PROC. N.S. INST. SCI. (1997)
Volume 41, Part 3, pp. 59-76.

ECOLOGICAL CONSIDERATIONS FOR PROTECTED AREA SYSTEM DESIGN

The need for an integrated approach to maintaining biological diversity

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Abstract: Island biogeography, conservation biology, landscape ecology, paleoecology, non-equilibrium ecology, and hierarchy theory provide insight into protected area system design. Ecological criteria may be identified for site selection and boundary delineation. Considerations of viable populations, critical habitat area, patch dynamics, and landscape context address the question of how much area is required to maintain biological diversity. Strategic methodologies integrating autecological, biogeographical, population viability and gap analyses provide context specific information for designing protected area systems. Biosphere reserve, node and corridor, and greater ecosystem models, and wilderness recovery, triad, coarse- and fine-filter, and target species approaches integrate protected area systems into broader sustainable regional landscapes.

Key words: protected areas, design, biological diversity, viable populations, ecological considerations

Introduction

Historically, parks and protected areas have been established with little contribution from ecological science. Consideration of ecological criteria could improve park and protected area system design for conservation objectives such as the maintenance of current levels of native biological diversity (biodiversity).

Through various conventions, agreements and initiatives, Canada and the Province of Nova Scotia have made commitments to maintaining biodiversity. Parks Canada has a mandate to maintain ecological integrity and complete a system of parks to represent the natural regions in Canada (Canadian Heritage 1994). The Province of Nova Scotia is currently in the process of delineating and establishing a province-wide parks and protected areas system (NSDNR 1994). There is much interest in how these objectives may best be accomplished.

This paper examines ideas from ecological science that provide insight into protected area system design. These include island biogeography, viable populations and critical habitat area, patch dynamics, landscape ecology, paleoecology, and non-equilibrium perspectives. The focus is on ecological considerations that address the question of how much area is required to maintain current levels of native biological diversity over time. The need for strategic and multiple integrated methodologies in planning and designing protected area systems is demonstrated. A selection of methodologies and their relationship to each other is described. Finally, design and planning concepts are introduced, along with approaches for integrating protected areas into the broader regional context.

The Role of Protected Areas

Protected areas have been established for various purposes. In examining the role of protected areas in maintaining biological diversity, many questions arise. For example, are protected areas *alone* expected to fulfill this role? And, are they intended to fulfill this role in perpetuity? If the answer is "yes" to these questions, then the prospects for biodiversity are grim. Existing protected areas are too few, too small and too isolated to enable most large mammals to persist in the shorter term, and many species will be lost over the longer term. Protected areas must work in concert with surrounding working landscapes to maintain biodiversity.

Protected areas have been variously defined as, "an area of land which has effectively been removed from the development stream for the purpose of perpetuating natural conditions", the central role being to protect natural diversity (Pyle 1980, 319); "a region set aside for the protection of the aggregate of species contained therein, as well as the supporting physical environment . . . to maintain, hopefully for perpetuity, a highly complex set of ecological, genetic, behavioral, evolutionary and physical processes and the co-evolved, compatible populations which participate in these processes" (Frankel and Soulé 1981, 98). More simply, "protected areas provide a repository for species and their gene pools, together with the natural selective forces that mould them" (Theberge 1993, 138). Protected areas may also refer to "biological management areas" within landscapes that are not strictly "protected", wherein human activities compatible with conservation objectives take place (Scott et al. 1993).

Theoretical Contributions to Protected Area System Design

Lessons from Island Biogeography

Island biogeography theories have led to applications of its models to terrestrial habitat "islands" and protected area design. Island biogeography theory suggests that species numbers will be larger on larger oceanic islands due to the species-area relationship (Preston 1960), and on islands closer to a continental land mass due to the distance or isolation effects of the equilibrium model (MacArthur and Wilson 1967). Principles for the design of terrestrial protected areas based on island biogeography were proposed (Diamond 1975), widely disputed and largely discredited (Soulé and Simberloff 1986; Margules et al. 1982; Shafer 1990). Substantial debate ensued about whether a single large protected area or several small protected areas (SLOSS) of equal total area would capture more species (for an overview see Shafer 1990).

Theoretical and empirical evidence has been presented both to support and dispute the theories, general design principles, and SLOSS arguments. The resolution seems to be that undue emphasis should not be placed on the application of general rules to the practice of conservation but, in most cases, a large protected area will capture more species than a small one. However, small protected areas are important to capture rare or endemic species with limited distribution. There are benefits to having several protected areas rather than a single one, for example: to reduce effects of disturbances such as disease, fire and pests; to maximize genetic diversity; to provide redundancy; and, to increase habitat variability, and environmental and biological diversity. However, several small protected areas may not protect wide-ranging species, interior species, those sensitive to human interference, and viable populations.

Several reasons have been given for the perceived deficiencies of island biogeographic theory for application to protected area design. The equilibrium theory has not been sufficiently tested and seems to hold true in a few systems and not in others; the species-area relationship is not best explained by the dynamic equilibrium theory and probably is affected primarily by the fact that larger sites tend to have more habitats; and, scientific findings from one system are not necessarily applicable in another (Margules et al. 1982; Soulé and Simberloff 1986). In regards to SLOSS, whether a single large or several small protected areas would capture more species is more likely to be explained by heterogeneity of habitat than by area considerations alone.

Shafer (1990) compiled a set of guidelines for the design of protected areas from consensus in the literature. Table I provides a selection of these guidelines. However, general guidelines should be applied with caution and with respect to the particular context. Decisions should be based on field studies, with a major consideration being to conserve enough habitat for the target species. This view reflects a "pre-equilibrium theory" idea of effective protected area design and supports a return to autecological and context specific research (Soulé and Simberloff 1986; Shafer 1990; Pickett et al. 1992).

Table I Selected Guidelines for Protected Area Design

- The more land you set aside, the more species you will preserve.
- A larger area usually captures more species of plants and animals, but returns typically diminish as area increases beyond a certain point.
- Habitat fragmentation and protected area insularization should be discouraged.
- Protected area boundaries should not create abrupt transitions that discourage animal movement to surrounding habitat.
- A large protected area is better than a small one, everything else being equal.
- Many large protected areas are needed in as many biotic communities as possible.
- Small protected areas can serve a useful purpose in any overall system design to conserve some species or to facilitate migration of other species.
- Small populations should be avoided; populations should be as large as possible, and should be replicated.
- Rare species and large-bodied, wide-ranging species are likely to be the most vulnerable to extinction.
- The establishment of corridors to facilitate animal movement should be based on autecological study of individual species and individual situations.
- The establishment of a new protected area should be based on studies of the distribution of species and communities in the region or country to avoid the sample effect.
- Autecological studies of individual species and their relationship to other species should be given a high priority.
- Protected areas for large mammals should usually be increased in size where opportunities exist to do so; buffer zones are an alternative.
- Under ideal conditions, protected area size should be such as to accommodate the largest, widest-ranging mammals, on the basis of their life history and territorial behavior, and will then serve as an area umbrella for other species.
- Protected area design should seek the theoretical ideal of maximizing alleles by preventing genetic drift in small populations and of preserving heterozygosity by discouraging inbreeding.
- Smaller protected areas probably will withstand less internal or external stress than larger ones.
- The design and management of protected areas should be viewed as potentially an interactive regional matrix.

(Source: Selected from Shafer 1990)

The distinction between site selection and boundary delineation

Selecting and evaluating protected areas from within a broader region requires quite different processes and criteria than for delineating a protected area boundary once a site has been selected. Both site selection and boundary delineation are part of the design process of a protected area system and relate to the question of how large of an area is required to maintain biodiversity. While site selection criteria will be briefly described, the main focus in this paper will be on boundary delineation.

Site Selection Criteria for site selection are well documented. The most commonly stated reasons for establishing and selecting protected areas are to conserve diversity of habitats and species, and characteristics of rarity or uniqueness, naturalness, representativeness, and large size (Table II). A procedure for selecting protected areas may consider various criteria in stages: 1) pre-evaluation classification or sorting stage; 2) representativeness; 3) threshold criteria (naturalness, area); 4) ranking criteria (diversity, rarity, or any other ecological criteria); and, 5) pragmatic criteria such as threat of interference (Margules 1986; Usher 1986).

Table II Evaluation criteria for assessing and selecting protected area sites

Margules and Usher (1981)	Smith and Theberge (1986)	Usher (1986)
Diversity	Rarity, Uniqueness	Diversity (habitats and/or species)
Rarity	Diversity	Naturalness
Naturalness	Size	Rarity (habitats and/or species)
Area	Naturalness	Area
Threat of human interference	Productivity	Threat of human interference
Typicalness or representativeness	Fragility	Amenity value
Educational Value	Representativeness, typicalness	Education value
Amenity value	Importance to wildlife, abundance	Representativeness
Recorded history	Threat	Scientific value
Scientific value	Educational value	Recorded history
Uniqueness	Recorded history / research investment	Population size
Wildlife reservoir potential	Scientific value	Typicalness
Ecological fragility	Recreational value	Ecological fragility, position in ecological / geographical unit
Position in ecological/ geographical unit	Level of significance	Potential value
Potential value	Consideration of buffers and boundaries	Uniqueness
Availability	Ecological/geographical location	Archaeological interest
Replaceability	Accessibility	Availability
Management consideration	Conservation effectiveness	Importance for migratory waterfowl
	Cultural resources	Management factors
	Shape	Replaceability
		Silviculture gene bank
		Successional stage
		Wildlife reservoir potential

* Criteria listed in order of frequency of use *(Compiled from Margules and Usher 1981; Usher 1986; and Smith and Theberge 1986; 1987)*

Currently in Canada, most protected areas are established with the objective of representing the biophysical regions of the particular planning jurisdiction. Both Parks Canada and the Province of Nova Scotia use "representivity" as a primary criteria for site selection (Canadian Heritage 1994; NSDNR 1994). Selecting representative protected areas requires that the jurisdiction be classified into regions. Approaches for classification can be of various types. Environmental approaches are based on climatic regions or a combination of land form, soils, lithology, vegetation and climate. Biological approaches focus on floristics, species distribution or biogeographic regions, or vegetation communities distribution (Usher 1986). World Wildlife Fund's (Canada) gap analysis for assessing respresentivity supports an "environmental" classification approach (Iacobelli et al.). Nova Scotia's Department of Natural Resources utilized a combined approach, identifying 77 natural landscapes in Nova Scotia (NSDNR 1994).

Boundary Delineation Many protected areas were originally created within areas of larger similar "wilderness" and for reasons unrelated to ecological integrity or biodiversity, such as scenic beauty, recreation or tourism. As the surrounding wilderness disappears, boundary issues become more critical in terms of conservation objectives. Greater protection inside the protected area results in a "generated edge" that reflects changes that occur along and across the boundary in human behavior and in species and resource distribution (Schonewald-Cox and Bayless 1986). If the generated edge is inside the protected area, effective size is reduced.

In eight of the largest protected areas in western Canada and the United States, the legal protected area boundaries are smaller than the "biotic boundaries". Biotic boundaries are "those necessary to maintain existing ecological processes and a given assemblage of species within a National Park" (Newmark 1985, 197). As these protected areas become increasingly insularized by surrounding land-use change they may experience faunal collapse.

Protected area boundaries need to be compatible with ecological realities to maintain biodiversity. Theberge (1989) described abiotic, biotic and cultural guidelines for delineating ecologically sound boundaries (Table III). These guidelines may be adapted for particular applications with consideration of the specific biogeographic context.

Table III Guidelines for drawing ecologically sound boundaries

Abiotic Guidelines

1. encompass the greatest possible proportion of the area drained by the river of highest order
2. include headwater areas
3. consider subsurface transbasin water flow
4. should not cross active terrain
5. include rare geomorphic and hydrologic features and processes

Biotic Guidelines

Community level:

6. should not sever rare or unique communities
7. should not sever highly diverse communities
8. should not sever communities with a high proportion of dependent faunal species

Species level:

9. should not jeopardize the ecological requirements of either numerically rare or distributionally rare (uncommon) species
10. should not jeopardize the ecological requirements of niche specialists
11. should not jeopardize populations of spatially vulnerable species
12. should not jeopardize populations of *k*-selected species
13. should not jeopardize populations of range-edge or disjunct species
14. should take into special account pollution-susceptible species
15. should take into special account the ecological requirements of ungulate species

Note: Cultural guidelines have been omitted
(Source: compiled from Theberge 1989)

Ecological Considerations for Determining Area Requirements

It is generally agreed that what is needed is as many, as large and as connected protected areas as possible. However, in light of the increasing competition for land resources, as well as demands for guidelines from protected area designers and managers, the idea that "bigger is better" must be refined to more precise prescriptions for how much area is enough to maintain biodiversity. This question remains unanswered. E.O. Wilson was referring to the task of determining the minimum area required to retain native biodiversity when he stated that "no process being addressed by modern science is more complicated or, in my opinion, more important" (1984 in Shafer 1990).

The ecological considerations in this process are complex and interrelated. However, they can be organized into three broad groups: 1) viable population and critical area; 2) patch dynamics and disturbance regimes; and, 3) landscape level considerations. These considerations may be informed by paleoecology and non-equilibrium perspectives.

Viable Populations and Critical Habitat Area

If the aim of protected areas is to preserve the processes of evolution in perpetuity rather than the present diversity of species *per se* , then the forces that affect species extinction and evolution must be considered. Factors leading to extinction include systematic pressures and stochastic perturbations. Protected areas remove or compensate for systematic pressures, however sources of uncertainty remain to which a population may be subject: demographic, genetic, and environmental stochasticity; natural catastrophes; and, dysfunction of social behavior at small population sizes (Shaffer 1981; Soulé 1983 in Boecklen 1986) (Table IV). A minimum viable population (MVP) is one which has a high probability (for example, a 99% chance) of enduring these sources of uncertainty within the context of its own particular biogeographic context, over a relative time frame (for example, 1000 years) (Shaffer 1981).

Table IV Sources of Uncertainty Threatening Species Persistence

Extrinsic factors:
Environmental stochasticity due to deleterious changes in habitat parameters and the populations of competitors, predators, parasites, and diseases;
Natural catastrophes, such as floods, fires, droughts, which may occur at random intervals through time;
Intrinsic factors:
Demographic stochasticity, which arises from chance events in the survival and reproductive success of a finite number of individuals, such as random variations in sex ratios or birth and death ratios;
Genetic stochasticity resulting from changes in gene frequencies due to founder effect, random fixation, or inbreeding;
Social dysfunction or behaviors that become maladaptive at small population sizes.
(Compiled from Shaffer 1981; and Soulé 1983 in Soulé and Simberloff 1986)

Genetic criteria have provided some understanding for minimum viable population calculations and protected area design (Shaffer 1981; Boecklen 1986; Shaffer 1990; Soulé and Simberloff 1986; Grumbine 1990a; Soulé 1980; Frankel and Soulé 1981).

The two aims of genetic conservation (preservation of heterozygosity and preservation of alleles) may be antithetical from a protected area design standpoint. Alleles are best maintained in subdivided populations with no migration, and heterozygosity is best preserved over the short term in intact populations and over the long term in subdivided populations with high rates of migration. It may not be possible to maintain sufficient numbers of individuals of some species at the present time, with the protected areas we have or are likely to establish in the near future, to allow evolutionary changes (Frankel and Soulé 1981; Soulé and Wilcox 1980). The best short-term objective may be to maintain enough genetic fitness for short term survival of species in order to maintain enough evolutionary potential for long term survival, in the hope that future protected area and land-use planning may leave enough space for ecological processes to reestablish an equilibrium (Frankel and Soulé 1981). Therefore, preservation of alleles should have the higher priority because heterozygosity can be reconstituted by increasing gene flow in the future or artificially. Thus, several protected areas and populations with occasional migrations among them may represent the optimal design strategy for genetic conservation (Franklin 1980; Boecklen 1986).

There are lower limits to the size of sub-populations where extinction probabilities increase, and these lower limits should not be violated. Although there is no "magic number" applicable to all species, Franklin estimated that, from inbreeding considerations alone, a minimum effective population of 50 is needed for short-term, and 500 for long-term survival (1980, 147). It is important to note that *effective* population size is significantly lower than census or total population size, because it assumes an *ideal* breeding population. Effective population size (Ne) may also be higher if other sources of uncertainty are considered along with inbreeding considerations. Further, Franklin's numbers were determined using the 1% rule of maximum tolerable rate of inbreeding developed by domestic animal breeders; effective population sizes for wild species in natural habitats may be significantly higher than Ne=50.

Clearly, minimum viable population size would be higher than effective population size, both in the short- and long-term. Franklin's numbers have been disputed: they are probably only correct in that they are within the right order of magnitude for most species; and, they are probably too low for real or wild populations (Grumbine 1990a; Lande and Barrowclough 1987 in Grumbine 1990 a). Thus, these figures could be dangerous if used as protected area design criteria. Subsequent estimates suggest that a short-term (50-100 years) minimum viable population for wolves is 148 breeding individuals, and for grizzly bears is 393 (Hummel and Pettigrew 1991).

Considerations of viable populations and critical habitat area should ideally be based on long-term survival, thus utilizing figures in the order of magnitude of Ne=500 and applying it to a target species. Minimum critical area (MCA) is determined by calculating the amount of habitat required to sustain the minimum viable population, including home range and migration patterns. The minimum critical area required to protect a viable population has been calculated as approximately 39,000-78,000 km^2 for wolves (Frankel and Soulé 1981, 122), and 12,233-122,330 km^2 for grizzly bears, depending on the location of the habitat (Craighead and Mitchell 1982 in Newmark 1985; Hummel and Pettigrew 1991).

Large mammals, particularly carnivores, are appropriate target species for area requirement calculations because as a group they tend to be sensitive indicators, vulnerable due to their low densities, and important or keystone in their communities. As well, they act as "umbrella" species, encompassing many other species with smaller area requirements (Frankel and Soulé, 1981; Hunter, 1990; Noss, 1990). Thus, protected areas are generally too small: 93% of all protected areas in the world are less than 5000 km^2, and 78% are less than 1000 km^2 (IUCN in Frankel and Soulé 1981, 129).

A methodology for determining protected area size is to: 1) identify target or keystone species; 2) determine the minimum number of individuals needed for survival; and, 3) estimate the area needed to sustain the minimum number, ensuring that: a) enough habitat exists to support the number of individuals in a population needed to guarantee a high probability of survival over a long time period; and, b) the dynamics of succession do not eliminate critical habitat (Soulé and Simberloff 1986).

Population Viability Analysis

Population viability analysis (PVA) is a tool for determining MVP and MCA by incorporating biogeographic distribution patterns, species-specific turnover rates and available population data into computer simulations designed to test extinction probabilities (Gilpin and Soulé 1986). Earlier population viability analyses focused on *demographic approaches* (MacArthur and Wilson 1967), while later studies focused on *genetic aspects* (Frankel and Soulé 1981; Gilpin and Soulé 1986) and environmental factors such as patch dynamics (Pickett and Thompson 1978). A combination of approaches is necessary to provide an integrated model of all the factors of extinction, but such a model may be too complex to use.

Population viability analysis encompasses at least three fields: 1) population phenotype; 2) environment-habitat quality and quantity; and, 3) population - structure and fitness. For PVAs associated with protected areas, the disturbance regime is often the most important factor in the environment because populations may be restricted to island-like habitats and be unable to escape to other suitable habitat areas (Gilpin and Soulé 1986). Thus, PVA requires the consideration of the biogeographic context, particularly patch dynamics and landscape structure. Meta-population viability analysis incorporates considerations of regional sub-population groups (meta-populations) and their relationships.

Minimum Dynamic Area and Effective Protected Area Size

Succession and disturbance regimes such as fire, windstorm, disease and herbivory are often the most significant aspects of the environment. These processes at various spatial and temporal scales across the landscape determine the size, density and temporal frequency of patches and result in heterogeneous patches or "patch dynamics" (Pickett and Thompson 1978) which together over time and space represent a "shifting mosaic steady state" (Bormann and Likens 1979). Patch dynamics should be considered in the design of protected areas because some species in protected areas may not be able to disperse to new sites in the face of disturbances that threaten their survival. Further, patch dynamics are ecological processes which create diverse habitat, resources and communities. Protected areas should allow for these processes, therefore consideration of disturbance regimes, including rare events and the associated patterns of succession, is required.

The design of protected areas should be based on analysis of the minimum dynamic area (MDA). MDA is "the smallest area with a natural disturbance regime, which maintains internal recolonization sources, and hence minimizes extinction" (Pickett and Thompson 1978, 34). In a protected area, the minimum dynamic area should be defined relative to the target species. In other words, viable population and critical area requirements must be combined with patch dynamic consideration to make decisions on effective protected area size. Protected areas should be large enough to contain regionally specific processes such as tree falls, wind throws, fire and disease, without affecting all of the habitat of any particular type. In the face of disturbances enough habitat should remain to support a minimum viable population of the target species.

Biogeographic Context and Regional Landscape Ecology

Protected areas alone will not preserve the present levels of native biological diversity, let alone provide for evolutionary speciation. Very few, if any, protected areas are large, connected and protected enough to support viable populations of large mammals or encompass minimum dynamic areas. Regardless of the care we exercise in utilizing ecological criteria, protected area boundaries are unlikely to remain congruent with biotic boundaries over time.

Species, materials and processes cross protected area boundaries in both directions. The ecological integrity of most protected areas will depend upon the suitability of surrounding lands as supplemental habitat, migration and dispersal routes and buffers. The maintenance of biodiversity will require utilization of protected areas and non-protected areas as habitat. For these reasons, protected area and broader land-use planning must be integrated to maintain biodiversity.

Protected area design should take into account potential edge-, buffer- and isolation- or connectivity- effects of surrounding land-uses and land-cover. At the landscape level, habitat fragmentation remains the principle threat to most species in the temperate zone (Wilcove et al. 1986). Fragmentation reduces habitat area and results in the redistribution of communities or populations into disjunct fragments. The various effects of fragmentation have been widely discussed (Wilcove et al. 1986; Burgess and Sharpe 1981; Harris 1984; 1988; Soulé 1986: Yahner 1988; Harris and Silva-Lopez 1992).

Recognition of the threat of fragmentation has resulted in debate about the potential role of corridors for migration and dispersal, including wide corridors for dispersal in response to climate change (Forman and Godron 1986; Noss 1987; Simberloff and Cox 1987; Shafer 1990; Peters and Darling 1985; Graham 1988; Hunter et al. 1988). However, the value of corridors *per se* is debatable, because characteristics that define an effective corridor vary according to the species in question; a corridor for some species may constitute a barrier for others. "Connectivity" may be a more useful concept than that of corridors; it is generally beneficial to maintain and restore pre-existing connections among protected areas. Areas which provide connectivity among protected areas include buffer zones, riparian strips, and areas of compatible land-uses.

Buffer zones provide a transition zone between protected areas and intensely used lands. They can increase the effective protected area, provide increased connectivity, and ameliorate boundary- or edge- effects. Considerations that have been used to determine buffer zones include: 1) the need of threatened wildlife species for resources outside of the protected area; 2) the need for buffer zones to serve other protective functions; 3) the need to contain wildlife species likely to move outside of the protected area; 4) the reasonable needs of the local people; and, 5) the amount of land actually available for buffer use (Mwalyosi 1991). These criteria are very general, however context specific criteria could be derived from biogeographical and population viability analysis for particular applications.

Integrative Theoretical Perspectives

Paleoecology

Paleoecology gives insight into considerations of long-term processes such as climate change and lends support to the coarse-filter approach of protecting areas representative of physical environment variability. Long-term studies of processes show that species respond to environmental changes in individual and novel ways; communities do not respond *in toto*. This suggests that, because biological communities are ephemeral over time, the long term survival of species will depend on their ability to move and survive in response to environmental changes.

Thus an effective protected area system design would focus on protecting representative physical environments rather than biological communities. Protected areas should be located and delineated according to the distribution and range of physical environments; and, should be connected with large-scale corridors with both north-south and east-west orientations to accommodate changes in species distributions in response to shifts in temperature and precipitation patterns. Further, they should be located near the northern limit of species range; in areas of high species diversity; where topography and soil types are diverse; and, in areas containing altitudinal variability. In the case of accelerated climate change due to anthropogenic influences, many species could not disperse fast enough to compensate for climatic shifts and management intervention may be required (Peters and Darling 1985; Hunter et al. 1988; Graham 1988).

The "Non-equilibrium" Paradigm

The "nonequilibrium paradigm" (Pickett et al. 1992) can be characterized as accepting natural systems as open, and emphasizing process. It can be portrayed metaphorically as "patch dynamics" or "shifting mosaic". This paradigm replaces aspects of the classical "equilibrium paradigm" which can be characterized by Clements' (1916) more static concept of the "climax state".

Resulting considerations for protected area design include a recognition of the importance of environmental and historical context, a focus on processes and heterogeneity at various scales, and the inclusion of people as agents of flux and disturbance. The goal of protected area design becomes to maintain the integrity of the processes that have generated the system, specific to the particular historic and biogeographic contexts, rather than attempt to conserve a "slice-in-time" or "static" communities. Natural systems should be viewed as *processes* rather than *entities* (Pickett et al. 1992; Noss 1992). Ecological considerations for protected area system design are suggested in conservation strategies developed from the non-equilibrium perspective (Table V).

Table V Information and strategies applicable to protected area system design

Information to be applied (Pickett et al. 1992):

1 processes governing the system;
2. context in which it is embedded;
3. historical range of flux in the system;
4. evolutionary and physiological limits of the organismal components; and,
5. nature and impacts of episodic and long-term phenomena, including the roles of people

Temporally expanded conservation strategy (Noss 1992):

1. based on long-term ecological and economic sustainability;
2. more dynamic, nonequilibrium view; concentrate on maintaining physical conditions and ecological processes rather than particular species associations;
3. recognize necessity for habitat connectivity and continuity for migration;
4. supplement interest in sustaining existing species with the notion of future evolutionary diversification

(Compiled from Pickett et al. 1992 and Noss. 1992)

Hierarchy Theory

Hierarchy theory provides a useful model for organizing spatial patterns and complex landscape dynamics at various scales. For example, a forest landscape may be understood as a hierarchical system of gaps, stands, watersheds and region. Nonequilibrium dynamics or spatial heterogeneity at one scale can be translated to equilibrium or constancy at a higher level, as in the shifting mosaic steady state (Bormann and Likens 1979) and minimum dynamic area concepts (Pickett and Thompson 1978). It is possible to define or bound an "equilibriating landscape", which is large enough to contain disturbance regimes while maintaining a constant but shifting distribution of patches of all types at all times (Urban et al. 1987).

Shugart and West (1981) simulated a forest "quasi-equilibrium" landscape and determined that the ratio of the "bounded" landscape to the disturbance regime was at least 50:1. Smaller landscapes were referred to as "nonequilibriating". Thus, protected areas should be approximately 50 times larger than the size of the characteristic disturbance regime in order to encompass an equilibriating landscape.

Integrative design and planning concepts

Integrative and strategic approaches to protected area system design include the biosphere reserve model, multiple-use modules, the greater ecosystem concept, wilderness recovery networks, the triad concept, coarse- and fine-filter approaches, and target-species approaches. These approaches have common elements such as buffer zones around core protected areas, linkages with other protected areas and/or the broader region, and cooperative or partnership arrangements with adjacent land owners and managers for furthering protected area values. Multiple-use modules and wilderness recovery plans are more explicit in recommending that connectivity be maintained and restored among "nodes" of protected areas, and, along with the coarse- and fine- filter approaches, include the concept of a larger system or network of protected areas.

The biosphere reserve model (UNESCO/MAB 1974) explicitly calls for integration among strictly protected core areas, buffer areas, and the surrounding zone of influence or cooperation. Research and monitoring to determine effects of human activities on core and buffer areas are integral components. Such research could advance our understanding of processes and causes of change and boundary issues (Francis 1985).

The multiple-use module (MUM) concept has been used to design a protected area system to support wide-ranging species and help reconcile species-level and ecosystem-level approaches (Harris 1984; Noss and Harris 1986). MUMs include nodes of high ecological value that are protected in an inviolable core and that are integrated into a functional regional network through an interconnected system of corridors. Thus, the MUM approach integrates protected areas into the regional context, and extends the focus from species and communities to heterogeneous landscapes.

The greater ecosystem approach attempts to manage protected areas as part of the larger region (Grumbine 1990b). The boundaries of the greater ecosystem often vary with the particular ecological relationships, processes and issues in question. Components of a greater ecosystem approach include: consideration of ecological relationships and hierarchical context; research, monitoring and adaptive management; cooperative and partnership arrangements; and, a recognition that humans are part of the system. The goal is to sustain ecological integrity, including viable populations of native species, evolutionary and ecological processes, and compatible human uses. The greater ecosystem concept is being applied in and around various protected areas in Canada and the United States (Woodley and Freedman 1995; Skibicki 1995).

The wilderness recovery network approach is essentially a land conservation strategy promoted by several conservation biologists (Soulé 1993; Johns 1993; Foreman et al. 1993; Noss 1994). Protected areas with connectivity or linkages among them and buffer zones are delineated at a bioregional level and ultimately could combine to form a continent-wide system. The approach integrates several ecological considerations including representation of all ecosystems, population viability of sensitive species, and perpetuation of ecological and evolutionary processes (Table VI). Estimates of land required to fulfill these considerations range in the order of 25-75 percent of a region, depending on the particular bioregional context (Noss 1994).

Table VI Principles and Approaches for a Wilderness Recovery Plan

A. Set ecological goals
B. Representation
C. Viable populations (especially vulnerable species and large carnivores):
   1. species distribution across their native range
   2. large blocks of habitat containing large populations
   3. blocks of habitat close together
   4. contiguous blocks rather than fragmented
   5. interconnected blocks rather than isolated
   6. roadless blocks and blocks inaccessible to humans
D. Maintain ecological and evolutionary processes, allowing for change
E. Land Conservation:
   1. protect populations of rare and endangered species
   2. maintain healthy populations of species that play critical roles
   3. protect examples of all communities
   4. manage greater ecosystems and landscapes for conservation and sustainability
F. Reconnaissance and selection of core protected areas:
   1. select areas in roadless, undeveloped or natural condition
   2. add areas relatively undeveloped and restorable
   3. map rare species distributions and add imperiled species
   4. select clusters or constellations of rare species and community types
   5. add unprotected and under-protected vegetation types and centers of species richness
   6. determine core protected areas and linkages, add corridors and buffer zones
G. Components:
   1. core protected areas
   2. buffer (multiple-use) zones
   3. connectivity / linkages as habitat, for seasonal movement, dispersal, and range-shifts
H. Size:
   1. Protected areas and population viability
   2. Protected areas and disturbance regimes

(Compiled from Noss 1994)

The triad approach is basically a model for characterizing the continuum of land-uses from 1) intensive commodity production areas, to 2) areas with little or no resource use by people, and to 3) areas where modest resource use compatible with ecological values occurs (Hunter and Calhoun 1993). It explicitly recognizes that all three levels of land-use are valid and it includes protected areas and buffer zones as critical components of a larger ecologically sustainable landscape. Considerations for integrating protected areas with broader landscape context have been widely discussed (Forman 1990; Hannson and Angelstam 1991; Nelson 1991; Shafer 1990; Wilcove et al. 1986; Diamond 1986; Pickett et al. 1992).

The coarse-filter approach is based on the idea that biological diversity will be maintained by protecting representative ecosystems or physical diversity. Canada's and Nova Scotia's initiatives to protect representative natural regions are both coarse-filter approaches. A gap analysis methodology developed by World Wildlife Fund (Canada) to assess progress in these initiatives describes a systematic coarse-filter approach based on representing "enduring" or physical features at various scales from ecoregions to soil landscapes (Iacobelli et al.). Other coarse-filter approaches focus on biological communities and utilize gap analysis to identify typical communities not yet represented, as well as rare ecosystems and "hot spots" of species richness and diversity (Scott et al. 1993).

One serious shortcoming is that the coarse-filter approach does not fully protect biodiversity. Although samples of biodiversity may be captured within representative protected areas, the boundaries are not necessarily congruent with the habitat requirements of viable populations or other ecological processes. This deficiency in the coarse-filter approach may be addressed through application of a "fine-filter" layer of ecological integrity considerations such as natural processes, viable populations and critical area, and compatible human uses (Noss 1995). This fine-filter layer should encompass the realm of ecological considerations that have formed a large part of this paper.

Ecological considerations suggest that protected area design must be driven at least partially by species-habitat information relating to focus- or target-species. It is not feasible to conduct autecological or population viability analysis for all species, therefore it is necessary to identify target species. Target species may be vulnerable, important or keystone species, sensitive or indicator species, wide-ranging, space demanding or "umbrella" species, and/or flagship or charismatic species that garner support for protection (Hunter 1990; Noss 1991; 1995). Methods for identifying target species or species of concern are being developed and tested (Millsap et al. 1990; Herman and Scott 1992; 1994; Theberge 1995; Elderkin and Boates 1996; Beazley 1997). Once target species are identified, habitat requirements can be determined, along with opportunities for linkages with other habitat areas and populations. Subsequent assessment can help to identify important sites for protection, area requirements for boundary delineation, and important connections with broader landscape components.

Conclusion

Ecological considerations for protected area design have evolved in response to new ecological understanding and conservation goals. To maintain current levels of native biodiversity over the long-term, various criteria must be considered. Protected area system planners must ensure representation of typical, unique, and gradients of physical environments, with additional areas for rare species and communities, and "hot spots" of species richness. Protected areas must be large and connected enough to maintain viable populations of target or umbrella species over time, while encompassing ecological processes such as patch dynamics. Buffers to minimize detrimental cross-boundary effects and linkages for dispersal, migration and range shifts should be included. Questions of protected area size and connectivity are informed by determining viable populations size and critical area requirements of target species, and ensuring enough habitat is protected to sustain viable populations over the long-term while allowing dynamics of succession and disturbance.

None of these considerations can be reduced to general design principles or models. Species and context specific information such as autecological, biogeographical, population viability and gap analyses are required. No single model or approach will be appropriate in every case. Multiple and integrated approaches that are goal and context driven are necessary. Generally, protected area system design needs to incorporate both coarse-filter (representative) and fine-filter (ecological integrity) approaches.

There remain many questions that ecological science cannot answer. Considerable uncertainty exists regarding processes beyond the normal human scale of observation. It is important to be cautious and to choose design guidelines and management thresholds that are well above ecological "minimums". Interventionist and adaptive management including on-going research and monitoring is required.

Ecological considerations illustrate the complexity of the task of maintaining biodiversity and other ecological processes, as well as the extent of land area required. It is unlikely that protected area initiatives alone will be comprehensive and extensive enough to meet the objectives. However, protected area systems are critical components and should be integrated with broader sustainable regional landscapes and land-use planning.

Social, political and economic criteria also need to be considered along with ecological ones in protected area system design. Protected areas that are not supported by or do not benefit local people and governments are at risk as land-use pressures and competition for scarce resources increase.

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This paper originated in response to a comprehensive examination question in 1995.

References:

Beazley, Karen. 1997. "Focus-species approach for trans-boundary biodiversity management in Nova Scotia / Indicator species for monitoring population viability as a trans-boundary phenomenon". Linking Protected Areas with Working Landscapes Conserving Biodiversity. Paper presented at SAMPA III, 3rd International Conference of Science and the Management of Protected Areas, 12-16 May 1997, University of Calgary, Calgary, Alberta. Conference proceedings in press.

Beazley, Karen. 1997. Expert consensus survey: Gathering information and identifying criteria for selecting focus species for biodiversity management in Nova Scotia - a Delphi approach. Unpublished Ph.D. research.

Boecklen, William J. 1986. "Optimal design of nature reserves: Consequences of genetic drift". *Biological Conservation.* 38:323-38.

Bormann, F.H. and G.E. Likens. 1979. *Pattern and Process in a Forested Ecosystem* Springer-Verlag. New York.

Burgess, R.L. and D.M. Sharpe, eds. 1981. *Forest Island Dynamics in Man-Dominated Landscapes.* Springer-Verlag. New York.

Canadian Heritage. 1994. *Parks Canada / Guiding principles and operational policies.* Minister of Supply and Services Canada.

Clements, F.J. 1916. *Plant succession: An analysis of the development of vegetation.* Carnegie Institution. Washington.

Craighead, J.G. and J.A. Mitchell. 1982. "Grizzly bear *Ursus arctos*". in Chapman, J.A. and G.A. Feldhammer (Eds.) *Wild mammals of North America.* John Hopkins Press. Baltimore: 515-56.

Diamond, J.M. 1975. "The island dilemma: lessons of modern biogeographic studies for the design of nature reserves" *Biological Conservation.* 7: 129-146.

Diamond, Jared. 1986. "The design of a nature reserve system for Indonesia New Guinea." in *Conservation Biology / The Science of Scarcity and Diversity.* Soulé, M.E. (Ed.) Sinauer Associates, Inc. Sunderland, Mass.: 485-503.

Elderkin, M.F. and J.S. Boates. 1996. Draft: *Proposal for ranking species in Nova Scotia under the National Framework for Endangered Species Conservation.* Unpublished. Nova Scotia Department of Natural Resources. Wildlife Division.

Foreman, Dave, John Davis, David Johns, Reed Noss, and Michael Soulé. 1993. "The Wildlands Project". *Wild Earth.* 1: 3-4.

Forman, R.T.T. 1990. "Ecologically sustainable landscapes: the role of spatial configuration". in *Changing Landscapes: An Ecological Perspective.* I.S. Zonneveld and R.T.T. Forman [Eds.]. Springer - Verlag. New York.: 261-78.

Forman, R.T.T. and M. Godron. 1986. *Landscape Ecology.* John Wiley and Sons. New York.

Francis, G. 1985. "Biosphere reserves: innovations for coooperation in the search for sustainable development". *Environments.* 17 (3). University of Waterloo. Waterloo Ontario.

Frankel, O.H. and Michael E. Soulé. 1981. *Conservation and Evolution.* Cambridge University Press. Cambridge.

Franklin, Ian R. 1980. "Evolutionary change in small populations". in Soulé, Michael E., and Bruce A. Wilcox (Eds.) *Conservation Biology / An evolutionary-ecological perspective.* Sinauer Associates, Inc. Sunderland, Massachusetts.: 135-49.

Gilpin, M.E. and Soulé, M.E. 1986. "Minimum viable populations: Processes of species extinction." in *Conservation Biology / The Science of Scarcity and Diversity.* Soulé, M.E. (Ed.) Sinauer Associates, Inc. Sunderland, Mass.: 19-34.

Graham, Russell W. 1988. "The Role of Climatic Change in the Design of Biological Reserves: The Paleoecological Perspective for Conservation Biology". *Conservation Biology.* 2 (4): 391- 394.

Grumbine, R. E. 1990a. "Viable Populations, Reserve Size, and Federal Lands Management: A Critique". *Conservation Biology.* 4 (2): 127-34.

Grumbine, R.E. 1990b. "Protecting Biological Diversity Through the Greater Ecosystem Concept". *Natural Areas Journal.* 10 (3): 114-20.

Hansson, Lennart and Angelstam, Per. 1991. "Landscape ecology as a theoretical basis for nature conservation". *Landscape Ecology.* 5 (4): 191-201.

Harris, L. D. 1988. "Edge Effects and Conservation of Biotic Diversity". *Conservation Biology.* 2 (4): 330-32.

Harris, L.D. 1984. *The Fragmented Forest / Island Biogeographic Theory and the Preservation of Biotic Diversity.* University of Chicago Press, Chicago.

Harris, Larry and Gilberto Silva-Lopez. 1992. "Forest fragmentation and the conservation of biological diversity". in Fiedler, Peggy L. and Subodh K. Jain (Eds.) *Conservation Biology / The theory and practice of nature conservation preservation and management.* Chapman and Hall. New York.: 197-237.

Herman, T. B. and F.W. Scott. 1992. "Global change at the local level: Assessing the vulnerability of vertebrate species to climatic warming" in Willison, J.H.M., S. Bondrup-Nielsen, C.D. Drysdale, T.B. Herman, N.W.P. Munro and T.L. Pollock. *Science and the Management of Protected Areas.* Elsevier. Amsterdam.

Herman, T.B., and F.W. Scott. 1994. "Protected areas and global climate change: assessing the regional or local vulnerability of vertebrate species". in Pernetta, J.C., R. Leemans, D. Elder, and S. Humphrey (Eds.). *Impacts of climate change on ecosystems and species: Implications for protected areas.* IUCN. Gland, Switzerland: 13-27.

Hummel, Monte and Sherry Pettigrew. 1991. *Wild hunters / predatorts in peril.* Key Porter Books. Toronto.

Hunter, M. and A. Calhoun. 1993. Draft. "A triad approach to land use allocation". Unpublished draft for proceedings of *Biodiversity of Managed Landscapes.* Oxford University Press.

Hunter, M. I., Jr., G.I. Jacobson Jr. and Webb, Thompson III. 1988. "Paleoecology and the coarse - filter approach to maintaining biological diversity". *Conservation Biology.* 2 (2): 375-85.

Hunter, Malcolm L. , Jr. 1990. *Wildlife, forests, and forestry / Principles of managing forests for biological diversity.* Regents/Prentice Hall. Englewood Cliffs, N.J.

Iacobelli. T., K. Kavanagh, and S. Rowe. (no date). *A protected areas gap analysis methodology: Planning for the conservation of biodiversity.* World Wildlife Fund Canada. Endangered Spaces Campaign. Toronto.

Johns, D.M. 1993. "The Wildlands Project in Landscape Scale Restoration: From Patching to Mending". *Restoration & Management Notes.* 11 (1): 18-19.

Lande, R. and G.F. Barrowclough. 1987. "Effective population size, genetic variation, and their use in population management. In *Viable populations.* Soulé, M.E. (Ed.) Cambridge University Press. New York: 87-123.

MacArthur, R.H. and E.O.Wilson. 1967. *The Theory of Island Biogeography.* Princeton University Press. New Jersey.

Margules, C. and M.J. Usher. 1981. "Criteria used in assessing wildlife conservation potential: a review". *Biological Conservation.* 21: 79-109.

Margules, C., A.J. Higgs and R.W. Rafe. 1982. "Modern biogeographic theory: are there any lessons for nature reserve design ?". *Biological Conservation..* 14: 115-28.

Margules, C.R. 1986. "Conservation evaluation in practice". in *Wildlife Conservation Evaluation.* Usher, M.B. (Ed.) Chapman and Hall. London: 297-314.

Millsap, B.A., J.A. Gore, D.E. Runde, and S.I. Cerulean. 1990. "Setting priorities for the conservation of fish and wildlife species in Florida". *Wildlife Monographs.* 111: 1-57.

Mwalyosi, R.B.B. 1991. "Ecological Evaluation for Wildlife Corridors and Buffer Zones for Lake Manyara National Park,Tanzania, and its Immediate Environment". *Biological Conservation.* 57: 171-86.

Nelson, J. G. 1991. "Beyond parks and protected areas: from public and private stewardship to landscape planning and management". *Environments.* 21 (1): 23-34.

Newmark, William D. 1985. "Legal and biotic boudaries of western North American National Parks: A problem of congruence". *Biological Conservation.* 33: 197-208.

Noss, R.F. 1987. "Corridors in real landscapes: a reply to Simberloff and Cox". *Conservation Biology.* 1 (2): 159-64.

Noss, R.F. 1990. "Can we maintain biological and ecological integrity". *Conservation*

Biology. 4 (3).

Noss, R.F. and L.D. Harris. 1986. "Nodes, networks, and MUMs: preserving diversity at all scales". *Environmental Management*. 10 (3): 299-309.

Noss, Reed F. 1990. "Indicators for monitoring biodiversity: A hierarchical approach". Conservation Biology. 4 (4): 355-64.

Noss, Reed F. 1991. "From endangered species to biodiversity". in Kohm, K.A. (Ed.) *Balancing on the brink of extiction*. Island Press. Washington, D.C.: 227-46.

Noss, Reed F. 1992. "Issues of scale in conservation biology". in Fiedler, Peggy L. and Subodh K. Jain (Eds.) *Conservation Biology / The theory and practice of nature conservation preservation and management*. Chapman and Hall. New York.: 239-50.

Noss, Reed F. 1994. "Building a Wilderness Recovery Network". *The George Wright FORUM*. 11 (4): 17-40.

Noss, Reed. 1995. *Maintaining ecological integrity in representative reserve networks*. A World Wildlife Fund - Canada - United States discussion paper. Toronto/ Washington.

NSDNR (Nova Scotia Deaprtment of Natural Resources). 1994. *A proposed systems plan for parks and protected areas in Nova Scotia*. Parks and Recreation Division. Department of Supply and Services. Publishing Division.

Peters, Robert L. and Darling, Joan D.S. 1985. "The Greenhouse Effect and Nature Reserves". *BioScience*. 35 (11): 707-17.

Pickett, S.T.A., and J. N. Thompson. 1978. "Patch dynamics and the design of nature reserves". *Biological Conservation*. 13: 27-37.

Pickett, Stewart, V.T.Parker, and Peggy Fiedler. 1992. "The new paradigm in ecology: Implications for conservation biology above the species level". in Fiedler, Peggy L. and Subodh K. Jain (Eds.) *Conservation Biology / The theory and practice of nature conservation preservation and management*. Chapman and Hall. New York.: 65-88.

Preston, F.W. 1960. "Time and space and the variation of species". *Ecology*. 41: 611-27.

Pyle, Robert Michael. 1980. "Management of Nature Reserves". in Soulé, Michael E., and Bruce A. Wilcox (Eds.) *Conservation Biology / An evolutionary-ecological perspective*. Sinauer Associates, Inc. Sunderland, Massachusetts.: 319-27.

Schonewald-Cox, Christine M. and Jonathan W. Bayless. 1986. "The boundary model: A geographical analysis of design and conservation of nature reserves". *Biological Conservation*. 38: 305-22.

Scott, J. M., F. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, F. D'erchia, T.C. Edwards, Jr., J. Ullman, and R.G. Wright. 1993. "Gap analysis: A geographical approach to protection of biological diversity". *Wildlife Monographs*. 123: 1-41.

Shafer, Craig L. 1990. *Nature Reserves / Island Theory and Conservation Practice*. Smithsonian Institution Press. Washington.

Shaffer, Mark L. 1981. "Minimum population sizes for species conservation". *BioScience*. 31(2): 131-34.

Shugart, H.H.,Jr. and D.C. West. 1981. "Long-term dynamics of forest ecosystems". *American Scientist*. 69: 647-52.

Simberloff, Daniel, and James Cox. 1987. "Consequences and Costs of Conservation Corridors". *Conservation Biology*. 1 (1): 63-71.

Skibicki, Andrew J. 1995. *Preliminary boundary analysis of the Greater Pukaskwa National Park Ecosystem using the ABC Resource Survey Approach*. National Parks Occasional Paper No. 6. Parks Canada.

Smith, P.G.R. and J.B. Theberge. 1986. "A review of criteria for evaluating natural areas". *Environmental Management.* 10 (6): 715-34.

Smith, P.G.R. and J.B. Theberge. 1987. "Evaluating natural areas using multiple criteria: theory and practice". *Environmental Management.* 11 (4): 447-60.

Soulé, M.E. 1980. "Thresholds for survival: Maintaining fitness and evolutionary potential". in Soule, Michael E., and Bruce A. Wilcox (Eds.) *Conservation Biology / An evolutionary-ecological perspective.* Sinauer Associates, Inc. Sunderland, Massachusetts.: 151-69.

Soulé, M.E. 1980. "Thresholhds for survival: maintaining fitness and evolutionary potential. In *Conservation Biology/An evolutionary-ecological perspective.* Soulé, Michael E. and Bruce A. Wilcox (Eds.) Sinauer Associates, Inc. Sunderland, Massachusetts.: 151-69.

Soulé, M.E. 1983. "What do we really know about extinction?" in *Genetics and conservation: A reference for managing wild animal and plant populations.* Schonewald-Cox, C.M., S.M. Chambers, B. McBryde,and L. Thomas. Benjamen/ Cummings. Menlo Park, Ca.: 111-25.

Soulé, M.E. 1986. "The effects of fragmentation". in *Conservation Biology / The Science of Scarcity and Diversity.* Soulé, M.E. (Ed.) Sinauer Associates, Inc. Sunderland, Mass.: 233-36.

Soulé, Michael E. 1993. "A Vision for the Meantime". *Wild Earth.* 1: 7-8.

Soulé, Michael E., and Bruce A. Wilcox (Eds.) 1980. *Conservation Biology / An evolutionary-ecological perspective.* Sinauer Associates, Inc. Sunderland, Massachusetts.

Soulé, Michael E., and Simberloff, Daniel. 1986. "What Do Genetics and Ecology Tell Us About the Design of Nature Reserves?" *Biological Conservation.* 35: 19-40.

Theberge, J.B. 1989. "Guidelines to drawing ecologically sound boundaries for national parks and nature reserves". *Environmental Management.* 13 (6): 695-702.

Theberge, John. 1993. "Ecology, Conservation and Protected Areas in Canada". in Dearden, Phillip and Rick Rollins (Eds.) *Parks and Protected Areas in Canada / Planning and Management.* Oxford University Press. Toronto: 137-53.

Theberge, John. 1995. "Vertebrate species approach to trans park boundary problems and landscape linkages". in Herman, Tom, Soren Bondrup-Nielsen, Martin Willison, and Neil Munro. (Eds.) *Ecosystem monitoring and protected areas.* Proceedings of the Second International Conference on Science and the Management of Protected Areas, Dalhousie University, Halifax, 16-20 May 1994. Science and the Management of Protected Areas Association, Wolfville, N.S.: 526-36.

UNESCO/MAB. 1974. *Final report. Task force on criteria and guidelines for the choice and establishment of biosphere reserves.* MAB report series no. 22. Paris.

Urban, D., R. O'Neill, and H. Shugart. 1987. "Landscape ecology: a hierarchical perspective can help scientists understand spatial patterns". *BioScience.* 37(2): 119-27.

Usher, Michael B. (Ed.) 1986. *Wildlife Conservation Evaluation.* Chapman and Hall Ltd. University Press, Cambridge, G.B.

Wilcove, D.S., C.H. McLellan, and A.P. Dobson. 1986. "Habitat fragmentation in the temperate zone." in *Conservation Biology / The Science of Scarcity and Diversity.* Soulé, M.E. (Ed.) Sinauer Associates, Inc. Sunderland, Mass.: 237-56.

Wilson, E.O. 1984. *Biophilia.* Harvard University Press. Cambridge, Mass.

Woodley, Stephen and Bill Freedman. 1995. "The Greater Fundy Ecosystem Project: Toward ecosystem management". *The George Wright Forum.* 12 (1): 7-14.

Yahner, Richard H. 1988. "Changes in Wildlife Communities Near Edges". *Conservation Biology.* 2 (4): 333-39.