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Applying landscape ecological concepts and metrics in sustainable landscape planning

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Abstract

It is increasingly recognized that more sustainable approaches are needed for planning and managing landscapes worldwide. New tools are needed to effectively apply sustainable principles to planning and management. The spatial dimension of sustainability engages processes and relations between different land uses, ecosystems and biotopes at different scales, and over time. Therefore, ecological knowledge is essential when planning for sustainability. The paper briefly reviews the historical role of ecology in planning, and ecological planning and management theories and methodologies. Building on existing ecological planning methods, we have developed a conceptual framework for sustainable landscape planning applying landscape ecological concepts and exploring the multiple potential roles of landscape metrics as ecological planning tools. We argue for a common framework that applies ecological knowledge in land planning, applicable to all physical planning activities. We believe this framework represents a significant contribution to increase the acceptance and use of ecological knowledge across the horizontal sectors planning, and to enhance communication between planners, thus contributing to an increased scientific and cultural consensus for sustainable landscape planning. Numerous quantitative metrics have emerged from landscape ecology that are useful for applying landscape ecology concepts to sustainable landscape planning. These metrics are essential tools to address the spatial dimension of sustainability in a quantitatively rigorous and robust manner. This paper proposes a core (sub)set of metrics, identified through literature reviews, which are understood as the most useful and relevant for landscape planning. A two-part sustainable landscape planning perspective is proposed, integrating horizontal and vertical perspectives. We believe that this dual approach can help to structure and clarify why, where, how and which landscape ecological principles and metrics can most effectively assist planning. We include a demonstration of this approach in the Mill River Watershed, USA. We argue that proper and informed use of landscape metrics will contribute to advance landscape planning theory and practice towards the goal of sustainability. © 2002 Published by Elsevier Science B.V.

Keywords: Sustainability; Ecosystem; Land management; Landscape ecological planning

1. Introduction

New approaches are needed to address the complex issues arising from increasing world population, depletion of resources and decreasing quality of human habitat. The sustainability paradigm has emerged from these global issues. The term sustainability was first used in 1980 in IUCN's World Conservation Strategy. The definition approved by the United Nations Food and Agricultural Organization (FAO) Council in 1988 for sustainable development reads: sustainability is the handling and conservation

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of natural resources and the orientation of technological and institutional change so as to ensure the continuous satisfaction of human needs for present and future generations (Ceña, 1999, p. 242). The sustainable paradigm includes the systems approach, another recent and fundamental paradigm in environmental sciences (Golley and Bellot, 1999, Grossman and Bellot, 1999). According to Jongman (1999, p. 114) sustainability is the capacity of the earth to maintain and support life and to persist as a system. The sustainability concept is arguably relevant to systems from the global to the local scale.

In this paper we focus on physical planning, one of the four principle currents of planning which also includes: social, public policy and economic planning (Burchel and Sternlieb, 1978 cited in Fabos, 1985). The main objective of physical planning is the optimization of the distribution of land uses in an often-limited space, focusing on land-use allocation (van Lier, 1998b, p. 84). According to van Lier (1998a, p. 79), "the notion to create more sustainable systems in the countryside has become a leading principle for all those scientists that are involved in planning future land uses". Many scientists believe that promoting sustainability is the overarching goal of landscape (and regional) planning including planning for conservation, protection and appropriate use of land and natural resources (Forman, 1995). To some, sustainability is the major objective of any planning (Grossman and Bellot, 1999, p. 318). Sustainability is multi-dimensional, involving the maintenance of natural resources and spatial patterns of land use that are ecologically, socially, and economically beneficial. Its spatial dimension is strongly related to the interdependence of land uses, and to spatial processes such as fragmentation (Bryden, 1994 cited in van Lier, 1998a, p. 79).

Sustainable landscape planning places physical planning in a broader perspective. We include land (re)development (van Lier, 1998b) to consider the improvement of ecological conditions for planned land uses. We also include land management by adopting adaptive management techniques that apply monitoring as an important part of a sustainable landscape planning process.

Scale is a key issue in sustainability planning. Due to the interdependencies of ecosystems, a planning approach is needed that examines a site in its broader context. The landscape provides an appropriately useful context for sustainable planning: "little literature on sustainability exists at the landscape and regional scales. Yet these scales may be the most important for attaining sustainability" (Forman, 1995). Many public and private conservation and land management organizations now view a landscape perspective as essential for sound resource management (Wallinger, 1995; Wigley and Sweeney, 1993 cited in Gustafson, 1998, p. 144).

Sustainable ecologically-based approaches to planning and management are desirable, and their application is widely advocated. Sustainability as a theoretical aim is challenged by virtually no one, yet problems and questions arise with its implementation (Ceña, 1999). Appropriate tools are needed to apply sustainable principles to planning and management. Landscape ecological concepts and applied metrics are likely to be useful to address the spatial dimension of sustainable planning. In response to this need we propose a conceptual framework for sustainable landscape planning and design to frame the operational objective, i.e. why, where, how, and which landscape ecological concepts and metrics should be applied in planning.

2. Historical overview of the role of ecology in planning

Ecology and planning have many common interests, ecology concerned with the functioning of resources, planning focusing on their appropriate use for human's benefit. According to Booth (1984) sound (short- and long-term) planning cannot be achieved without due consideration to ecology. However, planning was slow to adopt ecological principles, its trajectory reflecting society's priorities and how they changed mainly in the 19th and 20th centuries.

Existing theory and methodological frameworks in ecologically oriented land planning and management that were developed in the last two centuries inform our proposed framework. Historically and theoretically these did not evolve independently. Rather, they co-evolved, influencing one another and, in many cases, building on the frameworks that preceded them: landscape planning (McHarg, 1963, 1969; Marsh, 1978; Caldeira Cabral, 1982; Fabos, 1985; Steinitz, 1990), environmental impact assessment (EIA)

(National Environmental Policy Act (NEPA) in 1969, Marsh, 1991; Morgan, 1998; Treweek, 1999), landscape ecology (Naveh and Lieberman, 1984; Forman and Godron, 1986; Forman, 1995; Zonneveld, 1995; Farina, 2000), ecosystem management (Agee and Johnson, 1988; Grumbine, 1994, 1997; Haynes et al., 1998; McGarigal, 1998a; Szaro et al., 1998), environmental systems-based rural planning (Golley and Bellot, 1999) and landscape ecological planning (Berger, 1987; Harms et al., 1993; Forman, 1995; Hulse et al., 1997; Nassauer, 1997; Ndubisi, 1997; Thompson and Steiner, 1997; White et al., 1997; Steinitz et al., 1997, 1998; Ahern, 1999; Jongman, 1999). In order to clarify the origin of the fundamental premises of our methodological proposal, and to identify shared goals and issues with prior work, we will briefly describe how planning and ecology became integrated and how the theories referenced earlier fit into this evolution. We believe that sustainable landscape planning emerges as a natural outcome of the evolution of the planning discipline into the 21st century where new social values, such as the key concepts of sustainability (solidarity between present and future generations, and the need to balance development with nature), are increasingly being recognized and embedded into planning methods and legislation.

Explicitly or implicitly, ecology was already present in landscape planning in the second half of the 19th century in the work of the landscape architect and planner Frederick Law Olmsted, ‘‘pathfinder’’ for the planning profession in the US (Fabos, 1995). The association between planning and ecology was reflected also in Europe in the work of Patrick Geddes, a botanist and a planner from Scotland, and the progenitor of modern town planning (Booth, 1984). However since Geddes and until the 1960s the place of ecology in planning declined for three principle reasons: (1) changing social attitudes in the post-war period, (2) organization of pressure groups, such as foresters, industrialists, etc. that shaped public opinion, and (3) a misconception about ecology, interpreted as being equivalent only to conservation (Booth, 1984). In the post-war period, namely in the 1940s and 1950s UK planners were more concerned with managing urban sprawl and with less interested in rural planning and with the conservation of natural resources. The shared assumption was that there was no need for ecological, i.e. environmental concerns since the traditional rural practices would not conflict with other interests such as conservation, recreation, etc. Since then shifts in planning objectives ranged from public health (e.g. planning for urban networks of sanitary sewers), engineering considerations, sociological and economics, to environmental quality in the 1970s and 1980s (Roberts and Roberts, 1984). In the US, the Great Depression of the 1930s was characterized by chronic economic, social and environmental problems. The focus of conservation observed in the late 19th and early 20th centuries shifted to problems associated with the depression, such as soil conservation. From 1914 to 1955 the US’ contribution to world industrial production shifted from 38 to 58% (McRae, 1994). By then there was a growing recognition of the use and abuse of natural resources. Although the language of ecology was not explicitly used the emerging leaders in landscape planning and ecology continued to explore ways to use ecological principles to planning (Ndubisi, 1997).

By this time ecology was responding to these new global issues. Eugene Odum’s compartment model (1969) addressed ecosystems and their relationships with human habitats and functions, thus establishing a new ecological model that fully integrated human activities, in marked contrast with the traditional, essentially biocentric approaches of ecologists. Landscape ecology, a new branch of ecology, emerged in Europe in the 1960s with Neef (1963) and Troll (1968) (cited in McDonnell and Pickett, 1988). According to Forman and Godron (1986), landscape ecology focuses on (a) the distribution patterns of landscape elements or ecosystems, (b) the flows of animals, plants, energy, mineral nutrients, and water across these elements, and (3) the ecological changes in the landscape mosaic over time (Numata, 1995). They defined three fundamental landscape structural elements: patches, corridors, and the matrix—that together constitute the widely accepted ‘‘Patch–Corridor–Matrix model’’ (Forman, 1995).

Landscape ecology introduced several aspects that were important for planning. One fundamental aspect was its explicit attention to the spatial dimension of ecological processes, thus providing a common language for stronger interactions between ecologists and planners. Vertical relationships (topology) were integrated with horizontal relationships (chorology).

The focus on reciprocal pattern and process relationships offered theory and empirical evidence with which to understand and compare different spatial configurations of land cover (Forman, 1995), and enabled the ecological consequences of a plan's spatial configurations to be anticipated. The uses of metrics to support this understanding have been limited to scientific research. Few applications of metrics in planning have occurred. We maintain that this is due to uncertainly about which metric(s) to apply, and how to interpret the results for planning. A second fundamental aspect was landscape ecology's focus on human ecology, and its orientation towards planning and management, as opposed to more traditional biocentric ecological approaches. Human activities were explicitly considered part of the systems, not as a separate component. A third aspect adopted the landscape as its principle unit of study. Together with a systemic, holistic approach, this trans-disciplinary science enabled an integrated analysis of the complex human-made landscapes that were fast becoming dominant worldwide. The biotic component is no longer studied with the single (and most worthy) purpose of acquiring (ecological) knowledge, but also to provide for better insights about human and natural systems to support planning for sustainable use.

The late 1960s were characterized by an increased international environmental awareness. Nevertheless, worldwide natural resources planning and management focused on production. NEPA enacted in 1969 in the US established EIA as a major instrument for environmental protection. Through the EIA instrument the environmental component was to be incorporated into all planning activities over a certain dimension, e.g. in the fields of transportation, urban development, forestry and agriculture, water management, etc. The concept of EIA has spread internationally, strongly influencing environmental legislation in other developed countries, e.g. the EIA European Community Directive (85/337/EEC) (Glaria and Ceñal, 1999).

In the 1980s, following the German ''landschaft'' concept, Europe adopted integrated approaches at the landscape unit. The French introduced time as an important dimension in landscape studies (Golley and Bellot, 1999). They were also responsible for the first map of ecological risk. Later in the 1980s landscape ecology was definitively recognized in the US with Risser et al. (1983), Forman and Godron (1986) and Turner (1987), and in Europe with Schreiber (1986) (cited in McDonnell and Pickett, 1988). Since then this relatively new interdisciplinary science is increasingly recognized as a powerful scientific basis for land and landscape assessment, planning, management, conservation, and reclamation (Naveh and Lieberman, 1984).

In the early 1990s, traditional approaches to natural resource management were widely considered ineffective for promoting the ''new'' goal of sustainability (Szaro et al., 1998). As a consequence, ecosystem management emerged as a new paradigm for land-use management in the US, sustainability being its overall goal (McGarigal, 1998a). It has been implemented widely in the US by federal land-use management agencies collectively responsible for approximately 30% of the landmass of the US (Coulson et al., 1999). While each agency or organization defines it in slightly (or largely) different terms, at least two characteristics are common: (1) that management must be built on ecological science and on understanding ecosystem function and (2) that humans are integral components of ecosystems (Bartuska, 1999). To its credit, the field of landscape ecology anticipated many of the concepts that form the core of ecosystem management (Risser, 1999; Wiens, 1999).

Many have acknowledged the significance of the landscape ecological perspective for landscape planning, and a resulting need for reconsideration of planning theory and methods (Caldeira Cabral, 1982; Berger, 1987; Ahern, 1995; Forman, 1995; Ndubisi, 1997). By considering landscape ecological concepts in landscape planning, the landscape design process, expressed in a plan through spatial concepts (van Lier, 1998b), is embedded with the necessary ecological patterns and resulting functions. These are critical to assure the ecological sustainability of the final plan, and of the resultant future landscapes.

Several methodologies evolved in response to the new challenges to planning raised in the last half of the 20th century. These ranged from population-related environmental stress, expansion of urbanization, the need for more complex models to address environmental issues, and the need for more public participation in the planning process. In the 1950s planners started to use quantitative techniques (Fabos, 1985). In the 1970s geographical information systems (GISs) emerged as an important planning tool building on the rediscovery of the overlay method by McHarg (1969). Fabos et al. (1978) advanced this approach further with the Metland parametric approach, also integrating GIS as a fundamental tool. Since the 1990s, alternative/future planning scenarios have been increasingly applied. Their use has proven effective in proactive strategic planning, especially in The Netherlands, to communicate the spatial landscape consequences of specific policy decisions (Harms et al., 1993; Schooenboom, 1995; Veenenklaas et al., 1995). They have also been used in the US to promote discussion about future alternatives, as in Freemark et al. (1996); Hulse et al. (1997); Steinitz et al. (1997, 1998); Ahern (1997); White et al. (1997); Ahern (1999) and Ahern et al. (1998, 1999). Spatially-explicit ecological models have only recently been developed, based on metapopulation theory (Verboom et al., 1993; Verboom and Wamelink, 1999), enabling the use of such models into physical planning.

Public participation in the planning process is essential to successful planning. Research has shown that people are more likely to accept an issue resolved when they have had a voice in the decision-making process (Decker and Chase, 1997). Landscape planning and design professions have acknowledged this fact and incorporated participation in most methodologies (as in Hester, 1990). Strengths, weaknesses, opportunities and threats (SWOT) analysis is a powerful tool for group assessment of an issue of concern, in particular interventions or services (Borrini-Feyerabend et al., 2000). SWOT as other techniques have been also applied frequently in community development in developing countries (Borrini-Feyerabend, 1997; Borrini-Feyerabend et al., 2000). The work of many others could also be mentioned, e.g. of Rachel and Stephen Kaplan and of Robert Ryan in a closely related area, i.e. engaging people and applying this input into the design and management of parks and open spaces, backyard gardens, fields and forests (Kaplan et al., 1998).

We have revisited the fundamental ecologically-based planning theories and methodologies of the 20th century. They generally share the same basic planning steps or phases. These are integrated in our methodological proposal for sustainable landscape planning (Table 1 and Section 4). Fabos (1985) identified the basic steps of the planning process (Table 1). Some of these steps are also in Steinitz's (1990) landscape planning framework based on six different questions (Table 1). Steinitz' (1990) framework can be divided into descriptive/evaluative and prescriptive/planning components. The descriptive/evaluative part has strong parallels with landscape ecology in that it deals with articulating the fundamental dynamic of landscape pattern: process. This is included in Steinitz' framework's representation, process and evaluation models. In the prescriptive/planning component, change, impact and decision models are included with a landscape ecological perspective.

Before the last decade, it was not common for landscape ecological theory to be explicitly applied in landscape planning. However there are two noteworthy contributions, more or less coincident in time, from the US and The Netherlands. In Forman's (1995, p. 461) concord planning case study, in Massachusetts, US, a four phase planning process is identified based on landscape ecology principles. This framework for open space planning includes: the identification of spatial elements (large patch areas, major corridors, special sites), landscape functions (water protection, wildlife and human movement) and natural disturbances, and the establishment of relationships between structure and function in order to support decision processes (Table 1). In The Netherlands, Zonneveld recommends the adoption of the FAO/Wageningen system for land evaluation for applied landscape ecology. This method, and the context that it is proposed—Zonneveld's book "Land Ecology", can be seen as "being more directed to general land use, including agriculture in its widest sense" (Zonneveld, 1995, p. 112). It is based on matching land use type's requirements with the land unit's qualities to define land suitability maps. It explicitly incorporates socio-economic analysis and EIA considerations into the land evaluation process. Forman's approach, although also concerned with practical solutions to planning, is based on the analysis of structure and function. This reflects the background of these two founders of landscape ecology, Zonneveld from soil science, and Forman from ecology. Additionally, FAO's framework proposed by Zonneveld contemplates a phase of post-project evaluation (Table 1), in the spirit of adaptive management techniques to incorporate knew knowledge into the process such as post-implementation monitoring activities.

Table 1
Comparison of planning phases or stages in several ecological-based physical planning methodologies

Planning phases								
Landscape planning		Landscape ecology		EIA	Ecosystem management	Rural planning	Landscape ecological planning	Sustainable land planning (our proposal)
Fabos, 1985	Steinitz, 1990	Forman, 1995	Zonneveld, 1995	Morgan, 1998; Treweek, 1999	McGarigal, 1998a	Golley and Bellot, 1999	Ahern, 1999	
Identification of issues/needs	Representation: how to describe the landscape?	Structural and functional analysis	Initial consultations: objectives, data, etc.	Scoping	Definition of goals	Setting goals and objectives	Goals	Focus
Assessment of environmental and socio-economic resources	Process: how does the landscape work?	Establishing relationships between structure and function	Surveys: (a) land use requirements and limitations, (b) land qualities	Description of the study area: environmental, socio-economic, cultural	Caracterization of the study area: environmental, socio-economic and cultural	Inventory phase, public participation	Assessment of ABC resources, public participation	Analysis, public participation, e.g. SWOT
Goals and objectives	Evaluation: is the current landscape functioning well?	Evaluation based on two attributes: (a) rarity and (b) recovery	Land suitability studies comparison, matching of (a) and (b), socio-economic analyses, EIA considerations	Identification and description of environment, impacts	Needs assessment: identifying the issues	Diagnosis of the problem	Identification of spatial conflicts and design of spatial concepts	Diagnosis
Development of alternative plans	Change: how the landscape might be altered? Scenarios	Synthesis: setting land protection priorities	Presentation of results, discussion of management scenarios	Prediction of environmental impacts (sometimes includes development of alternatives and its evaluation	Finding solutions alternative plans and its evaluation	Alternative solutions, its evaluation and contrast, and cost-benefit analysis	Definition of planning strategies	Prognosis: alternative plans and evaluation, public participation, e.g. SWOT
Selection of an alternative	Impact: what differences might changes cause? Scenario evaluation		Implementation: reccommended use	Mitigation, public participation	Implementation: includes monitoring	Instrumentation	Scenario development and its evaluation. public participation	Syntheresis: implementation and monitoring
	Decision: should the landscape be changed and how?		Post-project evaluation	Monitoring		Monitoring	Implementation	
							Monitoring	

Although it has a quite different technique, based on identification, description, prediction and evaluation of environmental impacts, EIA generally shares its phases with all the other methods included in Table 1. As with Forman's and Zonneveld's planning procedures, the ecosystem management planning process as proposed by McGarigal (1998b) is based on landscape ecology. This approach additionally includes the definition of alternative management scenarios and the assessment of their impacts, and a monitoring plan as part of an implementation phase (Table 1).

The framework for rural planning based on an environmental systems perspective adopted by the Mediterranean Agronomic Institute of Zaragoza (IAMZ) (Spain) follows the concepts of H.T. Odum, F. González Bernáldez, R. Margalef and W. Haber (Golley and Bellot, 1999). It conceives the planning process as a linear series of six steps, very similar to the other landscape ecology-based frameworks. However, it recommends contemplating public participation early in the planning process, and includes multi-criteria analysis for the integration of an economic component, including cost-benefit analysis to evaluate alternative solutions.

Unique in Ahern's (1999) framework method for landscape ecological landscape planning is the design of spatial concepts and the adoption of planning strategies—protective, defensive, offensive or opportunistic. These concepts and strategies explicitly include the role of the planner, to provide knowledge and insights to formulate spatial solutions to landscape planning problems.

We found that the frameworks reviewed share common methods and planning steps overall, the most important being the recognition of sustainability as an overarching goal. In order to pursue that goal all advocate, implicitly or explicitly, the use of landscape ecology as the scientific basis for ecological analysis. The planning steps adopted by each can be collapsed into five basic phases: (1) setting goals and objectives, (2) analysis, (3) diagnosis, (4) prognosis, and (5) syntheresis, or implementation (Table 1). Some included more recent planning methods and tools such as spatial modeling and GIS, alternative scenarios and simulation techniques, monitoring, and the participation of stakeholders and public in general into the planning process. We find these fundamental components of sustainable landscape planning.

Sustainability is the underlying and fundamental goal of the reviewed and proposed frameworks. Tools are needed to pursue this goal. Ecological knowledge is the fundamental scientific basis to plan and manage for sustainable systems. Holism and systems theory open new perspectives and provide broader visions for planning. The landscape is an appropriate unit for sustainable planning. Pattern and process relationships are crucial to understand the functioning of landscapes. They are also important to model and anticipate ecological consequences of planning and design alternatives. Finally, human activities must be considered as integral parts of ecological systems. Landscape ecology responds to all these issues and provides useful conceptual and analytical tools, particularly landscape metrics, to bridge the gap between planning and ecology. We argue that sustainable planning represents a promising challenge to motivate and inspire trans-disciplinary collaboration based on landscape ecology principles and goals. We propose that landscape metrics can provide a new basis for realizing this higher level of professional and intellectual interaction.

3. Landscape ecological metrics: a useful tool for incorporating ecological knowledge into planning

3.1. Structure and function relationships

Structure, function and change are the three fundamental landscape characteristics when studying the ecology of landscapes. One most important notion is that landscape pattern strongly influences the ecological processes and characteristics (McGarigal and Marks, 1995). There is evidence that landscape structure has a close relationship with biotic abundance and diversity (McGarigal, 1998a). Turner (1989) describes how spatial structure influences most fundamental ecological processes, and how landscape planning and management, in turn, influence landscape structure.

Changes in landscape structure cause a change in function and vice-versa (Forman and Godron, 1986). The most effective manner for planners of the landscape to understand, plan and manage change is by developing a basic understanding of the dynamic interactions of structure and function. Table 2 illustrates how landscape pattern and process interact. Therefore, identifying the

Table 2
Matrix illustrating the relationships between landscape structure (pattern) and landscape function (or process) for water resources, people and wildlife

Landscape structural elements	Landscape functions or processes		
	Water	People	Wildlife
Matrix			
Forest	Filtration, infiltration, water cycle regulation	Timber, recreation, aesthetics	Main habitats to forest wildlife species, mainly interior species
Patches			
Wetlands	Filtration, infiltration, water cycle regulation	Water cleansing, control for point and non-point pollution, flood control, scientific research, recreation and aesthetics	Habitat for wetland species, stepping stones for migrant bird species
Corridors			
Roads	Car pollution source, erosion, increase run-off and concentration times, bridges as potential bottlenecks	Movement and transport, recreation	Conduit, barrier, major cause for habitat fragmentation, perturbation source, facilitating penetration by people and pollution
Major rivers	Water movement, flood control	Water for consumption, movement and transport production (fish, industries,...), comfort, e.g. air cooling, media were sours are rejected, scientific research, recreation and aesthetics	Habitat for larger species, bird and other small to medium sized riparian species, important corridor for movement of other species, like matrix sp., especially large mammals, barrier

main structural elements in the landscape, and its main landscape fluxes or processes are crucial tasks for understanding how landscapes function. The establishment of relationships between the two components enables the ecological consequences of proposed spatial solution(s) to be predicted.

Fragmentation of habitats is a common process related to landscape change, affecting both its structure and function. It causes the division of landscape elements into smaller pieces. Habitat fragmentation is one of the greatest threats to biodiversity worldwide (Sorrell, 1997; McGarigal, 1998a). Fragmentation has three major components, namely loss of the original habitat (attrition), reduction in habitat patch size (shrinkage), and increasing isolation of habitat patches (Andrén, 1994). According to Fahrig (1997) the effects of habitat loss far outweigh the other effects of habitat fragmentation. Isolation is due to landscape resistance exerted on remnant habitats by the surrounding matrix of non-habitat. It results in potential loss of biodiversity at the genetic level because it reduces the genetic exchanges among populations and, for species with metapopulation structure (McGarigal, 1998a), can contribute to their extinction.

Human activities such as agriculture and urban development are obvious causes of habitat fragmentation. Roads also cause significant fragmentation through direct caused by road construction. Indirect impacts result from auto pollution, and because roads create access for humans to engage in extraction, recreational or residential development activities. Forman's (2000) study on ecological road-effect zone estimates that transportation infrastructure in the US affects one-third of the total land area of the country.

Landscape heterogeneity, and habitat fragmentation processes, e.g. shrinkage, isolation and attrition are spatially measurable characteristics and processes. Landscape metrics enable these processes to be measured quantitatively, supporting a better understanding of landscape pattern and process. Our core set of landscape metrics supports this application.

3.2. Quantifying landscape structure

The ability to quantitatively describe landscape structure is a prerequisite to the study of landscape function and change and various metrics have emerged from landscape ecology for this purpose

(McGarigal and Marks, 1995). Landscape metrics describe the spatial structure of a landscape at a set point in time. They provide information about the contents of the mosaic, e.g. the proportion of each landscape type or category present in the study area, or the shape of the component landscape elements. It is important to establish the difference between spatial statistics and landscape metrics. Spatial statistics are tools that estimate the spatial structure of the values of a sampled variable (i.e. point data) while landscape metrics are tools that characterize the geometric and spatial properties of a patch (a spatially homogenous entity) or of a mosaic of patches (Fortín, 1999). While landscape metrics have been widely used in research their application in planning has been largely absent to date. We propose that this may be due to the large number of metrics available, and a resulting confusion about which metrics to use and how to interpret the results.

It is also important to differentiate between landscape metrics and change indices. Landscapes are dynamic and therefore subject to constant change. Landscape change indices describe the information regarding changes in a landscape mosaic over time. Some are calculated using the values of a metric at different times, e.g. rate of change (see Baker, 1989 for reviews models of landscape change). Dynamic spatial models address integration and interactions between spatial and temporal scales (Sklar and Constanza, 1991). In this paper we will focus only on landscape metrics.

Landscape structure has two basic components: (a) composition and (b) configuration. Composition is a non-spatially-explicit characteristic. It does not measure or reflect the patch geometry or geographic location. Composition metrics measure landscape characteristics such as proportion, richness, evenness or dominance (the complement of evenness), and diversity. Examples include area (and core area) metrics, e.g. number and proportion of classes or types (McGarigal and Marks, 1995; Riitters et al., 1995; Tinker et al., 1998), and diversity metrics, e.g. Shannon's and Simpson's indices (McGarigal and Marks, 1995; Gustafson, 1998). Landscape configuration, in contrast, relates to spatially-explicit characteristics of land cover types in a given landscape, namely those associated with patch geometry or with the spatial distribution of patches. Configuration metrics measure spatial characteristics such as size and shape metrics (e.g. ratio of perimeter:area as in Forman and Godron (1986) and Forman (1995), or radius of gyration (RGYR) applied in percolation theory as in Keitt et al., 1997); others measure the amount and type of edge, such as edge contrast, or the relative location of patch types in relation to one another, e.g. neighborhood, contagion and interspersion metrics.

Some landscape metrics, such as such as dominance, fractal dimension, and contagion have been proposed in the US as indicators for watershed integrity, landscape stability and resilience, biotic integrity and diversity (EPA, 1994, 1995). Recently in Europe metrics-based approaches have been suggested by the Joint Research Center of the European Community to develop biodiversity indicators at the landscape level based on remote sensing images (JRC, 1999).

Connectivity provides a good example for the application of landscape ecological concepts and metrics. It is an important, and measurable landscape characteristic, a parameter of landscape function and an important issue when assessing, or planning for, biodiversity (Bennett, 1998). A growing body of literature suggests that habitat connectivity is important to the persistence of both plant and animal populations in fragmented landscapes (Forman and Godron, 1986; Schreiber, 1988; Noss, 1991; Forman, 1995; Schumaker, 1996; Bennett, 1998; Brooker et al., 1999). Several benefits can be associated with networks of biotope systems, namely in connecting isolated patches and helping to counter the effects of fragmentation.

Connectivity is fundamental to spatial concepts that support some land-use planning and conservation strategies, such as the ecological network concept (van Lier, 1998b). The greenways movement (Fabos and Ahern, 1995) has been advocating and implementing ecological networks internationally. The European Ecological Network (EECONET, NATURA 2000), an important goal of the European Community's Habitat Directive, is also based largely on the concept of connectivity (Bennet, 1995). In addition, a network of ecological corridors to connect the entire Australian continent has been proposed (Bennett, 1998). In Section 4 we will provide an example of the use of connectivity in sustainable land planning.

Connectivity metrics has been applied to model ecological processes, e.g. average isolation to predict the relative connectivity of habitat islands (Gustafson and Parker, 1992 cited in Gustafson, 1998, p. 148), or patch cohesion used to model organism dispersion (Schumaker, 1996). Other connectivity metrics are based on network theory and explicitly consider physical connections, e.g. corridors and hedgerows (see reviews by Forman and Godron, 1986, pp. 415–420, Sklar and Constanza, 1991, p. 249, Forman, 1995, pp. 260–261; 272–274; 282, Gustafson, 1998, p. 148). Two methods commonly used in geography can be applied to evaluate network connectivity based on graph theory: the gamma index and the alpha index, or circuitry (Forman and Godron, 1986, pp. 417–419, Forman, 1995, p. 274). These indices calculate the complexity of networks. Linehan et al. (1995) applied these indices in greenway planning in central New England to assess connectivity and efficiency of a landscape ecological network.

3.3. A proposed core set of metrics

Quantitative techniques have been widely used in planning activities. Transportation planners introduced them in the late 1950s, followed by water resource planners in the late 1960s and urban and regional planners in the 1970s (Fabos, 1985). Since the introduction of GIS into landscape planning by Carl Steinitz and his colleagues at Harvard University in the 1960s the increased use of quantitative techniques has contributed to an increased objectivity and transparency in the planning process.

Landscape metrics are also useful and essential tools for applying landscape ecological concepts in planning. They are understood as fundamental ecological planning tools, and offer great promise to land planners and managers because they can measure the arrangement of landscape elements in both time and space. There are literally hundreds of metrics developed to analyze the landscape structure. According to several comparative studies and reviews (Riitters et al., 1995; Li and Reynolds, 1995 cited in Gustafson, 1998; McGarigal and McComb, 1995; Hargis et al., 1998; Tinker et al., 1998) landscape metrics are frequently strongly correlated, and can be confounded. Either through theoretical considerations or more objective criteria such as statistical analyses, i.e. principal component analysis (PCA) and correlation matrices, the aforementioned authors have considered the independence of selected metrics. All these studies were conducted in real landscapes, except for Hargis et al. (1998), which was based on simulated landscapes. In McGarigal and McComb (1995), Hargis et al. (1998) and Tinker et al. (1998) FRAGSTATS (McGarigal and Marks, 1995) was used to compute metrics. Based on theoretical considerations Li and Reynolds (1995) (cited in Gustafson, 1998) identified five types of metrics. Riitters et al. (1995) identified five independent groups of metrics based on PCA analyses. McGarigal and McComb (1995) PCA studies also revealed several independent metrics.

In the latter, the first three PCA axes (PC1, PC2, and PC3) accounted for a significantly large portion of the total data variance (78.3%). Several metrics took positions apart from one another in each of the three axes, thus denoting independency: on PC1 total edge contrast index (TECI) and edge density (ED) loaded respectively with 0.76 and 0.81 (% variance 33.2); on PC2 patch density (PD) loaded with 0.89 (% variance 23.3); and both mean patch size (MPS) and the largest patch index (LPI) loaded with 0.84 on PC3 (% variance 21.8) (McGarigal and McComb, 1995; McGarigal and Marks, 1995). Tinker et al. (1998) performed PCA analysis on 29 metrics and supported McGarigal and McComb's (1995) findings focusing on five metrics: patch core area, patch size, patch number (PN), ED and patch shape. Regarding patch core area and ED proposed by the latter we did not include them since they are correlated with other metrics already included in our core set, e.g. for patch core area—patch size and shape. Hargis et al. (1998) also performed a comparative study and found that mean nearest neighbor distance (MNND) and mean proximity index (MPI) comparatively low correlations with other metrics, suggesting that inter-patch distance metrics should be added to the set proposed by Riitters et al. (1995).

Analysis of these author's recommendations (including PCA values in McGarigal and McComb (1995), Riitters et al. (1995) and Tinker et al. (1998), and correlation matrices for Hargis et al. (1998)) revealed reasonable agreement on a core set of metrics. A caveat is in order, since the independency of the metrics found in these studies refers solely within the frame of each set of metrics that each paper addressed separately. Therefore, in almost all cases no statistical relationship was asserted among the four sets of metrics to one another, excluding the relationships that both studies of Hargis et al. (1998) and Gustafson (1998) established with Riitters et al. (1995) findings, and that Gustafson (1998) established with those of Li and Reynolds (1995) (cited in Gustafson (1998) and McGarigal and McComb (1995). Our recommendations are therefore based on our own theoretical considerations when integrating the findings of these studies into a proposed core set of metrics. We find that in the aggregate this core set can address the principal needs of applied landscape planning by describing landscape structure and its key associated spatial processes. Therefore, based upon this analysis and information we have selected the following nine basic metrics for sustainable landscape planning which are classified as composition or configuration metrics.

A proposed core set of landscape metrics is given as follows.

Landscape composition metrics:

(1) Patch richness (PR) and class area proportion (CAP).
(2) PN and PD.
(3) Patch size: MPS.

Landscape configuration metrics:

(4) Patch shape: Patch perimeter-to-area ratio (SHAPE).
(5) Edge contrast: TECI.
(6) Patch compaction: RGYR and correlation length I.
(7) Nearest neighbor distance: MNND.
(8) MPI.
(9) Contagion (CONTAG).

Although useful, metrics are not a panacea for all land planning situations or issues. The proposed core set was selected to provide the smallest set of tools possible to describe landscapes and plans, to improve communication between planners and ecologists, and to support a more quantitative approach that could enable plans to yield new information and understanding back to ecologists. Table 3 relates the core set of metrics to several fundamental ecological processes of concern to planners: loss of landscape diversity, fragmentation, and disturbance spread. Nonetheless, metrics are more suited to certain applications and, conversely, important limitations need to be understood in order to assure their proper use.

Table 3
Landscape metrics related to selected ecological processes

Ecological processes	Landscape metrics
Landscape simplification (or reduction of diversity, heterogeneity), e.g. an agricultural landscape composed solely of corn fields (Midwest, USA)	PR: measures the number of classes present in the landscape. At its lowest limit, there is only one land use or land cover class and the landscape lacks diversity. As PR increases greater diversity/heterogeneity is present. CAP: measures the proportion of each class in the landscape. If one class dominates completely the landscape then it will provide little support for multi-habitat species.
Fragmentation: a fragmented landscape provides less connectivity, greater isolation, and higher percentage of edge area in patches	NP: measures the total number of patches of a specified land use or land cover class. If NP is too high it indicates that the patch class is highly fragmented. MPS: measures the average patch size of a class of patches. If MPS is small it indicates a fragmented landscape. NP and MPS should be used complementary since high NP and low MPS values reinforce an interpretation of a fragmented landscape condition.
Spread of disturbance, e.g. disease, fire	MNND, and proximity (PROXIM) both metrics measure the relative distance between patches of the same class and can be used as a surrogate for connectivity. The spread of disturbances such as disease and fire are greater when MNND is low, and when PROXIM values are high. Contagion (CONTAG) measures the relative aggregation of patches of different types at the landscape scale. High levels of CONTAG may indicate a potential for disturbance spread.

PR-Patch Richness; CAP-Class Area Proportion; NP-Number of Patches; MPS-Mean Patch Size; MNND-Mean Nearest Neighbour Distance; MPI-Mean Proximity Index.

3.4. Use and limitations of landscape metrics in planning

It is often argued that the present knowledge of the relationships between landscape structural components and landscape functions is insufficient to build reliable models. Some argue that landscape ecological concepts lack the empirical evidence. "Much as been claimed about the importance of movement corridors in a landscape. Unfortunately, we do not yet understand how to design these most effectively, whether they act as corridors or as barriers, or if they are most important for the introduction of predators or disease-spreading species (Jongman, 1999)."

Another drawback lies in the intrinsic problem of lacking reliable information upon which to base models. Lack of information is frequently a decisive argument for not taking an action, due to the difficulty of predicting the probability of an irreversible disturbance (Fernandes, 2000). It is common to have little information available on the biology, ecology or the present distribution of a species, group of species, or populations to enable the analysis and modeling of ecological impacts caused by planned human activities.

Landscape ecological-based methodologies can reduce some of these problems. Its focus is not on the individuals, i.e. animal or plant species, but on their habitats and functional relationships, for which data is frequently more available e.g. land use/land cover maps (Fernandes, 2000).

A major value of landscape metrics is for comparing alternative landscape configurations—the same landscape at different times or under alternative scenarios, or different landscapes mapped in the same manner (Gustafson, 1998). According to Verboom and Wamelink (1999) even if no quantitative data is available to build into spatial models, expert guesses and a safety range can be used for the purpose of planning scenario studies. Although the exact quantitative outcome may have a high level of uncertainty (large confidence interval), the qualitative results may be robust provided that the model captured the essential qualitative behavior of the species or landscape under study (Verboom and Wamelink, 1999). These authors suggest a comparison with weather forecasts, which are considered important even though they often cannot predict the exact weather conditions. They finish by arguing that as long as we use models to compare situations, as in assessing the consequences of different alternative land use or management scenarios, we do not have to be exceedingly concerned about the exact quantitative outcome being correct. "Until empirical evidence is available we need rough generalizations. These may still be useful if they can rank planning options in terms of: option A is better than option B, for species function X (Jongman, 1999)." Our proposed core set of metrics supports this manner of informed comparisons.

Planners are used to quantitative techniques in other fields. Landscape ecology-based metrics quantify structure. The establishment of relationships between landscape structure and functions in the landscape allows planners to model, and therefore to predict the impacts of planned activities on ecological systems. Quantification of structural characteristics is therefore essential to sustainable landscape planning since it contributes to an understanding of ecological processes, allows for the construction of models and simulation studies, for the comparative evaluation of alternatives, and for monitoring.

We propose that metrics as quantitative ecological tools can play an important role in supporting landscape planning and management decisions. This is valid from the perspective of dealing with natural resources such as water, minerals, forests, wildlife, to approach human-related issues such as urban development and transportation, or in more comprehensive approaches such as land-use planning.

4. Two perspectives on sustainable landscape planning

In this section we will introduce sustainable landscape planning from a two-part perspective: horizontal and vertical. We assert that these two approaches complement each other to frame the use of landscape ecology concepts and landscape metrics that contribute to more sustainable landscape planning.

We will be arguing in this section for the need for sustainable landscape planning. Incorporating ecological knowledge into planning activities contributes significantly for more sustainable planning approaches. We will address the following questions: why, where, how, and which landscape ecological concepts and metrics should be applied in this context. Although landscape ecology is its fundamental scientific basis and it provides for such tools as metrics, our proposed framework proposes the use of other methodologies and tools.

The application of landscape ecological concepts and metrics in planning, can be approached from two perspectives: horizontal and vertical. The horizontal perspective analyzes the potential usefulness of ecological knowledge across current planning themes, sectors or applications including: water resources, mineral resources, conservation, urban (and suburban), or transportation planning. The vertical perspective refers to each phase of the planning process, common to every planning theme. Our focus is mainly on landscape metrics. We use the term planning phase to represent the stages of the planning process (see the columns in Table 1). A synthesis was prepared which compares both perspectives (see Table 4). To illustrate its application we provide an example in Section 4.2 for planning for biodiversity in the Mill River Watershed study, Springfield, MA, USA (Ahern et al., 1998, 1999).

4.1. A horizontal perspective

It is possible to identify several planning themes, fields or communities in society (Forman, 1999), i.e. minerals, water, vegetation, wildlife, forest and agriculture, urban development, transportation, and cultural resources and recreation. In the horizontal perspective we attempt to identify common issues or goals that should apply to all planning fields.

Forman (1995, p. 484) recasts the general principle of sustainability, first introduced by the World Conservation Strategy in 1980, in an operational form: "a sustainable environment is an area in which ecological integrity and basic human needs are concurrently maintained over generations". There are two main components in this definition to account for when planning for a "sustainable environment": to provide for "basic human needs" and, simultaneously, to abide by ecological principles.

All of the planning fields mentioned earlier have primary and secondary objectives. They are perceived as being human driven, ultimately to provide resources for people. Some examples of primary objectives are planning for water quantity and quality (water resources), biodiversity (conservation biology), or to provide efficient and safe mobility (transportation). But they should all be framed by the overarching goal of planning for sustainability. Thus, a secondary objective in all these fields is to "minimize environmental degradation", or to "accomplish the primary objective consistent with maintaining ecological integrity or healthy environment" (Forman, 1999).

As presented in Section 2, it is becoming widely recognized that ecological principles embedded in applied sciences such as ecosystem management and landscape ecology are most useful to pursue the goal of sustainability (Table 1). Recent approaches to resource management focus on sources—the ecosystem that produces the resources, rather than the earlier approaches which focused on the resources. An expanded, more holistic vision is required when planning to assure that the relationships among system components and between land uses and activities are fully accounted for.

Additionally, sustainability must be a precondition for planning rather than an afterthought (Christensen et al., 1996 cited in Grumbine, 1997). Thus, the carrying capacity of natural systems must be respected when planning sustainable land uses or activities. According to this goal, ecosystem products (goods and services) must be considered as outputs, not as constraining inputs. This is a corollary of basing resource planning and management on sustainability (McGarigal, 1998a). Establishing a parallel with a common daily life reality, a balanced management of any investment should cover its expenses based only, and at limit, on the investment returns. Living out of the capital in itself will lead inevitably to continuous impoverishment until there will be no capital at all. If we want to assure perennial supply of ecosystem products we should not exhaust natural systems by living on natural capital, but rather on its returns, i.e. production should be bounded by the land's carrying capacity.

Space and time are fundamental dimensions when planning for sustainability (Forman, 1995). An optimal spatial arrangement of elements where society's objectives are made spatially compatible is the key to reduce conflicts and pessimism towards planning (Forman, 1999). Hierarchy theory tells us that systems are nested within systems. Planning sustainability requires recognizing that wherever we are planning, for any use

Table 4
The role of landscape metrics in planning: a matrix combining the horizontal and vertical perspectives

Planning/themes/phases	Water resources planning	Mineral resources planning	Conservation planning	Urban and suburban planning
Focus: which are the most important issues?	In a dynamic i.e. iterative and cyclic planning process landscape metrics (LM) are useful to re-evaluate the pre-set goals according to methodological updates and monitoring results			
Landscape analysis: how does the landscape work? Which are the key landscape elements and functions?	Q: Is the hydrological system very dense or sparse? Is there many wetlands, and are they large, or few and small? LM: area (CAP, MPS) and cluster (MNND) metrics.	Q: Which are the main processes that influence the most the landscape or region where it is located? Identify the matrix. LM: area metrics (CAP), edge (TECI), cluster (CONTAG) and neighborhood metrics (MNND, MPI).		
Landscape diagnosis: is the landscape of today functioning at appropriate/acceptable levels?		Q: Is the mining site intersecting any major corridor and how much (be it for water flow surface or underground, people or animal movement)? LM: network connectivity metrics.	Q: Is the landscape fragmented? How much? LM: area metrics, cluster metrics (MNND, MPI).	Q: How can the pattern of urban areas be characterized, planned or unplanned? LM: shape metrics (SHAPE), edge metrics (TE).
Landscape prognosis				
Scenario design: the spatial concepts			Q: Which are the best places to propose wildlife corridors? Use metrics to define and refine the spatial solutions in a iterative process. LM: edge (TECI) and cluster metrics (MPI).	Q: Where are located the best places to allow for further urban development? Define spatial solutions and use LM to assess impacts as you go along. LM: area, edge and cluster metrics.
Evaluation of future alternatives (or scenarios)	Q: Which is the more efficient solution to protect water resources? Look for adjacencies with uses that are environmentally aggressive. LM: compare edge metrics of several alternatives.	Q: Which is the scenario that minimizes important habitat disruption. LM: area (CAP, edge metrics (TE, TECI)?		
Landscape syntheresis				
Monitoring	Q: Monitor the spatial disruption of the drainage system. LM: network connectivity metrics.		Q: Monitor losses (in area) on the most critical habitats. LM: area and diversity metrics (CAP, PE, Pdiv.).	

Q: questions that planners and managers ask about the landscape; LM: examples of landscape metrics that can be useful to address those questions (based on FRAGSTATS metrics (McGarigal and Marks, 1995) and include other than the metrics proposed in our core set. Area metrics: CAP-Class Area Proportion; MPS-Mean Patch Size; Edge Metrics: TE-Total Edge; TECI-Total Edge Contrast Index; Neighbourhood or "cluster" Metrics: MNND-Nearest Neighbour Distance; CONTAG-Contagion; MPI-Mean Proximity Index; Diversity Metrics: Pdiv-patch diversity; PE-Patch evenness.

or activity, the area being planned (site, landscape) is embedded within a larger ecological system and that important relationships exist to and from that larger system. Some argue even that context is usually more important than content (Dramstad et al., 1996, p. 69). Spatial interdependence of human activities must be acknowledged and incorporated in physical planning, which, in turn should be more comprehensive. "Sustainability absolutely depends on the sizes, shapes, and juxtaposition of the major areas for water protection, building, biodiversity, livestock and so forth (Forman, 1995, p. 516)." We should also look for the stability of the land mosaic, where chorological relationships dampen fluctuations, and provide for adaptability to respond to relatively frequent but unpredictable disturbances or changes (Forman, 1995, p. 519).

Time is also an important factor when planning for sustainability. We should plan in order to allow for natural variations and disturbances, in the order of several human generations (Forman, 1995). Additionally, past time, i.e. environmental history is important to understand present patterns and its interactions with human activities (Berger, 1987). Additionally, it provides criteria for selecting landscape attributes as assays for sustainability. Slowly changing attributes are the most appropriate since they are compatible with the necessary time frame to plan sustainably, e.g. biodiversity, water, soils, etc. (Forman, 1995).

A more proactive attitude in planning is advocated in order to anticipate consequences on ecological systems before they actually take place. Costs can be reduced if ecological damages are prevented at the source rather than to restore, or minimize environmental impacts, at a later stage. The best form of mitigation is avoidance through proper sitting and design; accordingly post-implementation mitigation should be considered as a last resort (Treweek, 1999).

Forman (1995) addresses the fundamental components of sustainability, as five dimensions particularly suited to incorporate in planning and management: (1) adopt a time frame of human generations, (2) equal balance of ecological and human dimensions, (3) focus on slowly-changing attributes, e.g. water, soil, productivity and biodiversity, (4) on relatively objective assays, and (5) thrive for a optimal spatial arrangement or structure of a landscape mosaic. If planning is to provide sustainability for human needs, then it is essential that it be framed by a deep understanding of ecological systems to assure an adequate, dynamic land mosaic, over an appropriate time and space framework.

Rather than proposing a totally new approach, we recognize the value that those frameworks and theoretical contributions reviewed (Section 2) brought to ecologically-based physical planning. We propose to join in one single framework a common set of procedures and tools, potentially responding to all planning activities. In short, we are seeking a framework that is universal in the application of ecological knowledge to physical planning. We argue that a common planning procedure could be applied either for natural resource management, rural planning, or landscape planning encompassing planning for water resources, wildlife, agriculture and forestry, or more human oriented planning such as for housing and recreation. But we would like to go further and propose that it could also be applied to other types of planning not addressed explicitly in the reviewed frameworks. These are mineral resources (Botequilha Leitão and Muge, 2001), transportation planning (Forman, 1999, 2000), urban and suburban development (see also Forman, 1995, 1999; and planning for biodiversity in Greenways, in Botequilha Leitão and Ahern, in press), or for nature reserves located in densely populated metropolitan areas (Botequilha Leitão et al., 2001). Additionally, the potential to apply the fundamentals of this framework to EIA is deemed high (Treweek, 1999). The goal is not to substitute the existent methodologies that address planning in the several sectors, e.g. water resources or agriculture but to inform these planning processes, approaching these at a higher level of analysis, and to provide guidelines to assure that they are oriented towards developing sustainability.

Unifying concepts into one framework applied to all planning activities, rather than a myriad of different approaches could help to build consensus around ecologically-based planning for sustainability. Planners not used to applying ecological principles could certainly benefit a unified framework provides a common basis for planning applications. It would also be useful for addressing multi-purpose, comprehensive planning focusing on different activities and land uses. For instance, when addressing ecologically-related issues experts in water resources and transportation would be using the same methodological approach. They would have a common (ecological) language, their contribution(s) could be more easily integrated, and teamwork within multi-disciplinary teams could be improved. We believe that planners, and other practitioners in general, e.g. engineers, architects, etc. would be much more receptive to incorporate ecological knowledge in their activities if presented with a single, coherent, consistent methodology along with a tool box for its application. This could also contribute to (scientific, philosophical) cohesiveness around ecological values and knowledge, enhancing communication between scientists and practitioners. In our opinion this would address Zonneveld's challenge for augmenting environmental awareness by enhancing human connectivity (Zonneveld, 1995, p. 140), by lowering the factor (*b*) of his formula for misery, i.e. minor people's irresponsibility behavior toward the environment; and to Forman's challenge of striving for cultural cohesion (Forman, 1995, p. 494) as a key component of a sustainable environment.

We would like to emphasize the importance and usefulness for sustainable landscape planning of such advanced planning tools as GIS, remote sensing and spatial statistics, the use of ecological models and simulation techniques. These can help planning to become more objective and transparent. They can also be of use to when dealing with wide sets of data, or with large areas with scarce data. Finally, and in combination with graphical tools, they can promote a better communication of planning issues, procedures and results to a non-expert audience, thus contributing to convey relevant information to the decision-making process.

Finally, meaningful and informed stakeholder and public participation is viewed as a most important dimension in a sustainable landscape planning process. It addresses the social and economic components. It also increases acceptance and the implementation success of a plan. It also contributes to lower costs, resulting from increased efficiency of the planning process by minimizing plan revisions at a final stage (Golley and Bellot, 1999). SWOT analysis, among others, combined with Internet-based techniques can contribute significantly to the consultation of stakeholders and the public. SWOT analysis is based on a structured brainstorming session aimed at eliciting group perceptions of the positive factors (strengths), the negative factors (weaknesses), the possible improvements (opportunities) and the constraints (threats and limitations) related to a given issue (Borrini-Feyerabend et al., 2000).

A balance between basic human needs and ecological integrity should be assured over time. An integrated approach to physical planning and management should be pursued, with a focus on the ecosystems (the source), not solely on the natural feature or landscape quality to be explored (the resource), and always with due consideration for the production capacity of the system. Sustainable planning should be proactive and anticipate consequences, rather than reacting after impacts exist. Cultural sustainability should be a goal (Forman, 1995; Nassauer, 1997); adopt viable spatial solutions over a reasonable period of time, i.e. several human generations; promote more objectiveness, clarity and transparence, and for gathering consensus, e.g. by adopting slowly-changed, objective indicators such as biodiversity, and the use of objective tools such as landscape metrics to build such indicators.

Where should landscape ecology be applied? When addressing environmental issues in planning (Zonneveld, 1995). Why apply ecological knowledge in general, and landscape ecology in particular to planning? We pose that landscape ecological concepts and metrics can assist planning for sustainability as tools that are suitable to address the spatial dimension of land use planning and management issues. It provides a common language between ecologists and planners. Because landscape ecology is a trans-disciplinary science, incorporating systems theory and holistic thinking, it provides also an appropriate scientific approach to inform planning at a higher level of integration, and to plan comprehensively for all planning sectors. We pose that applied landscape ecology can be effective to assist the implementation of the environmental component, in a more systemic, and proactive way. In the following section we will analyze the role of landscape ecological concepts and metrics in each phase of a sustainable landscape plan, the vertical perspective, responding to the other questions: how and which landscape ecological concepts and tools can be applied into (sustainable land) planning.

4.2. A vertical perspective

All the methodologies and tools referenced in the former section, such as public participation or adaptive management, and tools such as GIS and graphical presentation tools can be useful in some or all phases of a sustainable landscape planning process. We will focus on, but not restrict to the role of landscape ecological concepts and metrics in planning (Ahern et al., 1999; Botequilha Leitão and Muge, 2001; Botequilha Leitão et al., 2001;Botequilha Leitão and Ahern, submitted for publication). They can be useful to describe, and model pattern–process relationships (EPA, 1994, 1995; Frohn, 1998; Gustafson, 1998); to provide insights to assist spatial concept design; to assist the selection of planning strategies; to be used as an integration tool of different ecological resources (EPA, 1994, 1995); to evaluate future planning scenarios; and to monitor the implementation and success of management actions (Zorn and Upton, 1997). All these applications can be structured within five planning phases: focus, analysis, diagnosis, prognosis and syntheresis (see Table 1). Although it is acknowledged that abiotic, biotic and cultural (ABC) resources should be incorporated, in the examples used there is a focus on the biotic component. Biodiversity is a slowly changing, objective attribute to gauge sustainability (Forman, 1995). This component is approached mainly at the landscape level, i.e. diversity between ecosystems, as the concepts used are most particularly suited to approach it at this scale, rather than at the organismal or at the genetic levels of biodiversity (CBD, 1992 cited in Global Diversity Assessment—UNEP, 1995)

4.2.1. Landscape focus

This first phase defines and addresses the goals and objectives of a plan. It is the problem identification phase. Goals can be determined by political agendas, planner's goals or mandates, or as opportunities arising from the occurrence of a particular event localized both in place and time. These will determine and to focus on starting priorities, influencing all the process developed subsequently. Consequently, it is important to develop a clear statement of goals and objectives. However, the sustainable planning process is viewed as being highly dynamic and iterative. Therefore, the goals and objectives may be reviewed as many times as appropriate through the planning process, or after its first implementation when reviewing the plan as proposed by adaptive management. Adaptive management represents a strategic approach to decision making when information is uncertain or incomplete. Adaptive management conceives a planning or management decision as an experiment, based on the best available knowledge, structured by reasonable assumptions and monitored over time to gain the "results" of the experiment. Thus, over time, adaptive management yields new information and knowledge that can inform future planning and management decisions.

Because it is virtually impossible to study all components and functions it is also useful to define the scope of the planning study. It is a crucial phase to define the type of planning approach to consider, e.g. to start thinking ecologically, systemic and holistically about the issues of concern.

Finally, stakeholder and public involvement is desirable at this early stage of the process. First contacts can be established to introduce the project. Workshops can be set up to debate more general issues and thus to integrate community views and expectations early in the planning process. Public participation should not end at this point but continue throughout the several phases of this process, including the monitoring phase. If planners succeed, public acceptance and collaboration, it can represent a tremendous source of information not to be underestimated, e.g. by using the local populations as volunteers to monitor certain environmental conditions.

4.2.2. Landscape analysis

Landscape analysis describes a study area and its context in several dimensions, i.e. environmental, economic and social. It identifies the processes of interest that determine landscape functions and how they are influenced by the different elements that form the physical landscape.

Because they describe composition and configuration aspects of landscape structure, landscape metrics are useful for providing a first characterization of a landscape. As an example, a metric as simple as the number (PR) and relative proportions of classes (CAP) present in the landscape can be powerful descriptors for identifying the landscape matrix. According to Forman (1995) the matrix is the land use or land cover class that occupies at least 50% of the total landscape. Area metrics can also be useful to identify the largest patches in a landscape, which represent potentially significant core areas for biodiversity or important aquifer recharge areas. Other metrics as those that describe patch shape can provide insights regarding the degree of convolution of edges, and consequently about the potential for species dispersion from the patch or containment within the patch. According to landscape ecology's "form-and-function" principles compact forms are effective in conserving resources; convoluted forms enhance interactions with the surroundings (Forman, 1995, p. 124). An important characteristic influencing interactions between the matrix and a patch is boundary shape (Forman and Godron, 1986, p. 175). A straight boundary tends to have more species movement along it, whereas a convoluted boundary is more likely to have movement across it (Dramstad et al., 1996) e.g. animal movement from a patch to the surrounding matrix will be enhanced in more convoluted patches. Computing metrics such as edge contrast at the patch level can support the identification of corridors, barriers or resistance to animal movement. GIS maps based on metrics data can be produced and useful patterns revealed (Ahern et al., 1999). By identifying clusters of patches and isolated patches, with neighborhood and connectivity metrics, e.g. proximity, contagion, situations can be identified where connectivity is most impaired (e.g. where corridors should be placed).

Landscape metrics are also useful to integrate different ecological resources in a landscape approach (EPA, 1995). Landscape composition and pattern becomes the common denominator by which the condition of one resource type (e.g. streams) can be compared to another (e.g. agricultural lands).

4.2.3. Landscape diagnosis

This phase represents a landscape diagnostic, as done by a medical doctor, who after examining a patient gives a first impression about the patient's health (Bolós, 1992). It attempts to answer the following questions: is the landscape functioning well? If not, where it is not functioning well and why? This is analogous with Steinitz's evaluation phase (Steinitz, 1990) (Tables 1 and 4).

A preliminary diagnosis on the present condition of the landscape identifies the system components that are dysfunctional. It is performed based on landscape analysis and aims to identify landscape dysfunctions and land use conflicts. For instance, some metrics can be of use to assess the degree of human influence versus natural heterogeneity on a particular landscape (Hulshoff, 1995, Sorrell, 1997) e.g. patch shape metrics. Geometric patterns are indicators of human disturbance (forest stands, roads and urban areas), as more complex and irregular shapes are most common in nature (Forman, 1995). Area weighted indices are preferred as more emphasis is placed on patches of significantly larger size (Sorrell, 1997).

4.2.4. Landscape prognosis

Prognosis comes from the Greek words pro (before) and gnosis (knowledge) (Bolós, 1992). This phase is directed to develop possible visions on how the landscape could change to meet goals and to assure that the direction of those proposed changes leads overall towards a more sustainable condition. Again comparing with medicine, it forms a landscape prognostic. Evaluation and comparison of different alternatives is recommended to allow a better understanding about the potential pattern that changes and associated consequences could take. At the extremities of a planning continuum, landscape prognosis scenarios can contemplate such solutions as the complete development of the landscape under consideration e.g. the build-out scenario, to a conservation scenario where development is minimized. The wider the spectrum of alternatives the more useful it becomes both for public discussion and for increasing transparency in the decision-making process, since all, or at least a large number of possibilities are taken into consideration and therefore included into the discussion. Next, we will present some examples of landscape metrics applications in different steps included in the prognosis phase, i.e. designing spatial concepts, supporting criteria for selecting planning strategies, and evaluating planning scenarios.

4.2.4.1. Designing spatial concepts. A spatial concept expresses through words and images an understanding of a planning/design issue and the actions considered necessary to address it. It encompasses both rational knowledge and creative insights (Ahern, 1999). Landscape metrics can prove to be useful to provide insights, and to help assist the process of spatial concept design, as in Ahern et al. (1999). As an example, consider the Patch–Corridor–Matrix model (Forman, 1995), and the four indispensable patterns for sustainable planning (Forman, 1995, p. 452). A spatial concept for a particular landscape can be drawn by applying these concepts: (1) maintain large patches of native vegetation, (2) maintain wide riparian corridors, (3) maintain connectivity for movement of key species among the large patches and (4) maintain heterogeneous bits of nature throughout human-developed areas.

Area metrics can assist the identification of the largest patches in the landscape, which represent significant resource areas, e.g. core areas for interior animal species, or large "natural" areas for aquifer recharge. Identifying clusters of patches and isolated patches, using metrics such as neighborhood, e.g. nearest neighbor and connectivity metrics, e.g. proximity, contagion, can identify situations where corridors should be placed. As pointed out before, computing metrics such as edge contrast can identify corridors, barriers and landscape resistance to animal movement. This information can guide the planner in defining the "best" alternatives to plan for corridors based on the "least" resistant or more conductive land uses or land covers to constitute preferred paths for wildlife movement.

4.2.4.2. Supporting criteria for selecting planning strategies. Ahern (1995) proposed a typology comprised of four planning strategies: protective, defensive, offensive and opportunistic. For example, an offensive strategy is appropriate when the landscape is already deficient with respect to supporting ABC resources. Guided by a spatial concept, it promotes a "possible" future landscape that can be realized only through restoration or regeneration. These four strategies are not mutually exclusive. Rather, they are more often used in an integrated manner.

Landscape metrics can be useful to support decisions regarding where to apply these different planning strategies. As an example, they can help in identifying which are the most important existent patches, or land uses to protect (protective, defensive strategies) in order to maintain current levels of connectivity in the landscape. They can also help to identify which patches could contribute the most to increase connectivity if the original land use is converted or restored to the habitat type of interest (offensive strategy).

4.2.4.3. Evaluating planning scenarios. Landscape metrics are useful to evaluate planning scenarios. Criteria are defined based on previous assumptions for the future landscape. Different scenarios are developed according to different strategies. Strategies are then expressed spatially in the plan (spatial concept), e.g. define links to establish, areas to protect, corridors to implement, etc. Metrics are used to assess impacts of the proposed changes on the processes of concern, e.g. biodiversity or hydrological functions. These are computed on the base scenario and again on the proposed scenarios, and compared (Ahern et al., 1999; Botequilha Leitão and Ahern, 2002). A scenario can then be chosen according to the evaluation of impacts, and on the pre-set goals and objectives for the conservation of the target species habitat and populations.

The Mill River Watershed study is presented as a demonstration application of the vertical methods, and supported with landscape metrics (Ahern et al., 1999). One of the scenarios in the prognosis phase was the build-out scenario, based on the net usable land area (NULA) analysis that identifies all constrained land as that not developed, protected or regulated. All lands not identified are considered available in the build-out scenario for future urban uses (Ahern, 1999). The habitat areas for the snowshoe hare and the bobcat remaining under the build-out scenario were obtained by combining the habitat map for the snowshoe hare and the bobcat (Fig. 1a), with the build-out map (Fig. 1b).

Metrics were computed on the snowshoe hare and bobcat habitat class, both in the present condition and in the Built-out maps, and values compared. Results summaries are shown in bar charts (Fig. 2). The habitats are coincident for both the snowshoe hare and bobcat, and thus values are aggregated. However, since these two species have different home ranges and dispersal capabilities, proximity (MPI) values differ (Fig. 2).

The Mill River results clearly shows the habitat changes for these two species between the present condition and under a potential build-out scenario: (a) sharp decrease of both total amount of habitat and core area for these two species (almost five times less); (b) decrease of MPS (also almost five times less), and of size variation (MPSSD)—which corresponds to a decrease of diversity; (c) decrease of MPI (almost 10 times less), which corresponds to a decrease of total landscape connectivity for these species.

These results are conditioned to the assumptions imposed to the study, to the species selected, and to the

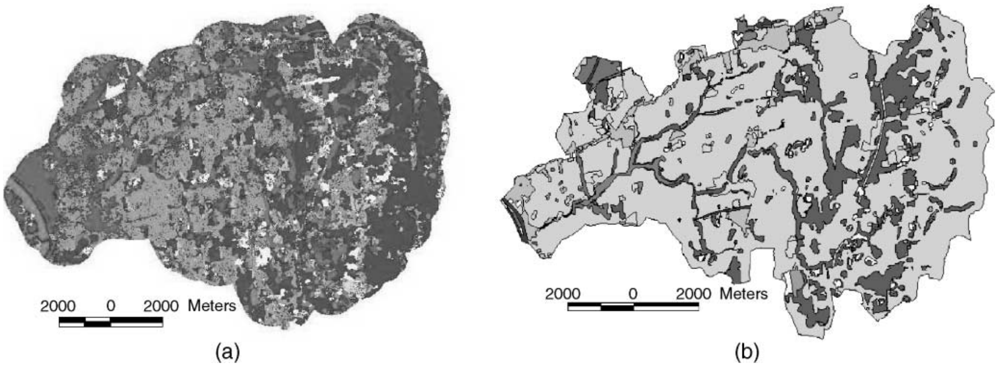

Fig. 1. Comparing scenarios. (a) Present condition: habitat map for the snowshoe hare and the bobcat, and (b) Build-out scenario, for the Mill River Watershed. Landscape metrics for (a) and (b) were compared to evaluate the changes in habitat conditions. Habitat is represented in dark grey, present urban areas in black and build-out areas in light grey.

classification used to construct the habitat maps. Even if argued that these results may not represent completely accurate quantitative information, the direction that they point to is clearly shown: a sharp decrease (almost five times less or more) on both habitat quantity (area and core area) and quality (MPS, MPSSD, MPI) for these two species under the build-out scenario. This kind of information can help decision-makers to envision potential threats of some alternatives, and decide accordingly. Maps, bar charts, graphs and other graphical information, combined with these approaches can constitute powerful tools to planners to convey information to stakeholders, that otherwise could be difficult to be understood.

4.2.5. *Landscape syntheresis*

Syntheresis comes from the Greek word syntereo, which means to preserve (Bolós, 1992). In this phase plans and actions are defined in order to prevent future negative impacts on the landscape and to assure their sustainable functioning. This phase is where the actual plan is designed and implemented. It also includes the

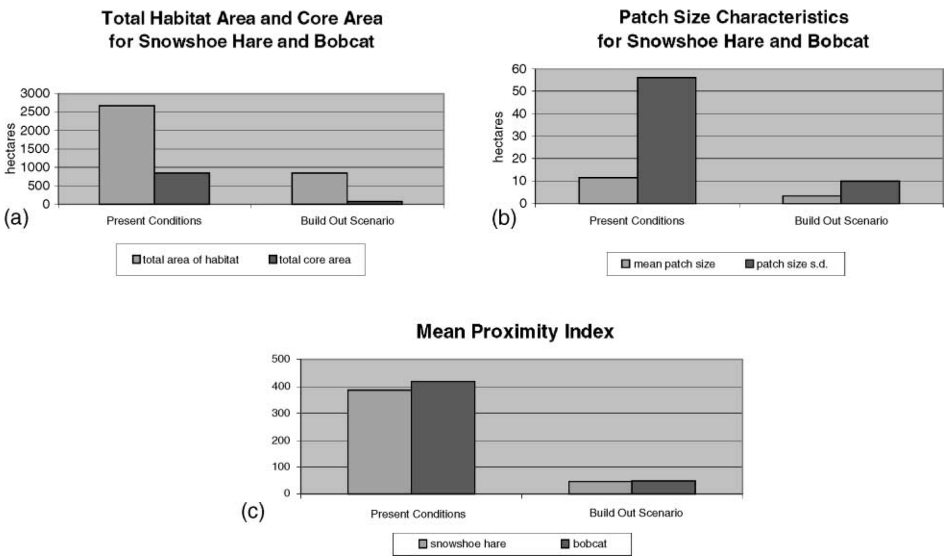

Fig. 2. The Mill River Watershed study. Landscape metrics for both the present condition and the build-out scenario, for snowshoe hare and bobcat habitat: (a) habitat area and core area (CA); (b) mean patch size (MPS) and MPS S.D.; (c) mean proximity index (MPI).

monitoring of the on-going processes and changes. Evaluation of the changes on processes occurring as a consequence of the proposed plan's new configurations allows feedback into the planning process. It is useful in assessing the efficiency of the proposed actions in meeting the original goals. Often, they are also helpful to re-evaluate goals and allow changes in the plan according to new findings, thus supporting a more dynamic and iterative planning process.

4.2.5.1. Monitoring. "Sustainability is a goal that no one as yet knows how to achieve. The act of sustainable planning and design is a heuristic process; that is, one in which we learn by doing, observing, and recording the changing conditions and consequences of our actions (Franklin, 1997)." Therefore, monitoring is essential for sustainable systems—allowing us to learn as we go along the planning process. The adaptive management paradigm (Holling, 1978; Peck, 1998) recognizes monitoring as an essential part of a planning process, where planning is viewed as a continuous and dynamic process. As it becomes available, new knowledge is incorporated and contributes to the reassessment and fine-tuning of the plan.

Monitoring can be done at different levels. Noss and Cooperrider (1994) cited in Lee and Bradshaw (1998) divide monitoring into four basic types: baseline, implementation, effectiveness, and validation. Landscape ecological concepts and metrics are useful in all of types of monitoring: for describing patterns, to allow for future comparisons (baseline monitoring, implementation monitoring, effectiveness monitoring) or to model structure–function relationships (validation monitoring). Additionally monitoring the evolution of the landscape can be accomplished through different monitoring activities, and aiming at slightly different aspects of the quality of the environment, e.g. water quality for human consumption, habitat for the selected species or visual scenery in a national park.

In this section, we discussed several roles that metrics can play in a sustainable landscape planning process. They can be useful to describe, and model pattern–process relationships, to provide insights to assist spatial concept design, to assist the selection of planning strategies, as integration tools for different ecological resources, to evaluate future planning scenarios and to monitor the implementation and success of management actions. We have also discussed the role of other methodologies, e.g. public participation or monitoring, and advanced planning tools such as GIS and graphics. All these applications were structured within five planning phases: focus, analysis, diagnosis, prognosis, and syntheresis. In the next section, we will describe how these phases relate with the issues presented earlier in the horizontal perspective. Since the vertical perspective is common to every planning theme it is only natural that the intersection of the two will produce similar questions. However, we will be able to realize that sometimes different metrics are applied to address the same issue or at the same level, e.g. description issues differ among planning themes and so do metrics to address those issues. An example is at the description phase, wildlife resources being described through metrics that address core area for habitats, or connectivity measures to describe potential for animal movement; for transportation planning other metrics play a substantial role, e.g. edge metrics such as total edge per class or edge contrast (TECI), and neighborhood metrics such as nearest neighbor (MNND).

4.3. Combining the horizontal and the vertical perspectives

The horizontal and vertical perspectives intersect and produce questions. They both approach planning although from different points of view. The horizontal is a more conceptual approach to planning, oriented to provide an overall framework. The horizontal perspective is particularly well suited to address the challenge of sustainable planning. It defines the principle factors as human and ecological, space and time. It addresses the different planning themes and identifies common factors. The vertical is more technically oriented, solution-providing, results-oriented approach. Table 4 summarizes the role of landscape metrics to combine the horizontal and vertical perspectives. Representative questions that planners can pose will be given for the three main type of tasks referenced earlier.

4.3.1. Landscape description: to describe, to understand, to analyze

In order to make plans it is essential to understand how a landscape functions i.e. to identify and describe the landscape components and their functional relationships. It is a common phase to every planning theme or methodology (Table 1). In Section 2 we reviewed planning methodologies to formulate general questions: What are the most important elements to study? What are the most valuable elements? How is the landscape structured, e.g. which elements, which components, etc.? How does the landscape function? How do the patches, corridors, and sites relate to one another spatially? What are the functional and structural relationships among its elements? Is the landscape functioning well?

Landscape metrics can be used to answer these questions by supporting the description of resources, be they abiotic e.g. water surfaces and streams, or biotic e.g. forests and pastures. They can also support the description of landscape processes (Table 2) such as the movement of animals and people (see Tables 3 and 4 for potential application of metrics). Following are a set of fundamental questions (Q) produced within each planning theme that can be answered (A) via the use of landscape metrics.

Water resources planners and managers:

Q: What type of landscape is being planned for: agricultural, forested, urban or industrial?
A: Use area metrics to define the landscape matrix; the land use or ecosystem identified as dominant (CAP) will determine the landscape matrix.
Q: Are wetlands large and numerous or small and rare in the landscape?
A: Use area metrics and patch number PN or density (PD) to characterize wetlands number and size.

Mineral resource planners and managers:

Q: Which are the key processes that influence the landscape or region where a mining site is located?
A: The land use or ecosystem identified as the matrix (CAP) will determine the key processes.
Q: Does an urban environment surround the extraction site?
A: Use edge and neighborhood metrics to identify the dominant uses around a particular land use class or type (TECI, MNND).
Q: Noise and pollution levels for example must comply with regulations, and safety must be assured. Are those more intensive human uses too close or are they far apart? Are there important ecological or environmental values in the area, e.g. protected sites or lakes used to provide drinking water? How close or how far apart are they?
A: Use neighboring, or edge contrast metrics (TECI, MNND, PROXIM).

4.3.2. Landscape modelling: to mimic, to predict

In Section 3.1, we discussed the value of establishing valid relationships between pattern and process (see Table 2). Metrics allow quantifying landscape pattern and can be a surrogate for some landscape functions. Once established, these allow planners to anticipate the consequences of their actions. This is useful not only for comparing planning scenarios, but also for designing spatial concepts in an iterative and incremental process (Section 4.2.4). Again general questions asked can be: What differences changes might cause? What is the likely outcome of a defined system change? Following are examples of such questions (Q) that can be addressed by the use of metrics (A).

Forest resource planners and managers:

Q: Are there stand configurations in my study area that affect deer browsing?
A: Run shape indices and compare with ecological effects affecting more straight boundaries versus more convoluted boundaries (SHAPE).

Conservation planners and wildlife biologists:

Q: Is the study area adequate for the survival of a certain species or group of species?
A: Run class area metrics to assess if the landscape have enough total habitat area for that species or group of species (CAP, MPS).
Q: Are there a number of habitat patches that fulfill the minimum area requirements of the species, or group of species of concern?
A: Run area metrics at the patch level in order to identify which patches are most suited as habitat for those species or group of species; (patch size metrics).
Q: If it is a multi-habitat species, are these patches too isolated or are they clustered?
A: Run cluster metrics such as RGYR, nearest neighbor (MNND), or Proximity metrics (MPI).

5. Landscape evaluation: to gauge, to select

Spatial characteristics of alternative planning solutions can be compared based on landscape metrics (Section 4.2.4). This is a common procedure in routine planning activities: to choose from two or more spatial solutions based on pre-defined criteria. General questions posed by planners can be: Should the landscape be changed, and how? What are the priorities for protection? What is the significance and importance (magnitude) of the impacts? Landscape metrics can assist planners introducing more objectivity and transparency into the planning process. Following are some questions (Q) that planners can pose when comparing alternatives, and that metrics can assist in answering (A).

Forest resource planners and managers:

Q: Which is the best timber harvest alternative that maximizes yield and minimizes edge effects?

A: Design several alternative configurations and use edge metrics to compare them (PN, MPS, in combination with CONTAG and edge metrics).

Urban and suburban planning:

Q: How to plan more efficiently for expanding the green areas in a city to support the most functions?

A: Use connectivity metrics to optimize sitting of green spaces in an iterative design process (see Section 4.2.4).

These are examples of questions that planners can pose and that landscape ecology concepts and landscape metrics can assist. These are organized according to the main type of questions described earlier. How to describe the landscape? How to model and predict changes? How to compare alternatives? The relationships between both perspectives are summarized in Table 4.

We presented a framework for sustainable landscape planning. From a horizontal perspective, it applies ecological knowledge in one single framework applicable to all planning activities. It seeks a balance between (basic) human needs and ecological integrity, over time; views sustainability as a precondition for management rather than an afterthought; focuses on the source, not on the resource; considers space and time as fundamental dimensions for sustainability; seeks a proactive attitude towards planning; promotes public participation into the planning process; promotes the use of adaptive management techniques; strives for cultural cohesiveness and cultural sustainability; and advocates for the use of advanced methods and techniques to support better planning. All constitute relevant variables to consider when planning for sustainability. Furthermore, we proposed a vertical perspective to use landscape ecological concepts and metrics in each step of the planning framework. We believe that this approach can improve planning practice, by introducing more objectivity and quantitative methods to promote better ecological design into physical planning solutions.

6. Conclusions

The methodological concepts discussed in this paper have been analyzed in the context of several related planning disciplines and fields of applied science, i.e. landscape planning, landscape ecology, EIA, ecosystem management, systems-based rural planning and landscape ecological planning. We argue that they coalesce into a common body of theory and goals identified under the paradigm of sustainable landscape planning. We proposed a framework that crosses all planning themes. The integration of several methods developed originally to address specific planning activities into a common framework potentially applicable to all planning activities is considered a step forward in the application of ecologically-based methodologies into planning and an advance in planning theory.

We recognize the need for appropriate tools to effectively apply sustainable principles to planning and management. In response to that need we proposed a conceptual framework for sustainable landscape planning based on an integrated, two-part perspective. This integration responds to the following questions: why, where, how, and which landscape ecological concepts and metrics should be applied. We argue that this dual approach can help to structure and clarify the role of (landscape) ecological knowledge and other advanced methodologies and tools in assisting effectively planning.

The main purpose of the sustainable landscape planning framework is to provide for a unified framework for planning for sustainability, incorporating (landscape) ecological knowledge, and other advanced planning methods and techniques, applicable to all physical planning activities. Its basic assumptions are: (a) planning more sustainable is essential and urgent in order to plan for a suitable and enduring habitat for humankind, (b) (landscape) ecology is an appropriate scientific basis to introduce sustainable principles in physical planning, (c) those principles should and can be applied in all planning activities, (d) one single framework to apply them to all planning activities has potential advantages compared to having several, and (e) there is a lack for tools to implement these principles to planning. There are many characteristics that this proposal shares with the theoretical contributions of the authors reviewed in Sections 2 and 4.

The sustainable landscape planning framework innovative characteristics are basically two-fold. At a more theoretical level, it proposes a common framework for all physical planning activities, which seek the integration of all the characteristics presented in Section 4, which are currently dispersed in different frameworks, planning activities, or authors' contributions. It does so because it recognizes its high value for sustainable landscape planning. Additionally it provides a two-way perspective to quantitatively analyze the role of landscape ecological concepts and metrics in the planning process. To our knowledge, no other framework has proposed this consideration of issues in a single framework and, that is potentially applicable to all physical planning activities focused on the goal of sustainability.

The advantages of the sustainable landscape planning framework include:

1. A single framework, which the ecology community could agree upon, would present a unified front, and thus a stronger case to apply ecological knowledge in planning, as opposed to the present myriad of approaches. Landscape ecology as a trans-disciplinary science is particularly well suited to act as a scientific umbrella for a planning framework aimed to include all physical planning activities. This framework's goal would be, not to substitute the existent methodologies that address planning in the several sectors, e.g. forestry or transportation, but to inform those methods at a higher level of analysis, and to provide guidelines to assure sustainability for these planning processes.
2. A single framework is more accessible for planners not used to ecological thinking. Synthesis, i.e. simplification, transparency, and turning principles into operational procedures is surely seen as most welcomed by planners who intend to use (landscape) ecology to design sustainable systems.
3. The framework facilitates communication and knowledge transfer between the research conducted by the scientific community and the practitioners such as planners, or architects and engineers who can use this knowledge to devise better planning solutions. It responds to Forman's (1995), Zonneveld's (1995) and Ahern's (1999) appeals for bridging the gap between scientists and practitioners, improving communication between science and action (the leit motif for the IALE world conference in 1999).
4. It promotes philosophical, scientific, and professional cohesiveness in applying ecological knowledge into planning; as Forman (1995, p. 494) argues, "cultural cohesiveness" is essential for sustainable planning and managing environments.
5. By promoting cohesiveness it also thrives for increasing environmental, i.e. ecological awareness; it helps to build consensus around the concepts of sustainability and the need for incorporating ecological knowledge into planning; it helps for gathering a critical mass for bringing the necessary changes; it would improve or lower the irresponsible behavior of people towards the environment.

Recommendations for the use of metrics in sustainable landscape planning:

1. Landscape metrics are useful in several planning phases, e.g. Analysis—landscape ecological characterization of structure, e.g. determining the matrix, Prognosis—to support the selection of planning strategies and the design of spatial concepts, and in evaluating planning scenarios; and in the Syntheresis phase—by providing indicators for landscape monitoring.

2. Focus on the proposed core set of metrics for planning.
3. Use metrics primarily in comparative terms, e.g. to compare alternative landscape configurations.
4. Use of each metric per se is frequently insufficient to fully characterize and model the spatial dimension of landscape ecological processes. Instead use several metrics from the core set in conjunction, each revealing a distinct but complementary aspect of complex land transformation processes such as fragmentation.
5. Planners are familiar with qualitative data and to incorporate intuitive thinking in the planning process. Landscape metrics can provide useful directions to planning, even in cases when they cannot provide definitive and quantitative data about exact landscape structure–function relationships. Metrics can provide comparative measurements and information to inform insight about those relationships.

Finally, it is important to point out the limitations and caveats of this framework. These are the very same challenges that need to be addressed in the context of planning for sustainable systems.

1. Sustainability should be seen as a direction, rather than a concrete goal (Forman, 1995; Zonneveld, 1995).
2. Although we are convinced that these principles in general are applicable to all resources, we acknowledge that potentially this framework may be less applicable when addressing the particular case of non-renewable resources, due to the finiteness of these resources and their inevitable exhaustion.
3. Landscape ecological science still needs to further invest on research to establish solid relationships between pattern and process, and at several scales; on the role of disturbance; and in the integration of ecological and socio-economic components.
4. Scientists need to develop more practice-oriented research and orient research to the development of operational tools. Consequently they need to understand planners' goals.
5. Planners need to work harder in promoting effectively the integration of several disciplines, and to incorporate ecological theory appropriately.
6. Integration of such tools as GIS, landscape metrics, and animal population models for instance, must be pursued further to enable the construction of better spatially-explicit ecological models.
7. Regarding the use of metrics we would like to point out that our core set is not the ultimate set. There are cases where other metrics may be more appropriate; and that metrics should always be used critically, aware of the usefulness and limitations of a resulting range of metric-derived values. View them as an additional tool to support to better planning and management of landscapes, rather than as a self-sufficient tool.
8. There is an urgent need of inter-institutional cooperation, and (planning) legislation that reflects the need for integrated planning of human activities sectors.
9. This cooperation is also needed within the society in itself to enable people to enforce (effectively) for their views and legitimate expectations. Society in general needs to participate more in planning processes, to cooperate, to promote sound values and increase global awareness.
10. Education needs to incorporate in all planning activities concepts of trans-disciplinarity, systems theory, and environmental and ecological theory including its spatial dimension. This should be done as early as possible and starting at the most basic teaching levels.

We view the main value of this work as forging a new synthesis of planning methods and making landscape metrics accessible to planners. In so doing, we have "filtered" a significant body of research and literature, and produced a new and useful synthesis. Our main contributions, the integrated framework and core set of metrics, may be useful to planners. We argue that these contributions can be useful to focus and advance the contemporary debate about planning for sustainability. In arguing these methodologies planners may verify the merits of existing methods, may adopt ours, or use this debate to develop new methods and tool for sustainability planning. Additionally, by adopting a common or core set of metrics as tools for planning, a more trans-disciplinary integration of basic and applied science may be affected.

As a closing statement we would like to stress the urgent need to aim for more sustainable planning.

We believe deeply in humanity's capacity to endorse the ''sustainable challenge'' and to plan its activities accordingly. After all, every successful animal harvests some portion of the biota and does so sustainably (McLarney, 1999). As the so-called species that represents the top of the evolutionary pyramid, we believe that would be a paradox that we wouldn't be able to do as much ourselves.

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