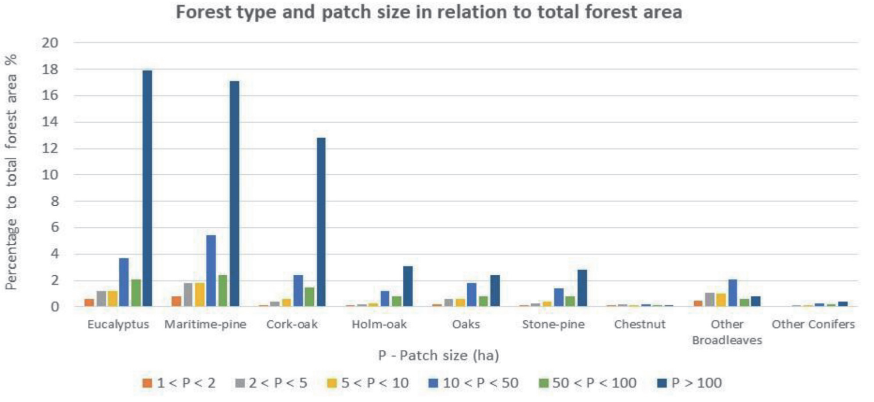

Figure 8.
Forest type and patch size in relation to total forest area in Portugal (contribution of each forest type and patch size to the total country forest area).

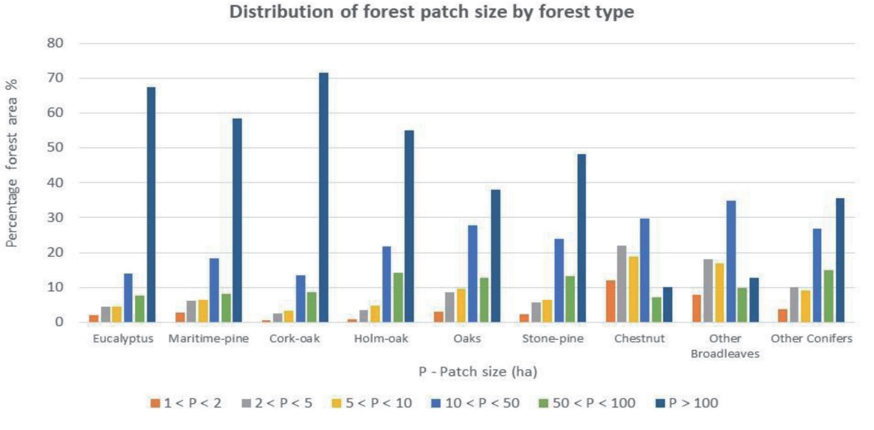

Figure 9.
Distribution of patch size for different forest types (percentage in relation to each forest type).

6.1 The landscape plan

The landscape plan that will define the composition and location of the forest in the landscape must respond to the aspects mentioned: soil conservation, water conservation, biodiversity conservation and conservation of the forest itself, such as many others related to the human activities (accessibility, urban settlements, etc.).

The former text highlights the following keywords: water retention, infiltration, headwater system, land morphology, lithology, permeability, species, combustibility, leaf litter, margins, floodwaters and springs, soil and its texture and structure, building and/or compaction, erosion, cultural practices, continuity, landscape fire-prevention network. All these keywords give an idea of the complexity of the subject of the landscape/land-use planning.

The areas of the river basin where nature conservation issues (*latu sensu*) must be addressed have already been mentioned and constitute the materials of the landscape plan (**Figure 10**). In addition to the location, the species to be used must be defined as well as cultural practices and management models. The species to be used must correspond to their ecological suitability [76], and depending on the role, a specie or mixture of species can perform in the ecosystem [49]. As for the most combustible species, such as *Pinus pinaster* Aiton. and *Eucalyptus globulus* Labill., in case of use, a place may be reserved for them, and always outside areas where nature conservation or ecological restoration is a priority [77], such as extremely degraded areas.

In Portugal, the native species were almost banned, in the name of an economy linked to paper pulp and other wood products, opting for faster growing species managed in monospecific stands that constitute deserts, both animals and people. This model has had severe consequences on the depopulation of the countryside, with emigration and exodus to the cities, living in unhealthy settlements and underpaid jobs, leading to the current high risk of rural fires. It is important to take technical and political measures to improve and valuate native broadleaved species by their several goods and services, combined with management techniques that provide better profitability and contributing to sustainability.

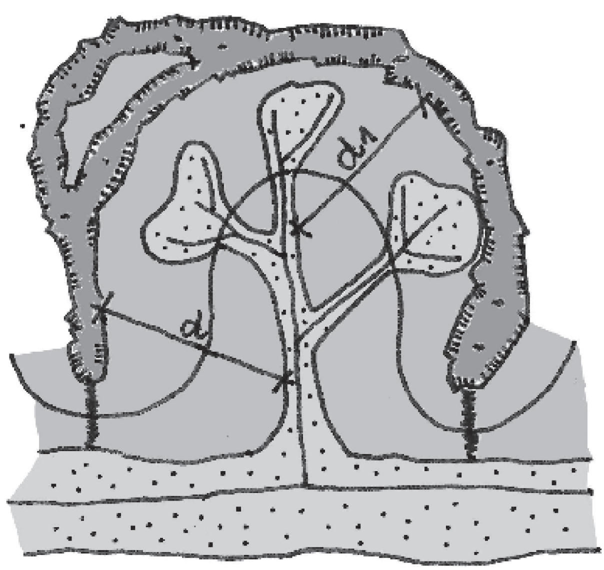

Figure 10.
Conceptual scheme of landscape intervention on a river basin. The valley bottom and streams should be used for agriculture, grazing and/or riparian species; headwater systems should be covered by hardwoods which might be interspersed with void fields intended for grazing purposes. Hillslopes might be covered with woods for production interspersed with longitudinal and transversal autochthonous hardwood species, depending on the slope length (d, d1) and along the contours (adapted from Magalhães et al. [66]).

It is now necessary to reverse this landscape organization model, through a new paradigm that will take at least three decades to implement and that has to be actively funded by the government.

7. Conclusion

The analysis of the forest characteristics, the type of forest and its current location in the landscape of Portugal indicates that the silviculture and the landscape planning paradigm need to be changed.

Forest ecosystems involve biotic and abiotic processes occurring at different spatial and temporal scales, and at different levels of biological hierarchy. A relatively uniform management originates a pattern of relatively low diversity, which results in a loss of some processes and species. An excessive artificiality of the forest also increases their susceptibility to disturbances. Several studies show that complexity improves important forest attributes such as biodiversity, yield, resistance and resilience to several factors or disturbances (e.g., Hansen et al. [78]; Lindenmayer and Franklin [4]). Stand structural diversity, connectivity and landscape heterogeneity are important for ecosystem functioning and biodiversity.

Silviculture may be also related to the spatial and temporal scales in which the different ecological processes occur. It may be incorporated into a planned landscape, which can encompass different ecosystems and forms of intervention, seeking the sustainability of natural resources.

Diversity and landscape interactions can be promoted considering variations on the following main elements: site ecological conditions; composition and structural characteristics of the forest stands; forms of land use (forestry, agro-forestry, agriculture and pasture).

At the landscape level, management requires a spatial and temporal coordination of silviculture applied to different stands, trying the ecological maintenance or restoration of the landscape. At the forest stand level, according to the site conditions, objectives and assigned functions, silviculture suits the stand characteristics related to structure and composition. An integrated ecological-based silviculture provides a set of values that improve the economic efficiency and ecological conditions of the stand. In turn, at the landscape scale, forestry can be combined with other forms of land use, as well as with the variations of the site characteristics that might lead to forest patches with different characteristics and silviculture. In larger forest areas, units can be built differing by their characteristics and objectives, which may allow a diversification of interventions and operations, within a classified division and planning.

Biodiversity should also be evaluated in the spatial and temporal scales. For example, different units are viewed as interacting elements that continuously vary in space and time. Depending on the requirements of a given species, there may be a hierarchical space structuration for different groups, populations and metapopulations. The integration of biodiversity into the multifunctional silviculture is achievable considering a wide living space of habitats where the flora and fauna coexist and interrelate. Therefore, organizing communities and processes requires considering the spatial and temporal scales. Different habitat components can be managed in different scales (tree, stand and landscape). Ideally, various components of biodiversity are considered at different scales. Increasing structural diversity and spatial variability creates different ecological conditions that can promote biodiversity and resilience to disturbances (e.g., Turner et al. [79]).

Silviculture has a major influence on the presence and maintenance of microhabitats. The abundance and diversity of microhabitats considerably increase with tree size and age. The existence of trees with cavities and dead wood is of particular interest to many specialist species. The tree species also plays an important role, and there is interest in certain species by their naturalness, kind of tree-related micro-habitats and associated species. Silviculture should allow the maintenance of large trees, dead wood as well as certain species, which exhibit certain features of interest for biodiversity. Trees without economic value may be maintained by its biological value, without decreasing stand production, and avoiding harvesting costs, and, on the other hand, contribute to a better functioning of the ecosystem, with positive effects on the production of the stand.

Besides ecosystems and species diversity, biodiversity also involves genetic diversity. Genetic diversity in a given population of trees is determined by the long evolutionary history and population dynamics. A genetic diversity, in terms of intra- and interpopulation variability, is also an aspect to consider in silviculture given its importance to various levels as element of biodiversity in forest growth and production and survival and adaptability and as a vital part of the ecosystem functioning. This is important in terms of reproductive success, adaptability with implications for evolution, and climate change adaptation.

The tree regeneration is a key process that influences the genetic diversity of the stand population, affecting adaptation and demographic processes. The natural regeneration improves genetic diversity and enables continuous adaptation and evolution of the population in a given location. Evaluations conducted on the application of selective cuts show that natural regeneration has positive effects in genetic diversity [80, 81].

Habitat loss, overexploitation and inadequate silviculture are the main factors of the Mediterranean forest degradation (e.g., Chiatante et al. [82]). Some practices such as clearcutting and fragmentation might have negative effects for soil and water status, as well on the stand regeneration. In turn, an excessive fragmentation can have negative effects on the tree seed predation and dispersion as shown by Santos and Tellería [83] and Morán-López et al. [84].

Reducing fragmentation through appropriate silviculture helps to maintain biodiversity and the ability of forest natural adaptation. The recommended solutions resulting from specific studies vary depending on the biological groups, the forest type, the site characteristics, the distribution pattern and targets [55, 85]. Measures to solve fragmentation should also be combined with actions for forest fire prevention, particularly: actions at the social level; forest partitioning or segregation with other forms of land use (agriculture, agro-forestry and pasture); utilization of forest species more resistant to fire, with a lower combustibility and fire propagation.

Several programs related to the conservation and promotion of biodiversity have highlighted the importance of an integrated approach in silviculture. Some studies have shown that biodiversity conservation involves combining different types of strategies and measures applied at different scales. The level of integration of conservation measures will depend on several factors, namely, related to the ecosystem characteristics, conservation needs and forest management objectives. Several authors (e.g., Kohm and Franklin [86]; Lindenmayer and Franklin [4]) indicate the promotion or maintenance of the following key elements for the biodiversity conservation and its relationship with the landscape: stand structural complexity, connectivity and landscape heterogeneity. Continuity in space and time is an essential element to support populations, since there is a wide range of life strategies and habitat requirements.

Silviculture should enable the development of these elements at the tree, stand and landscape levels. Different values can be achieved or involve different spatial scales. This can create heterogeneity and spatial variability.

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