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Landscape Ecology: A Helicopter View

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Authors' contributions

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ABSTRACT

This article reviews some of the main areas of landscape ecology. It includes the ideas and views of authors to the knowledge and understanding of the interplay between spatial heterogeneity and ecological processes, both in terrestrial and aquatic habitats at their varying scales. Moreover, the ecological consequences of landscape disturbance and landscape fragmentation are reviewed. Man and fire are discussed as the main agents of alternation of the natural landscape both at local and global scales. Studies on landscape restoration and management that emphasize the integration of various stakeholders for effective landscape restoration and management for sustainable biodiversity and socioeconomic benefits to man are as well reviewed. This paper further highlights the integration of the innovative remote sensing and Geographic Information System (GIS) technologies in the generation and analyses of spatial data. The current integration of population genetics in landscape ecology is also visited in this review.

Keywords: Landscape ecology; heterogeneity; fragmentation; remote sensing; GIS; landscape genetics.

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1. INTRODUCTION

Heterogeneity in ecological systems has been observed and described by scientists for quite a long time. However, an explicit focus on understanding spatial heterogeneity, revealing its myriads abiotic and biotic causes and its ecological consequences emerged in the 1980s as landscape ecology developed and spatial data analysis methods became more widely available [1]. Landscape ecology, a term coined by German biogeographer, Carl Troll and elaborated in 1950 [2], arose from the European traditions of regional geography and vegetation science and was motivated by the new perspective offered by aerial photography. Landscape ecology has since been defined in various ways [3,4,5], but common to all definition is focus on understanding the reciprocal interplay between spatial heterogeneity and ecological processes [6]. In other words, the fundamental difference between landscape ecology and broader ecological theory is that the later does not explicate the importance of space. The goal of a landscape ecologist is to understand and describe landscape structure; how this structure influences the movement of organisms, material, or energy across the landscape, and how and why landscape structure changes over time. Landscape ecological approaches are not limited to land, but are also applied in aquatic and marine ecosystems [7].

A landscape structure can be quantified by describing characteristics of patches, such as their number, size, shape, position, and composition [4]. Patch a term fundamental to landscape ecology, is defined as the relatively homogeneous area that differs from its surroundings [4]. Patches are the basic unit of the landscape that change and fluctuate, a process called patch dynamics. Landscape patches have a boundary between them which can be defined or fuzzy [8]. The quantification of spatial heterogeneity is necessary to elucidate relationships between ecological processes and spatial patterns, thus the measurement, analysis, and interpretation of spatial patterns receive much attention in landscape ecology. A number of studies have related landscape patterns to variable sets that include both biophysical and socioeconomic factors and their surrogates. Interactions between landownership and landscape position have emerged as strong determinants of land cover patterns and changes [9,10].

Landscape spatial structure is important in understanding the influence of habitat fragmentation on population survival. [11] referred to fragmentation as simply the disruption of continuity. Habitat fragmentation implies a loss of habitat, reduced patch size and an increasing distance between patches, although this can create new habitat. Local extinctions of fragmented populations are common. It is apparently clear that researches in landscape ecology have broadened perceptions of the causes and consequences of spatial heterogeneity and their varying scales, and this has influenced restoration and management of both the natural and human-inhabited landscapes.

Landscape ecology studies often employ remote sensing data together with field measurements, and undertakes geospatial analyses (using Geographic Information Systems, GIS) or simulation modeling [1]. These tools play a critical role in the data acquisition and processing components of spatial analysis [12]. Also, the development of landscape ecology as a discipline has been particularly simulated by technological developments in remote sensing and GIS.

2. LANDSCAPE HETEROGENEITY AND BIODIVERSITY

Landscape heterogeneity has long been considered a key determinant of biodiversity [13,14] Landscape ecologists emphasize how organisms use resources that are spatially heterogeneous and how they live, reproduce, disperse, and interact in landscape mosaic. Understanding the influence of large and small heterogeneity on species distribution and abundance is one of the major foci of landscape ecology research [15]. Studies have been carried on to understand the effects of landscape composition and landscape configuration (i.e., how is it spatially arranged) on biodiversity. Previous studies have reported contrasting associations between landscape heterogeneity and species richness, from positive to negative, and the negative effect is often reported to be the result of landscape fragmentation [16,17,14]. Simulation studies also suggest that changes in landscape composition are likely to have a greater effect on population persistence.

Analyses conducted at multiple scales have demonstrated the importance of landscape context for a wide range of taxa [18,19,20], although the influence may be less if the focal habitat is abundant and well connected [21]. Much has been learned from studies that have evaluated factors that explain variation in the landscape. Patch size has a strong effect on edge and interior species but is negligible for generalist species [22]. However, local habitat conditions may be inadequate to explain species presence or abundance. Many studies have demonstrated that habitat connectivity is scale dependent; that is, whether a given pattern of habitat is connected depends on the mobility of the species and the pattern of the habitat [23]. Organisms may respond to multivariate habitat heterogeneity at multiple scales, and identification of the factors and scales that best explain variation in the presence or abundance of organisms remains a key goal in landscape ecology.

Two mechanisms which operate at different time scales can initiate varied response of organisms to landscapes. The first mechanism is evolutionary adaptation of species to landscape heterogeneity or homogeneity over longtime scales [24,25], and the second is selective extinction of species inhabiting homogenous landscapes, such as forests or grasslands, by anthropogenic land-cover change over shorter time scale [26,27]. The latter mechanism is called an ‘extinction filter’ [28]. The magnitude of human-induced environmental change at the global scale is considered to be enormous. Furthermore, the main force driving the global transformation of the biosphere is human population growth, together with increasing resource consumption and sociocultural change. Extinction is a natural event and from geological perspective routine, that is, most species that have ever lived have gone extinct during different geological times.

3. HETEROGENEITY AND HIERARCHY OF SCALE

Scale is an important concept in both natural and social sciences, and has been defined in several different ways [29,30]. From landscape perspective, scale refers primarily to grain (or resolution) and extent in space or/and time. Scale may be absolute (measured in spatial or times units) or relative (denoted as ratio). Scale may be the observer’s measuring stick or viewing window size, a spatial or temporal characteristic of an ecological pattern or process, or a fundamental framework in which diverse ecological phenomena can be more effectively studied and understood individually and collectively.

Scaling, on the other hand usually defined as the process of extrapolating or translating information from one scale to another, including scaling up and scaling down [31,32]. Scale and scaling have become buzzwords in ecology in recent years as the research emphasis of the field has shifted from local to increasingly broader scales [33]. As spatial heterogeneity becomes a major theme in wide range of ecological studies, the concepts of scale, scaling and hierarchy become increasingly crucial in ecology in general. A literature survey by [33] reveals that the number of papers that contain words, “scaling”, “hierarchy”, “hierarchies”, or “hierarchy theory”, has increased exponentially in four of the major ecology journals since 1930s. This confirms, and is indicative of, the rapidly rising awareness of the importance of scale and hierarchy of ecologists.

In dealing with scale in ecological studies and applications, three related but distinctive tasks stand out. First, we need to appreciate and understand how changing the scale of observation affects research results and their interpretation. Second, if ecological systems are multiple-scaled or hierarchically structured, identifying characteristic scales and hierarchical levels become extremely important for understanding and predicting ecological phenomena. Third, theories, models, procedures for extrapolating information across scales need to be developed for understanding and managing heterogeneous landscapes. Although simple “scaling laws” do exist in ecology, extrapolating information over a wide range of scales may often require a hierarchical approach.

4. AQUATIC ECOSYSTEMS IN LANDSCAPE ECOLOGY

Despite the traditional focus on land, landscape ecologists have not entirely ignored aquatic systems. Generally, they have considered rivers as element of a landscape mosaic; rivers linked with their surroundings by boundary dynamics; and rivers as internally heterogeneous landscapes (see Fig. 1). This is the viewpoint that is fostered by remote sensing geographical information systems (GIS), or landscape mapping [34]. Water is an increasing valuable resource to humans in most parts of the world, and rivers and streams have been the focus of human culture and activities since the dawn of civilization.

Rivers are used as transport corridors, as water sources for settlements or farmlands, as fisheries, as waste disposal conduits, and so on, and rivers in a landscape can be differentiated according to these differing uses [34]. But again, the view of a river is a channel separated from the other elements of the landscape by its edges. The river has neither dynamics nor internal structure of its own. Another view of rivers considers them as functional parts of landscapes that are connected by boundary flows, by exchanges of materials, organisms, energy, or information across boundaries between adjacent landscape elements [35]. Although terrestrial ecologists may think of such flows in rivers simplistically, in terms of downstream hydrology alone, any riverine ecologist knows that a wide array of exchanges occurs across river boundaries. All of the structural and functional features that can be used to characterize a river as a part of a broader terrestrial landscape also apply to the landscape within a river. In many cases, this within-river landscape is also quite dynamic, varying in patch composition and configuration in response to changes in hydrologic flow regimes [36].

Recognizing that patches differ in quality is the first step in transforming a descriptive map of a mosaic into something that can represent the spatial component of ecological processes. Several studies in streams and rivers illustrate the effects of variation in patch quality. For example, [37] documented that larval chironomids and adult copepods were more abundant in patches of leaves than in sand patches in a fine scale streambed mosaic. The recognition that patches in a stream differ in quality and that organisms respond to these spatial variations is not new, of course in 1920s, [38] noted the selection of patches of high velocity, where respiration is facilitated by lotic invertebrates. Patch quality changes over time, especially in such dynamic systems as streams and rivers. [39] documented the shifting nature of patch quality by experimentally determining how the distribution of stream invertebrates among patches varied under different flow regimes.

5. WETLANDS IN LANDSCAPE ECOLOGY

A wetland is a distinct ecosystem that is flooded by water, either permanently or seasonally, where oxygen-free processes prevail [40]. The primary factor that distinguishes wetlands from other land forms or water bodies is the characteristic vegetation of aquatic plants, adapted to the unique hydric soil. Wetlands play a number of functions, including water purification, water storage, processing of carbon and other nutrients, stabilization of shorelines, and support of plants and animals. Wetlands are also considered the most biologically diverse of all ecosystems, serving as home to a wide range of plant and animal life. Wetlands occur naturally on every continent [41].

Fig. 1. A river surrounded by the other elements of the landscape by its edges

Physico-chemical constituents of the water column (e.g. pH, nutrients, conductivity) are regarded as potentially important determinants of biotic assemblage composition in wetlands and other freshwater ecosystems e.g. [42,43]. More specifically, in the south-western Cape, South Africa, [44] established that physico-chemical factors exert a significant structuring effect on invertebrate assemblage composition in temporary depression wetlands. Alternation of these factors through anthropogonic disturbance has potential to mediate ecosystem changes in these wetlands, through bottom-up effects on biota such as aquatic invertebrates and amphibians. Studies have focused on permanent wetland types, from which various authors have reported significant effects of habitat fragmentation on an array of individual physico-chemical variables including turbidity, pH, nutrients, conductivity and dissolved oxygen [45,46,47], while very few studies have specifically addressed relationships between terrestrial habitat transformation and physic-chemical conditions within temporary wetlands [48].

6. DISTURBANCE AND LANDSCAPE HETEROGENEITY

Studies of disturbance and succession continue to generate new understanding about the interactions between ecological processes and landscape pattern [1]. A disturbance is any relatively discreet event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment [49]. The type of disturbance is broad, encompassing such diverse events as wildfire, insect outbreaks, hurricanes, coral bleaching, and floods [50]. Disturbance may either increase or decrease heterogeneity, may enhance or inhibit the spread of disturbance. Disturbance can play an important role in these dynamics, by initiating cycles of secondary succession and generating opportunities for communities of long-lived organisms to reorganize in alternative configuration.

The relationship between disturbance and heterogeneity in a landscape is complex and depends on the scale of disturbance and important underlying environmental gradient [51]. The occurrence or effects of disturbance may depend on the system's state before disturbance occurred. Thus, disturbances are particularly interesting in landscape ecology because they both respond to and create spatial heterogeneity.

In all cases, disturbances result in functional, structural, biological, and biogeochemical legacies [50,52,53], a template left on the ecosystem with which subsequent disturbances may interact in some fashions. The legacies take the form of altered functioning (e.g., rapid growth of surviving individuals, altered nutrient cycling), dead material, residual (e.g., survivors) and regenerating individuals and communities, and unique spatial patterns in community and unique spatial patterns in cover types, ranging from undisturbed to highly disrupted.

A number of studies have documented significant influences of landscape heterogeneity on the spread or effects of disturbances. Effects of hurricane, wind events, and fires can vary with spatial location on the landscape. Researches have frequently found a strong influence of landforms on these effects. For example, the severity of hurricanes on vegetation varies with the exposure of the sites [54]. In general, landscape position influences disturbance when the disturbance has a distinct directionality or locational specificity such that some locations are exposed more than others.

7. LANDSCAPE MODELS

Quantification of ecological processes and formulation of the mathematical expressions that describe those processes in computer models has been a cornerstone of landscape ecology research and its application. Consequently, the body of publications on simulation models in landscape ecology has grown rapidly in recent decade. This trend is also evident in the subfield of forest landscape ecology, particularly in relation to the topic of disturbance [55].

Spatially, when a study is expanded to the order of 10^3-10^6 ha, experimental studies become limited and additional complexities such as environmental heterogeneity and natural disturbances may further complicate the study. Thus, computer models become useful tools for landscape scale experiments [56,57]. With modeling techniques, knowledge of physiological factors and their effects on the modeled processes and interactions within a population system can be explicitly represented using mathematical equations and logical sequences. Those data can be used in models to deduce results, especially at broad spatial and temporal scales, that cannot otherwise be investigated [58,59].

Forest landscape models share common features, including: simulation (1) forest vegetation response at large spatial and temporal scales (e.g. in excess of 100,000 ha and 100 years) and (2) the outcomes of repeated, stochastic spatial processes (e.g. seed dispersal, fire, wind, insects, diseases, harvests, and fuel treatments). Depending on the model's purpose and design limitations, they may differ in the key ecological processes incorporated, the extent to which mechanistic details are simulated for each process, and the type and scope of applications [60].

Over the last 15 years, we have seen rapid development in the field of forest landscape modeling, fueled by both technological and theoretical advances. Forest landscape models have benefited greatly from technological advances, including increased computing capacity, the development of GIS, remote sensing, and software engineering. Ecological processes and their interactions in forest landscape models can be represented by well-designed computer software [61]. The core of landscape ecology provides a conceptual basis for forest landscape modeling from a theoretical perspective: the interaction of spatial patterns and ecological processes under various spatiotemporal scales, theories of disturbance, and equilibrium and non-equilibrium approaches to vegetation and ecosystems [60].

8. LANDSCAPE FRAGMENTATION

Landscape fragmentation is increasingly considered an important environmental indicator in the fields of sustainable land use and biodiversity. The habitat loss and fragmentation associated with human use in many regions is well described in landscape ecology and conservation biology [62,63,64]. A dominant effect of increasing landscape fragmentation is increase in patch areas, with resulting declines in population density and species richness, and significant alternations to community composition, species interactions and ecosystem functioning. For species restricted to the original type of habitat, fragmentation means disintegration into small, spatially disjunct patches, separated by land which is unsuitable to reproduce or find food or shelter [65].

Habitat fragmentation is one of the most cited threats to species extinction and an ensuring loss of biological diversity, making it perhaps the most important contemporary conservation issue [66]. [11] referred to fragmentation as simply the disruption of continuity. Increases in the number of endangered species and the patterns of global extinction are in part the result of habitat loss and landscape fragmentation. These threats isolate populations by disrupting the migration and dispersal of species vital life processes for sustaining population health and species persistence, and alter ecological elements such as fire, stream flow, drought, and species interactions.

9. LANDSCAPE MOSAIC AND CONNECTIVITY

Landscape connectivity is a product of boundaries defined by the distinct communities, called patches, which form its element. Landscape connectivity can be defined as the degree to which the landscape facilitates or impedes movement between resources patches [67]. Landscape connectivity is considered a crucial element of landscape structure because of its importance to population survival. Movement of individuals, materials, nutrients, energy, or disturbances through a landscape involve more than boundary configuration, permeability, and context. If a landscape is indeed a mosaic of patches of different types, then these movements are affected by how the patches are in the mosaic. Connectivity includes both structural connectivity (the physical arrangements of disturbance and/or patches) and functional connectivity (the movement of individuals across contours of disturbance and/or among patches) [68,69].

Connectivity is a fundamental feature of most natural landscapes [70]. The theoretical works of [71,72,73,74] coupled with considerable empirical evidence [75,76] suggest that physically connected patches of habitat on the landscape are one means to support and maintain a great richness of indigenous species and system integrity [77]. Baudry and Merriam [78] noted how connectivity is a parameter receiving value from processes moving across landscape elements while connectedness is demonstrated through structural landscape features. Thus, landscape connectivity can be defined as the degree to which the landscape facilitates or impedes movement between resources patches [67].

The role of environmental corridors in facilitating seed dispersal and the movement of animals and other phenomena such as disease has been reviewed in depth [79]. The degree to which a landscape is connected determines the amount of dispersal there is among patches, which influences gene flow, local adaptation, extinction risk, colonization probability, and the potential for organisms to move as they cope with climate change [80,81].

10. HUMAN-INDUCED LANDSCAPES

Landscapes are continuously altered by humans to make them better adapt to their social, economic or ecological needs. With such developing landscapes, the ecosystem network is bound to change in harmony, thus the capacity of landscapes to sustain biodiversity is questioned. Agricultural dynamics and high rate of urbanization are the chief human-induced factors that adversely affect the natural landscapes.

11. AGRICULTURAL LAND USE

The world's natural landscapes have greatly been interfered with by man, and the concomitant effects are progressively increasing in tempo, as a result of man's inherent dominion over the natural ecosystems. The consequences of world ecosystem structure of man's cultural progression from a predator to a domesticator and farmer, and the associated diffusion of agricultural concepts throughout the world, have really been profound [82]. Exploitative and seriously destructive agricultural systems have been recently extended in scales in the recent times by the widespread adoption of evermore intensive methods of food crop production, especially monoculture. As a result of forest clearance, the extent to which forest ecosystem interrelationships are further altered depends mainly on the type of agricultural system adopted and on the human population density and these have altered the landscape, with serious ecological consequences for flora and fauna world-wide, although at different degrees and rates among regions.

Agricultural dynamics and associated alternations in the structure of habitat patches affect species composition and distribution in the landscape. There is empirical evidence that the proportion of land uses and their spatial arrangement can affect the long-term dynamics of bird species in agro-landscape [17]. Piha et al. [83] observed from their research that landscape structure and agricultural land use were the principal determinants of the bird assemblage.

Fig. 2. o-MARCELLUS-SHALE-DRILL-PAD-facebook (1)
Man's interference in the natural forests through urbanization has led to alternation in the structure of the natural landscape, with serious consequences for species composition and distribution

12. URBANIZATION EXPANSION

The problems of landscape pattern change and region ecological risk under urbanization expansion have drawn the increasing attention of the ecologists. From the view point of landscape ecology, urbanization is the process in which landscape/cover landscape changes from natural landscape which is mainly made of water, soil, and vegetation to man-made landscape which is mainly composed of cement, asphalt, chemical materials and metals [84,85]. Urbanization is mainly viewed from social and economic viewpoints while paying little or no attention to influence on ecological impacts. Urbanization causes profound changes in the ecological functioning of the landscape and gradually results in a changing spatial structure, that is, forms new landscape patterns (see Fig. 2) Studies have shown relationship between urbanization and the influence on the landscape. [86] showed that significant positive relation existed between urbanization intensity and regional ecological risk in Chinese coastal city. Meanwhile, the change of land-use/cover landscape pattern could be interpreted as the changes of patch shape, area quality, and spatial combination [87,88].

13. THE INFLUENCE OF FIRE ON LANDSCAPE PATTERNS

The influence of fire in controlling landscape composition and structure both at local and global scales is apparent. Fire contributes to the structure of landscapes ranging from tropical savannas to boreal forests. However, fire plays a particularly prominent role in regions with a Mediterranean climate. Mediterranean landscapes are dynamic systems that undergo temporal changes in composition and structure in response to disturbances such as fire [89] (see Fig. 3). Fire regimes are determined by complex interactions between climate, land use, vegetation attribute and the pattern of ignition [90,91]. However, at larger temporal spatial scales, fire regimes appear to be more determined by climatic variability with periods of high fire risk linked to particular weather conditions accounting for more fire events [92]. Fire frequency and severity vary with the amount, spatial distribution and conditions of available fuels, as well as moisture, temperature and ignition sources [93].

For thousands of years, natural and man-caused fires have shaped landscapes across the globe, affecting structure and connectivity of biomass, liberating and recycling stored nutrients and converting natural landscapes for human uses [94]. Conversion of forests and shrublands to agricultural or pastoral uses through burning, suppression of fire in fire-adapted landscapes, and continual expansion of the interface between urban population and flammable forests are directly influencing fire in boreal [95,96,97], temperate [98,99] and grassland systems, and introducing fire to desert [100] and tropical [101,102,103,104] biomes. Research conducted by [89] on the influence of topography and fire in

Fig. 3.The deleterious influence of fire on the forest landscape

controlling landscapes composition and structure in Sierra de Gredos (Central Spain) revealed that the impact of fire on landscape patterns was high variable among regions due to the different regeneration abilities to main landscapes, the topographic constraints and the fire histories of each region. Although climate and ecosystem properties continue to be important component of global fire regimes, in recent decades a shift from climate controlled fire regimes towards human-controlled fire regimes has taken place over much of the globe [105,106].

14. LANDSCAPE LEGACIES

The persistent influence of land-use history on explaining the vegetation and biogeochemical characteristics of contemporary ecosystems has become increasingly apparent [107]. Landscape legacies reveal the evolutionary history of contemporary landscapes. A landscape history exposes the evolutionary patterns of a specific landscape by revealing its ecological stages, cultural periods, and keystone processes. Such history can be a valuable tool as it has the potential to improve description, prediction, and prescription in landscape planning [108]. Ecologists, conservationists, and natural resource policy makers now recognize that the legacies of land-use activities continue to influence ecosystem structure, or even longer after those activities have ceased. As a result, environmental history emerges as an integral part of ecological science and conservation planning.

Recognition of the importance of land-use history and its legacies in most ecological systems has been a major factor driving the recent focus on human activity as a legitimate and essential subject of environmental science. At stand to landscape scales, differences in land-use history strongly controls modern vegetation patterns [109]. Studies from Harvard forest show that another enduring legacy of land use in New England is the homogenization of tree species composition at a regional scale [110]. Because of the broadly similar history of agriculture, logging, and reforestation, a subset of the regional tree flora with disturbance-adapted life history traits has been favoured. The result is a shift from pre European patterns of forest variation that correspond to subtle gradients in regional climate to a more homogenous condition [111].

Land-use legacies have different relevance in context of varying landscape and management objectives. Recognition that the history of disturbance shapes the long-term structure, composition, and function of most ecosystems and landscapes can increase the effectiveness of management [112]. In contrast, ignoring historical legacies may lead to the development of ill-conceived conservation and management schemes [113]. Historical perspectives aid the interpretation of landscapes that we wish to manage and contribute to the identification of realistic goals and appropriate tools and approaches to achieve those ends [114].

15. FOREST LANDSCAPE RESTORATION

Understanding how to restore and maintain spatial ecological processes can be considered the most important element of landscape ecology [115,116]. Landscape restoration is defined as a planned process to regain ecological integrity and enhance human well-being in deforested or degraded landscape. Forest landscape restoration recognizes that forest restoration has social and economic functions [117]. It aims to achieve the best possible compromise between meeting with conservation goals and the needs of rural communities [118]. Forest landscape restoration (FLR) includes both the planning and implementation of measures to restore degraded forests within the perspective of the wider landscapes.

Forest can be restored in wide range of circumstances, but degraded sites within protected areas are a high priority, especially where some climax forest remains as a seed source within the landscape. Landscape restoration is a specialized form of reforestation, but it differs from conventional tree plantations in that its primary goals are biodiversity recovery and environmental protection [119,120]. As human pressure on landscapes increases, forest restoration will most commonly be practiced within a mosaic of other forms of forest management to meet the economic needs of local people.

It is becoming increasingly recognized that landscape restoration requires the involvement of multiple stakeholders operating in multiple sectors, and at multiple scales. Forest restoration is any inclusive process, which depends on collaboration among a wide range of stakeholders including local community, government officials, non-governmental organizations, scientists and funding agencies. This type of stakeholders' involvement in design, planning and decision-making of forest landscape restoration programme is increasingly referred to by the term 'landscape governance' [121,122]. During the last decade the concept of landscape governance has become generally accepted as referring to the multi-stakeholder process of negotiation and decision making about policies and programmes for effective conservation and sustainable use of forests, and for implementing the planned measures within spatial landscape units [123,124]. Despite the general acceptance there is still divergence in the way landscape governance is perceived and implemented in different restoration programmes [125]. [126] identify different modes of governance with respect to three different dimensions of politics, polity and policy.

16. RIVERINE LANDSCAPE RESTORATION

The intensive use and alternation of riverine landscapes by humans have led to severe degradation of river-flood plain, especially in highly industrialized countries. Recent water-related regulations and legislation focusing on high standards of ecological integrity back efforts to restore or rehabilitate these systems [126]. Restoration tests the feasibility of recreating complex ecosystems from more simple and degraded states, thereby presenting a major challenge to ecological science. Therefore, close cooperation between practitioners and scientists would be beneficial, but most river restoration projects are currently performed with little or no scientific involvement. Ecological restoration is a recent discipline that should be conducted scientifically and rigorously to move from trial-and-error process to a predictive science to increase its success and the self-sustainability of restored ecosystems [127].

Restoration of important ecological processes often implies improving connectivity of the stream. For example, longitudinal and lateral connectivity can be enhanced by restoring fluvial dynamics on flood-suppressed rivers and by increasing water availability in rivers subject to water diversion or withdrawal, thereby increasing habitat and species diversity. Restoring links between surface and ground water flow enhances vertical connectivity and communities associated with the hyporheic zone.

17. FOREST LANDSCAPE MANAGEMENT STRATEGIES

To maintain biodiversity over long period of time, natural landscape patterns of heterogeneity and other emergent ecological processes must be recognized and addressed at the level of regional ecological planning [127,128,77]. To effectively manage heterogeneous landscape to maintain biodiversity, we need to understand the mechanisms of such variability in the associations between landscape heterogeneity and species richness at multiple spatial scales [129,130,131]. One reason for such context-dependent patterns may be the difference among biomes in the sensitivity of species pools to fragmented landscapes, with lower sensitivity in the temperate zones of the Northern Hemisphere than in Oceania and tropical regions [26,132].

Acting on the spatial arrangements of land uses to increase heterogeneity of landscapes without altering the proportion of land uses, could help to reconcile production and biodiversity in agro-landscapes. Modifying the proportion of land uses, through the conversion of some intensive land uses into extensive ones often involves a trade-off for production [133].

Recent studies emphasize the need for integration of various stakeholders for effective and result-oriented forest management. This method is termed integrated landscape management. Integrated landscape management is a way of managing a landscape that brings together multiple stakeholders, who collaborate to integrate policy and practice for their different land-use objectives, with the purpose of achieving sustainable landscape [134,135]. Reed et al. [135] elaborated systematic ways to implement integrated landscape management. According to them five elements of landscape management describe the implementation cycle of a landscape approach, namely (1) interested stakeholders in the landscape come together for cooperative dialogue and action in a multi-stakeholder platform (2) they undertake a systematic process to exchange information and discuss perspective to achieve a shared understanding of the landscape conditions, challenges and opportunities (3) this enables collaborative planning to develop an agreed action plan (4) stakeholders then implement the plan, with attention to maintaining collaborative commitments (5) and finally, monitoring for adaptive management and accountability, feeds into subsequent rounds of dialogue and the design of new collaborative action. These five elements can be presented graphically in a circle, similar to the project management cycle.

18. FIRE MANAGEMENT STRATEGIES

Management strategies to restore forest landscapes are often designed to concurrently reduce fire risk. Both fire risk reduction forest restoration objectives will benefit from spatially coordinated landscape level planning among landowners [136]. Understanding the role and the relative weight of different factors leading to changes in fire regime is thus of critical importance to anticipate the fate of biodiversity, or to implement management strategies aiming at mitigating or modulating the impact of fires arising from such changes [137].

Fire suppression has long been used to mitigate fire, especially in the Mediterranean basin. Fire suppressing is a direct anthropogenic activity altering fire regime, even though its significance has been a point of debate [138]. Fire suppression efforts are aimed at limiting fire impact by decreasing fire severity or decreasing fire effective fire size. In fact, because a fire suppression policy is conducive to fuel build up and more intense fires, it can ultimately contribute to larger and more severe fires [139,140]. The ultimate goal of fire management is to modify the fire regime, which results from the interactions between ignitions and the fire environment, that is, topography, weather and vegetation (fuels).

Because of the debates on the usefulness of fire suppression as a fire management strategy, especially in the Mediterranean basin, researches show that fire suppression gives room to more fire occurrence. Fire management policies in the Mediterranean basin rely heavily on fire suppression and do not sufficiently address the socioeconomic and land management issues behind the inception and spread of fires [139]. As the Mediterranean becomes a more fire-prone environment due to continuing rural abandonment and climate change, it will be advisable to consider the management fires, both as a fuel treatment and an ecological process [141].

Innovational strategies aimed at fire management have emphasized the efficiency of integrated approach. In line with this, [142] proved that both ecological benefits and socioeconomic gains can be achieved using fire-smart forest management approach. They defined fire-smart forest management as an integrated approach primarily based on fuel treatments through which the socioeconomic impacts of fire are minimized while its ecological benefits are maintained and maximized, by lowering ignition likelihood and fire behaviour potential, fire suppression capacity is increased and forests and landscapes become more resistant to fire spread and more resilient to its occurrence.

19. REMOTE SENSING DATA AND TECHNIQUES IN LANDSCAPE STUDIES

As with many areas in physical geography and interrelated fields, remote sensing is a key technology for quantifying landscape patterns and processes in the twenty-first century. The interpretation and classification of data generated from remote sensors has matured as a discipline with growing specialist literature. Advanced tools and algorithms can be used to pre-process (radiometric corrections, atmospheric corrections, image registration), analyze (pixel classification), post-process (generalize, error report) and visualize imagery. These tools play a critical role in the data acquisition and processing components of spatial analysis [143]. The remote sensing community has developed rich and varied traditional, cartographic products [144].

Satellite remote sensing imagery revolutionized land cover mapping with the introduction of Landsat Thematic Mapper in the 1970s, which provided global coverage at high temporal and spatial resolution. Over the years, sensor and data processing technologies have progressed significantly and the methods for mapping the Earth’s surface have evolved. The availability of continuous spatial information provided by remote sensing and advancement in spatial analysis techniques supported by powerful personal computing began to address the need for synthesized natural resources information at an operational level. Methods and techniques have been gradually developed into standards for terrestrial needs and have begun to adapt to coastal marine needs [145,146]. This ability to collect information remotely is advantageous to coastal marine research as access to the sea floor by boat is usually complicated and costly [147].

Satellite imagery in digital format allows for the acquisition of environmental data and land occupation patterns and features over large areas [148]. Sensors in satellites record multispectral data from different wave bands in digital format. Different features of the terrain reflect differently in each waveband, allowing for their recognition in the images. The main limitations of satellite images are cloud cover and resolution. Even with the best resolution available (pixels < 30 m), it is not possible to see houses, to adequately classify some types of agricultural practice, or to locate some breeding sites [148]. Some of the problems may be circumvented by using satellite navigation receivers, which enables a user to obtain an instantaneous three-dimensional position, anywhere on the earth, at any time, under any weather condition.

20. GEOGRAPHIC INFORMATION SYSTEM (GIS) IN LANDSCAPE ECOLOGY

One of the most exciting and rapidly growing technologies for the 1990s is that of Geographic Information System (GIS). The computerized retrieval, manipulation, analysis and display of geographic information allow experts in a variety of geographic disciplines to improve their effectiveness and efficiency when addressing location-based problems and issues [149]. A Geographic Information System (GIS) is a computer-based tool for mapping and analyzing things that exist and events that happen on the earth. GIS integrates common database operations, such as query and statistical analysis, with the unique visualization and geographic analysis offered by maps (http://www.hgac.cog/tx.us/geography/cep/whatis.html). It consists of a powerful set of automated tools for collecting, retrieving, analyzing and communicating spatial data.

Using GIS to explore the spatial relationships of animal populations is a relatively new field for ecologists. GIS is well-established in habitat-based studies of animal populations to analyze remotely-sensed databases [150] and as a predictive tool for animal or plant species distributions [151,152]. In addition, GIS is now used to create databases, manipulate spatially explicit surfaces to represent specific parameters, and to displace spatial relationships through simulation modeling, hydrologic constructs, and species relationships [153,154].

Geographic Information System (GIS) technology can help establish cross-sectoral communication by providing not only powerful tools for storage and analysis of multisectoral spatial and statistical data, but also by integrating databases of different sectors in the same format, structure and map projection in the GIS system [155].

21. LANDSCAPE GENETICS

Landscape genetics is an interdisciplinary field combining tools and concepts from both landscape ecology and population genetics to relate landscape structure to patterns and genetic variations [156,157]. It broadly encompasses any study that analyses plant or animal population genetic data in conjunction with data on the landscape features and matrix quality where the sampled population lives. This allows for the analyses of microevolutionary processes affecting the species in light of landscape spatial patterns, providing a more realistic view of how populations interact with their environments. [157].The field has evolved tremendously since Manel’s landmark paper in 2003 [156], moving from descriptive assignment tests used to define population boundaries to a more explicit analytical framework including landscape variables as predictors in genetic models [158]. A recent review categorized the types of questions and methods used in landscape genetic studies compared to papers published in its predecessor fields and found that most of self-identifying landscape genetic studies fall more into the realm of population genetics (e.g. using terms such as “genetic”, “gene”, and “barrier” [161]. Landscape genetics attempts to determine which landscape features are barriers to dispersal and gene flow, how human-induced landscape changes after the evolution of populations, the source-sink dynamics of a given population, and how diseases or invasive species spread across landscapes [159].

22. SUMMARY AND CONCLUSIONS

Landscape genetics differs from the fields of biogeography and phylogeography by providing information on finer temporal and spatial scales (i.e. at the level of individual genetic variation within a population). Because it focuses on sampling individuals, landscape genetics has the advantage of not having to subjectively define discrete populations prior to analysis. Genetic tools are used to detect abrupt genetic differences between individuals within a population and statistical tools are used to correlate these genetic discontinuities with landscape and environmental features. As a tool, molecular genetics can make hard-to-observe processes visible and thus should be useful for landscape ecologists working on species whose movements are hard to track. For example, genetic markers have been used to estimate both contemporary and historical effective population size [160], assess sex-biased dispersal [161,162,163], identify population bottlenecks [164], and characterize meta-population dynamics [165]. Genetics can be used to quantify actual functional connectivity either directly or indirectly, and thus provides the means to test hypotheses about how aspects of the intervening landscape matrix support or inhibit dispersal and gene flow [166,167,168]. The results of landscape genetics studies have potentially important applications to conservation biology and land management practices [156].

As a new and fast growing interdisciplinary field with explicitly identified practices, landscape genetics has been subject to a number of flaws in both study design and interpretation [169]. [159] identified four common pitfalls of landscape genetics research that should be targeted for correction. These include assuming gene flow is always advantageous, over-generalizing results, failing to consider the practices that affect the genetic structure of populations, and mistaking quantitative methods for robust study design [169].

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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