

Changing perspectives on biodiversity conservation: from species protection to regional sustainability

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Abstract: Biodiversity is the basis for ecosystem goods and services that provide for human survival and prosperity. With a rapidly increasing human population and its demands for natural resources, landscapes are being fragmented, habitats are being destroyed, and biodiversity is declining. How can biodiversity be effectively conserved in the face of increasing human pressures? In this paper, I review changing perspectives on biodiversity conservation, and discuss their relevance to the practice of biodiversity conservation. The major points include: The notion of balance of nature is a myth rather than a scientific concept; the theory of island biogeography is useful heuristically but flawed practically; the SLOSS debate is intriguing in theory but irrelevant in reality; the concept of minimum viable population and population viability analysis are useful, but technically inefficient and conceptually inadequate; metapopulation theory is mathematically elegant but ecologically oversimplistic; and integrative perspectives and approaches for biodiversity conservation are needed that incorporate insights from landscape ecology and sustainability science. I further discuss some key principles for regional conservation planning, and argue that the long-term success of biodiversity conservation in any region will ultimately depend on the economic and social sustainability of that region. Both research and practice in biodiversity conservation, therefore, need to adopt a broader perspective of sustainability.

Key words: biodiversity, conservation biology, landscape ecology, sustainability science

Introduction

Biodiversity, short for biological diversity and a term first introduced in 1988 (Wilson, 1988), usually refers to all varieties of life on the earth which exist at three principal levels: (1) ecosystem diversity – the variety of ecosystems in a given region, (2) species diversity – the variety of species that make up biological communities, and (3) genetic diversity – the variety of genes of organisms that form populations and species. Among the three levels, species diversity has been the most familiar to most people, scientists and otherwise, because humans can readily relate themselves to species of other organisms. How many species are there? Conservative estimates of the total number of living species on earth range from 3 to 30 million, with most of the species being arthropods (May, 1988; Ehrlich & Wilson, 1991; Lawton & May, 1995). To date, about 1.4 to 1.5 million species of plants, animals and microorganisms have been classified and documented (Ehrlich & Wilson, 1991; Stork, 1997). The most biologically rich ecosystems are tropical rainforests, coral reefs, and wetlands. Tropical rainforests occupy about 7% of the earth's surface, but host more than 50% of species of all kinds, including an estimated 5 million species of plants and animals (Lovejoy, 1997).

Biodiversity is important for its intrinsic values and for the survival of humans. For example, biodiversity is crucial for maintaining ecosystem structure and function (e.g., food webs, primary production, nutrient cycling, decomposition) as well as ecosystem stability (Chapin *et al.*, 2000). At the same time, biodiversity provides humans with essential goods (e.g., food, shelters, timber, fiber, and pharmaceuticals) and services (e.g., water and air purification, climate control, nutrient recycling, carbon sequestration, and control of pests and diseases). With the rapid increase in human population and escalating anthropogenic influences on the natural environment, biodiversity loss has become one of the most pressing problems for the survival and prosperity of the modern human society. Main causes of biodiversity loss include habitat loss and fragmentation, pollution (air, water, and solid wastes), over-exploitation of natural resources, and introduction of exotic species. The Food and Agriculture Organization of the United Nations (FAO) reported that the deforestation rate for the tropical forests of the world, including tropical rainforest and other types of forests, was 15.4 million hectares per year during the 1980s (FAO, 1993). The deforestation and fragmentation of tropical forests, the primary reservoir of biodiversity, have resulted in species loss and ecosystem

degradation at an astonishing rate (Wilson, 1988).

Evidently, biodiversity is essential for humanity, and biodiversity loss has been greatly accelerated by human activities. The real question is: how can biodiversity be conserved with ever increasing human pressures on the natural environment? This central question begs a series of more specific questions: Is it possible to keep the “balance of nature”, or is there such balance in nature at all? Are there sound scientific theories and principles for biodiversity conservation? What are they? Is it enough to set aside a certain number of protected natural areas and leave them alone? How should humans and their activities be viewed and treated in planning and managing natural resources for conserving biodiversity? These questions can be addressed at local, regional, and global scales, and indeed they must be addressed at all these scales if we are to achieve the goals of conserving biodiversity and sustaining the biosphere.

However, the regional scale deserves particular attention because it represents the scale at which many if not most environmental policies, planning activities, and implementation actions should and usually do take place. One primary reason is that a region, with multiple interactive ecosystems in a geographic area with similar climate, geomorphology, and land use and land cover patterns, is large enough to include the essential components and interactions of nature-society coupled systems, but still small enough to allow for relatively detailed studies and feasible implementation of policies and action plans. I have argued elsewhere that the human landscapes and regions, at which most landscape ecological studies are conducted, are the most operationally important scales for sustainability research (Wu, 2006). For these reasons, the emphasis of this paper on landscape and regional scales is intended. Specifically, the main goal of this paper is to explore the questions concerning biodiversity conservation by reviewing and synthesizing the evolving perspectives in ecology and biodiversity research in the recent decades. In addition, I argue that these issues can be better addressed with the new insights emerging from landscape ecology and sustainability science.

Balance of Nature: A Myth Rather Than a Scientific Concept

The notion of “the balance of nature” emerged in antiquity (e.g., evident in early Greek cosmologies), and has been a background assumption in ecology for centuries (Egerton, 1973; Wu & Loucks, 1995). It usually implies that nature maintains a permanence of structure and function with a harmonious order if left

alone, and that it can self-organize and return to its previous equilibrium after disturbances. The idea of the balance of nature has profoundly influenced both the theory and practice of ecology for the past several decades (Egerton, 1973; Botkin, 1990; Pickett *et al.*, 1992; Wu & Loucks, 1995). The imprints of the balance of nature are obvious in the supraorganismic concept of plant communities, the cybernetic concept of ecosystems, and a number of similar concepts such as equilibrium, steady-state, stability, and homeostasis, which are central concepts of the classical equilibrium paradigm (Botkin, 1990; Wu & Loucks, 1995). Many ecology textbooks and influential scientific and popular articles have claimed that populations, communities, ecosystems, and even the entire earth are self-regulating systems that would be kept in a stable equilibrium by predictable forces without human disturbances. Such ideas have penetrated pervasively into the guiding principles and practices of biodiversity conservation and environmental protection in the 1970s and 1980s (e.g., the design of nature reserves; see Pickett *et al.*, 1992). Unfortunately, our understanding of the natural world and ability to solve environmental problems may have been significantly hindered by myths and metaphors such as the balance of nature (Botkin, 1990).

However, many ecologists have challenged the notion of the balance of nature and the related concepts of equilibrium and stability during the past several decades. Little empirical evidence can be found anywhere to support the existence of equilibrium states for ecological systems; and on the other hand, studies have repeatedly shown that spatial heterogeneity and nonlinear dynamics, which are deemphasized or completely ignored in the classic equilibrium paradigm, are pervasive on all levels of biological organization. Nature is not in constant balance; rather, it is in eternal flux (Wu & Loucks, 1995). Patchiness, both a source and consequence of the complex dynamics of nature, is ubiquitous across all spatiotemporal scales and levels of organization. Since the 1980s, mainstream ecological perspectives have shifted their focus from equilibrium, homogeneity, determinism, and single-scale phenomena to nonequilibrium, heterogeneity, stochasticity, and multi-scale linkages of ecological systems.

As a result, a new ecological paradigm, the hierarchical patch dynamics paradigm (HPDP) has emerged (Wu & Levin, 1994; Wu & Loucks, 1995; Pickett *et al.*, 1999; Wu, 1999). The major tenets of HPDP include: (1) ecological systems are spatially nested patch hierarchies, in which larger patches consist of smaller patches; (2) dynamics of an ecological system can be studied as the composite dynamics of individ-

ual patches and their interactions at adjacent hierarchical levels; (3) pattern and process are scale dependent, and interactive when operating in the same domain of scale in space and time; (4) nonequilibrium and stochastic processes are not only common, but also essential for the structure and functioning of ecological systems; and (5) ecological stability frequently takes the form of metastability that is achieved through structural and functional redundancy and incorporation in space and time. Based on HPDP, "harmony is embedded in the patterns of fluctuation, and ecological persistence is 'order within disorder'" (Wu & Loucks, 1995). Thus, HPDP may be seen as a framework that integrates equilibrium and nonequilibrium perspectives across multiple spatiotemporal scales and levels of organization. The hierarchical patch dynamics paradigm has quite different practical implications for biodiversity conservation because of its emphasis on the dual effects of disturbances, heterogeneity, and scale multiplicity (Wu & Loucks, 1995). These perspectives of HPDP are best reflected in landscape ecology which will be discussed later in this paper.

Theory of Island Biogeography: Heuristically Useful but Practically Flawed

The equilibrium theory of island biogeography by MacArthur and Wilson (1963, 1967) asserts that species diversity on an island is primarily determined by immigration and extinction. The predictions of the theory include: (1) the existence of an equilibrium species diversity for a given island as extinction and immigration rates become equal; (2) the effect of island-mainland distance on the species immigration rate, and the effect of island area on the extinction rate; (3) higher equilibrium species diversity on larger and less distant islands; and (4) greater species turnover on smaller and less distant islands (Wu & Vankat, 1991, 1995).

The island biogeographic theory has had pervasive influences in ecology applications, particularly in the design of nature reserves to maximize species diversity. In the early 1970s, general principles for nature reserve design were proposed based on the equilibrium theory, and were adopted as part of the "World Conservation Strategy" by the International Union for the Conservation of Nature and Natural Resources in 1980. Some of the key design principles included: (1) a large reserve is superior to a small one; (2) a single large reserve is better than several small reserves with the same total area; (3) when two or more reserves are inevitable for some specific habitat or species, inter-reserve distance should be as short as possible; (4)

corridors between reserves are recommended to increase inter-reserve immigration; and (5) a circular shape is optimal because it minimizes dispersal distances within the reserve (Wu & Vankat, 1995).

However, although it may still be regarded as a great heuristic device, both the validity of the equilibrium theory of island biogeography itself and its application are unwarranted (Wu & Vankat, 1995). The theory is a typical example of the classic equilibrium paradigm which, as discussed earlier, has a number of problems when it is carefully scrutinized against reality. Given that landscapes are ever-changing, most of which are being increasingly fragmented, the equilibrium assumption behind the theory is, at best, shaky. Also, it does not consider the multi-faceted influences on the protected area of the surrounding landscape context as well as the internal habitat heterogeneity, disturbance regimes and associated patch dynamics, edge effects, and multiple sources for species. All these factors are important to species persistence and ecosystem functioning, and have been some of the key issues in landscape ecology. In short, the theory of island biogeography is heuristically useful, but practically flawed. As Jazen (1983) put it concisely and precisely: "No park is an island"!

SLOSS: Theoretically Intriguing but Practically Irrelevant

The heated debate of SLOSS (single large or several small reserves) in the 1970s and 1980s, was related to the application of the theory of island biogeography in nature conservation. Although the topic seems quite relevant to the design of nature reserves and biodiversity conservation planning in general, a closer examination reveals that the debate oversimplified the complexity of species diversity dynamics and overlooked several issues critically important to conservation planning and implementation. Studies have shown that the slope of the species-area relationship, the proportion of common species among small reserves of concern, and the variability in colonizing abilities of species in the available pool all can affect the outcome of the debate (Soulé & Simberloff, 1986; Zimmerman & Bierregaard, 1986; Wu & Vankat, 1995). It is now widely accepted that both large and small habitat patches have advantages and disadvantages for conserving biodiversity and ecosystem functioning. Major ecological values of large patches include enough habitat to sustain populations of patch-interior species, core habitat and escape cover for wide-ranging animals, sources of species for colonization, accommodation of natural disturbance regime, buffer against species extinction during environmental change, water

quality protection for aquifers and lakes, stream network connectivity, and ecosystem stability; on the other hand, small habitat patches also have a number of benefits, including greater habitat for small-patch-restricted and rare species, habitat and stepping stones for species dispersal and recolonization, abundant edge species with high population densities, overall habitat heterogeneity, lower intra- and interspecific competition, and reduced risk of spreading diseases, disturbances and invasive species (Forman, 1995; Wu & Vankat, 1995).

Therefore, the SLOSS debate is not really relevant to the practice of biodiversity conservation in already fragmented landscapes with multiple competing land use demands. A challenging but practical question is how both large and small habitat patches can be used together to achieve the overall goals of biodiversity conservation that vary geographically around the world. To address this question, we must consider a number of factors that are beyond the scope of SLOSS, including the minimum viable population (MVP) sizes of target species, the minimum area to sustain MVP, the minimum dynamic area (i.e., the minimum area that allows for the completion of the internal recolonization process despite the effect of natural disturbance, according to Pickett & Thompson, 1978), landscape connectivity, and specific conservation goals. Both common sense and scientific research support the general rule of thumb that, whenever feasible, the larger, the better. It is generally true for the purpose of biodiversity conservation that large patches tend to provide large benefits, and small patches small supplemental benefits (Forman, 1995). Nevertheless, in no way should the small habitat patches be excluded from any biodiversity conservation planning.

MVP/PVA: Useful but Technically Inefficient and Conceptually Inadequate

The question of how many individuals of a species are enough to ensure the long-term persistence of the species is important both theoretically and practically. The concept of “minimum viable populations” (MVP) attracted much research attention in the 1980s and the early 1990s. Shaffer (1981) offered a quantitative definition of MVP as “the smallest isolated population having a 99% chance of remaining extant for 1,000 years despite the foreseeable effects of demographic, environmental, and genetic stochasticity, and natural catastrophes.” The MVP concept implies that for a given population there exists a threshold size above which the population will persist for a significantly longer period of time (Shaffer, 1981; Gilpin & Soule, 1986; Burgman *et al.*, 1988). The process of comput-

ing the extinction risk of a particular species or estimating its MVP has been known as the “population viability analysis” (PVA), and a number of conceptual procedures and computer software packages for PVA have been developed in the past few decades (Gilpin & Soule, 1986; Morris & Doak, 2002).

Because MVP connects the size of a population directly with its probability of extinction, its utility to species conservation is seemingly obvious. However, in view of the multi-level definition of biodiversity, the use of MVP and PVA in conservation practices is clearly limited by their focus on single species and reductionistic methodology and the great demand for detailed data (Poiani *et al.*, 2000). In many situations and for many species deriving a reliable value of MVP may not be possible simply because of data scarcity and uncertainties, and in other situations such a species-specific approach may not work just because it is too time-consuming or costly. In addition, it is hard to imagine the MVP or extinction risk of a given species will remain constant when the landscape in which it resides keeps changing! Based on a review of PVA studies, Reed *et al.* (2002) discussed several caveats of PVA, and pointed out that using population viability analysis to determine MVP is a “wrong conservation focus” because of the uncertainties associated with the models and data used in PVA. Nevertheless, PVA remains a quite useful tool for assessing the effectiveness of alternative conservation or management plans for protecting rare and endangered species (Reed *et al.*, 2002; Wu, 2008).

Metapopulation Theory: Mathematically Elegant but Ecologically Oversimplistic

A metapopulation is “a population of populations which go extinct locally and recolonize” (Levins, 1970). The concept of metapopulation dynamics resembles the MacArthur-Wilson model of island biogeography in that extinction and colonization are the key processes. However, species colonization in most metapopulations usually takes place among subpopulations, all of which may be subject to local extinction. A major finding from metapopulation studies is that a species can still persist at the landscape level even though its subpopulations are subject to frequent local extinction (Wu *et al.*, 1993; Wu & Levin, 1994; Hanski & Gaggiotti, 2004). Much of the insight from metapopulation studies so far has been generated from theoretical and mathematical modeling work.

The theory of metapopulation is more relevant to biodiversity conservation than the classic equilibrium population models and the theory of island biogeography because it explicitly deals with the interactions

among local populations in physically isolated but functionally connected habitat patches. However, its use for conservation planning is limited by its species-specific focus and inadequate consideration of the heterogeneity of landscape matrix and socioeconomic processes that affect population dynamics and species persistence. In reality, populations do not live in habitat patches that can be neatly delineated and that are surrounded by a homogeneous landscape matrix, as assumed in most metapopulation models. Rather, they are situated in heterogeneous and dynamically complex landscapes that are shaped by a myriad of physical, biological, and socioeconomic processes. Thus, the metapopulation approach is useful, but certainly not adequate for achieving the overall goal of conserving all levels of biodiversity (Wu, 2008).

The theory of island biogeography, metapopulation theory, and most PVA models all focus on the “islands” in a homogeneous matrix. In contrast with this island perspective, a landscape approach explicitly considers all landscape elements and their spatial configuration in relation to population dynamics and ecosystem processes across a heterogeneous geographic area (Saunders *et al.*, 1991; Wu, 2008).

Integrative Perspectives and Approaches for Biodiversity Conservation

From the previous sections, it becomes clear that, although all the different theories and perspectives are useful, at least in some respects, to biodiversity conservation, none of them can adequately capture the complex patterns and processes that are essential to the different levels of biodiversity. A more comprehensive conceptual framework is needed that explicitly relates the different levels of biodiversity to the spatial patterns of real landscapes and their underlying ecological and socioeconomic processes. Clearly, such conceptual framework has to be highly interdisciplinary, cutting across natural and social sciences. Towards this end, different integrative perspectives and approaches have been developed in recent years, indicating a shift from the traditional species-based focus to a multi-level and multi-scale landscape perspective in both the theory and practice of biodiversity conservation (Noss, 1990; Wu & Loucks, 1995; Meffe & Carroll, 1997; Poiani *et al.*, 2000; Wu & Hobbs, 2002, 2007). In this section, I review some of the most noticeable developments in this front, and argue that landscape ecology and sustainability science have much to offer to the further development of comprehensive conservation strategies at the landscape, regional, and global scales.

Perspectives of Landscape Ecology and Sustainability Science

Landscape ecology is the science and art of studying and improving the relationship between spatial pattern and ecological processes on a range of scales and organizational levels (Wu & Hobbs, 2002, 2007). Landscapes are commonly defined as spatially heterogeneous geographic areas characterized by diverse interacting patches or ecosystems, ranging from relatively natural terrestrial and aquatic systems such as forests, grasslands and lakes to human-dominated environments including agricultural and urban settings. The most salient characteristics of landscape ecology are its unequivocal emphasis on the relationship among pattern, process and scale and its focus on broad-scale ecological and environmental issues that necessitates the coupling between biophysical and socioeconomic processes. As a highly interdisciplinary and transdisciplinary enterprise, landscape ecology integrates biophysical and analytical approaches with humanistic and holistic perspectives across natural and social sciences.

Key research topics in landscape ecology include: (1) ecological flows in landscape mosaics; (2) causes, processes, and consequences of land use and land cover change; (3) nonlinear dynamics and landscape complexity; (4) scaling, i.e., the translation of information from one scale to another; (5) methodologies for dealing with spatial heterogeneity; (6) relating measures of landscape pattern to ecological processes; (7) integrating humans and their activities in ecological research; (8) optimization of landscape pattern; (9) landscape conservation and sustainability; and (10) data acquisition and accuracy assessment. Studies in landscape ecology usually involve the extensive use of spatial information from field survey, aerial photography and satellite remote sensing, as well as pattern indices, spatial statistics and computer simulation modeling. The intellectual thrust of this highly interdisciplinary enterprise is to understand the causes, mechanisms, and consequences of spatial heterogeneity, while its ultimate goal is to provide a scientific basis and practical guidelines for developing and maintaining ecologically, economically, and socially sustainable landscapes.

The essence of sustainable development is meeting fundamental human needs while conserving the life-support systems of the earth for future generations (National Research Council, 1999; Kates *et al.*, 2001; Parris & Kates, 2003). Sustainability science focuses on the dynamic interactions between nature and society, and addresses issues of self-organizing complexity, vulnerability and resilience, inertia,

thresholds, complex responses to multiple interacting stresses, adaptive management, and social learning (National Research Council, 1999; Kates *et al.*, 2001; Clark & Dickson, 2003). Thus, it is committed to place-based and solution-driven research that integrates environmental, economic, and social dimensions and encompasses local, regional, and global scales.

Wu (2006) argued that landscape ecology is necessarily an important part of the scientific core of sustainability research for several reasons. First, the human-perceived landscape represents a critically important spatial unit for studying and maintaining sustainability because it represents the smallest scale below which nature–society interactions usually cannot be adequately addressed. Second, landscape ecology provides a hierarchical and integrative ecological basis for dealing with issues of biodiversity and ecosystem functioning at multiple scales. Third, landscape ecology has already developed a number of interdisciplinary and transdisciplinary approaches to studying nature–society interactions. Fourth, landscape ecology offers theories and methods for studying the relationships between spatial pattern and ecological processes. Fifth, landscape ecology provides a suite of methods and metrics that are helpful for developing sustainability indicators. Finally, landscape ecology provides both theoretical and methodological tools for dealing with scaling and uncertainty issues that are fundamental to nature–society systems.

Principles for Regional-Scale Biodiversity Conservation Planning

Landscape ecological principles have been increasingly applied in biodiversity conservation (e.g., Noss, 1983, 1987; Franklin, 1993; Poiani *et al.*, 1998, 2000; Gutzwiller, 2002; Kazmierski *et al.*, 2004). In particular, a number of landscape ecologists and conservation biologists provided general and specific guidelines in the book edited by Gutzwiller (2002). Instead of reviewing the details of the rapidly expanding literature in this area, here I will focus a few examples that are useful for regional-scale biodiversity conservation planning.

The landscape approach (also sometimes referred to as the ecosystem approach) is often characterized by the multiplicity in organizational levels and spatial scales, the explicit consideration of both biodiversity and ecosystem processes, and the emphasis on the overall landscape and regional sustainability. The most comprehensive landscape approach to biodiversity conservation takes into account the diversity and configuration of all land use and land cover types in a

region, ranging from the remnant ecosystems to the heavily populated or urbanized areas. This landscape-level continuum view is in sharp contrast with the traditional conservation focus primarily centered on the protected areas (Poiani *et al.*, 2000; Groves *et al.*, 2002). The increasing recognition of the importance and necessity of the landscape approach is at least partly responsible for the recent shift in conservation planning towards broader spatial scales worldwide. The following are two examples from highly respected conservation programs.

The first example is a set of 12 “ecosystem approach principles” for the conservation of biological biodiversity developed by the United Nations Environmental Programme (UNEP-CBD, 2005). These principles are: (1) setting the objectives of ecosystem management and biodiversity conservation is a matter of societal choices; (2) management should be decentralized to the lowest appropriate level; (3) effects of management and conservation actions on adjacent and other ecosystems should be considered; (4) understand and manage ecosystems in an economic context while promoting biodiversity conservation and sustainable use; (5) conserve ecosystem structure and functioning in order to maintain ecosystem services; (6) manage ecosystems within the limits of their functioning; (7) manage ecosystems on the appropriate spatial and temporal scales; (8) manage ecosystems with clear long-term plans and objectives; (9) manage ecosystems from a dynamic perspective; (10) balance and integrate between conservation and use of biodiversity; (11) manage ecosystems based on all forms of relevant information, including scientific as well as indigenous knowledge, innovations and practices; and (12) manage ecosystems with involvement of all relevant sectors of society and scientific disciplines.

The second example is the recent planning framework developed by The Nature Conservancy (TNC), which incorporates the idea of multi-level and multi-scale biodiversity (Table 1), systematic conservation planning approaches, and many principles from landscape ecology and sustainability science (Poiani *et al.*, 1998, 2000; Groves *et al.*, 2002). The TNC approach integrates both the “coarse-filter” strategy that focuses on ecosystems and the “fine-filter” strategy that focuses on species (particularly rare and endangered species). Specifically, a seven-step regional conservation planning framework was presented by Groves *et al.* (2002) as follows:

Step 1: Identify conservation targets. Three types of targets are distinguished as abiotic or landscape (physically or environmentally derived targets such as elevation, soil, and geological features), communities and ecosystems, and species (e.g., imperiled or en-

dangered, endemic, focal, keystone).

Step 2: Collect information and identify information gaps. This is accomplished by using a variety of data sources, a variety of methods including rapid ecological assessments, rapid assessment programs, and biological inventories, and expert workshops.

Table 1 Two levels of biodiversity (species and ecosystems), their characteristics, and corresponding spatial scales (adapted from Poiani *et al.*, 2000).

Spatial scale	Biodiversity	Characteristics
Regional geographic scale (millions of hectares or greater)	Regional-scale species	Wide-ranging
Coarse geographic scale (tens of thousands to millions of hectares)	Matrix ecosystems	Successional mosaic, large spatial extent, amorphous boundaries
	Coarse-scale species	Area-dependent, habitat-generalists
Intermediate geographic (hundreds to tens of thousands of hectares)	Large-patch ecosystems	Defined by physical factors/regimes, internal structure and composition either homogeneous or patchy
	Intermediate-scale species	Utilize large patches or multiple habitats
Local geographic scale (square meters to thousands of hectares)	Small-patch ecosystems	Geomorphologically defined, spatially fixed discrete boundaries
	Local-scale species	

The goals should be realistic.

Step 4: Assess existing conservation areas. This step is to determine what biodiversity features are already adequately protected within existing conservation areas, and what more need to be done.

Step 5: Evaluate ability of conservation targets to persist. Three criteria – size, condition, and landscape context – should be used to make sure of the long-term persistence of the conservation targets. This involves PVA for species, estimating minimum dynamic area for communities and ecosystems, and a suite of landscape ecological methods for assessing habitat connectivity and landscape integrity.

Step 6: Assemble a portfolio of conservation areas. This step is to identify a set of potential conservation areas in the region which can be facilitated by GIS and computerized selection algorithms, and to select the appropriate conservation areas and design the network configuration based on principles of biogeographic theory and landscape ecology.

Step 7: Identify priority conservation areas. The TNC planning framework uses five criteria to set priorities: degree of existing protection (extent and quality), conservation value (the number, diversity and persistence of conservation targets), threat (by various disturbances), feasibility (likelihood of land acquisition and logistic issues), and leverage (broader impacts).

The principles for conservation planning used in these two examples clearly go far beyond the traditional specie-based strategies, incorporate many new

Step 3: Establish conservation goals. Two components of goals are the representation and quality of the conservation targets identified above. These targets should be distributed across environmental gradients.

findings in biodiversity research, and fit well with the perspectives of landscape ecology and sustainability science. The TNC framework has been tested and revised in implementing more than 45 regional conservation plans in the United States, Latin America, the Caribbean, Micronesia, and China (Groves *et al.*, 2002).

Concluding Remarks

The world is highly fragmented ecologically, economically, and politically. To survive and persist in such a world, biological organisms as well as humans must be able to cope with heterogeneity. Patchiness in space and time is ubiquitous with or without human influences. Nature is not in balance; rather it is in constant flux. To conserve biodiversity, we must move beyond the traditional dogmas and metaphors such as “superorganisms,” “balance of nature,” and “nature knows best.” Effective conservation strategies must explicitly recognize that biodiversity manifests itself at multiple organizational levels and spatial scales, that landscapes in which biodiversity resides are ever-changing in a hardly predictable way, and that biodiversity is but one essential component of a sustainable landscape or a sustainable world. The ultimate success of biodiversity conservation in any region is likely to be tied with the economic and social sustainability of that region. Therefore, future research and practice of biodiversity conservation need to be further integrated with landscape ecology and sustainability science.

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