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A Fine Balance: Corridors — Connectivity or Chaos?

By Shelley McCann, B.A. Honors

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the Faculty of Graduate Studies
in partial fulfillment of
the requirements for the degree of

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ABSTRACT

The growing popularity of outdoor recreation puts modern park resources under severe pressure. Tourism and recreation pressures threaten both the ecological integrity and recreational quality of parks. Managers are pressed to provide the desired benefits, without the costs of continued park use. Recreation can support conservation efforts if managed effectively.

Newly advanced multi-use corridor policies promise to balance competing resource demands. Promised benefits, however, remain elusive in day-to-day park management. The present research develops a decision support system, linking novel spatial analysis tools to provide a new approach for the design and management of multi-use parks. A GIS-based model is applied to evaluate the multi-use corridor strategy proposed for the Ottawa Greenbelt case study area and to identify and predict areas where recreation encroaches on fragile environments. Results of this research target conflicting uses and sites in the local planning environment and explore broader issues concerning the multi-use park management.

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CHAPTER 1: INTRODUCTION

“Landscape linkages, land bridges, wildlife corridors, greenways, shelterbelts, turkeytrots – call them what you will.”

-Chadwick, 1990

1.1 Broad Context of the Research

Parks and natural areas provide the setting for an expanding range of activities. Increasing mobility, income and leisure time have fueled a steady growth in outdoor recreation (Figure 1.1). Growing numbers of visitors are drawn to unique and often fragile natural environments. Alongside climbing recreational use levels has come a rise in the diversity of recreational activities. Diverse forms of recreation such as mountain biking, hiking and cross-country skiing place unique demands on park resources. Complex visitor-use patterns, both within and between natural areas, place popular sites under considerable stress (Roggenbuck and Lucas, 1987 in Manning 1999).

Excessive recreation pressures threaten fragile ecological systems and degrade recreation quality. Habitat fragmentation, wildlife displacement and aesthetic quality loss are listed among the many concerns linked to recreation use (Brunson, 1996). Park visitors and managers alike have grown increasingly concerned about the negative ecological and recreational impacts associated with these trends (Ballinger and Marion, 1996 in Manning, 1999). Pressing concerns surrounding the preservation of valued park resources highlight the need for sustainable, multi-use management. Unfortunately, little guidance can be found to direct the design and management of shared resources. **What has created all this confusion?**

Figure 1.1: Recreational Use Trends
Annual Use of Areas Administered by the National Park Service and US Forest Service

Lack of targeted strategies and management 'tools' has stirred a cloud of confusion in the management of park resources. Conservation and recreation goals are often pitted against one another as excess pressures threaten varied park resources. A conventional focus on single attribute concerns and a reliance on resource-intensive field methods have undermined efforts to balance diverse park uses.

Failure to establish comprehensive strategies and codes of practice may ultimately culminate in damaging long term losses. Efforts to recover from resource degradation can be costly in terms of both ecological values and public perceptions.

1.2 Proposed Solution – The Ottawa Greenbelt Corridor Strategy

Well informed, preventative measures are needed to foster sustainable use of popular park areas and maintain and preserve the quality of valuable resources (Manning, 2003).

Comprehensive strategies designed to protect the natural ecosystems upon which outdoor recreation and tourism depend may yield economically, socially and environmentally sustainable solutions. Realization of this goal will require an approach that attempts to minimize unacceptable risks to key values and attributes. While some park areas may be highly resilient, others may require strict visitor regulations and guidelines to remain viable. Local managers must respond with recreation management strategies that offer the desired benefits without incurring the associated problems.

Multi-use corridor strategies are proposed as a sustainable approach to park design and management. Corridors linking core natural areas¹ promise to enhance ecological functioning, while accommodating growing recreation demands (NCC, 1996). Numerous local and regional planning bodies have recently adopted this creative approach to park management (National Capital Commission, 1996; City of London, 2001; Fayetteville, 2004).

In the present study the Ottawa Greenbelt serves as a case study to assess the feasibility of multi-use corridor strategies. The design and management of corridors is highly dependent upon the 'desired benefits' or intended functions as defined by site-specific goals (Hess and Fischer, 2001). Attempts to evaluate the relative success or failure of a planned corridor network must be premised on explicit management goals. The following section outlines management goals for the proposed Ottawa Greenbelt corridor network.

¹ Core natural areas or remnants are defined as large, significant and/or sensitive natural areas (NCC, 1996).

The Ottawa Greenbelt is a crescent-shaped area of publicly owned, protected land surrounding the inner urban core (Figure 1.2). The Greenbelt spans two to ten kilometers in width and represents an area of approximately 200 km². This area supports a diverse mix of land uses, including low intensity farming and forestry, ecological and wetland conservation and recreational facilities. Since the initial adoption of a greenbelt policy in 1950, modification of the surrounding urban landscape has exerted growing pressure on the natural areas of the Greenbelt. Rapid urban expansion coupled with changing trends in outdoor recreation has fueled an increase in the intensity and diversity of recreational activities housed in the Greenbelt (NCC, 1996).

Acknowledging the changing character of the urban landscape, the Regional Studies Association (1986) concluded that the existing Greenbelt policy failed to reflect the current ecological, social and economic needs of the community (NCC, 1991). Changing ecological and recreational landscape demands have prompted a re-examination of existing plans resulting in the formulation of a new, long range planning policy.

The adopted Greenbelt Master Plan (NCC, 1996) is intended to serve as a framework for future planning decisions over the next 20 years rather than provide a 'blueprint' for site design and management. Site-specific management plans are not specified. This change in policy is indicative of a broader shift in the planning community from single-attribute to multi-use management (NCC, 1993). Multi-use management policies are forwarded as a means to preserve the 'diverse mix of land uses and landscapes currently housed in the Greenbelt' (NCC, 1996).

Figure 1.2: NCC Greenbelt Study Area

The concept of a 'Continuous Natural Environment', where significant natural areas (e.g. Shirley's Bay, Stony Swamp, Mer Bleue, Green's Creek) are connected via protected corridors, is a key element of this policy. The 'continuous natural environment' comprises three major land use designations as follows: (1) core natural areas, (2) natural area buffers and (3) natural area linkages (NCC, 1996). Natural area linkages, referred to as corridors, are the focus of the present study.

Management objectives outline the intended function of corridors in maintaining ecosystem connectivity, while providing recreational opportunities. Visitor demands are echoed in these goals. A recent visitor and management survey conducted at trail access points in the Greenbelt (NCC, 2003) points to the need for an improved, connected trail system, where access to fragile areas is regulated or prohibited. Acknowledging recent budget limitations, alternative funding sources and cost-sensitive approaches to planning are critical. Sustainable recreation and tourism has been forwarded as a means to support local conservation efforts.

In the rapid shift towards multi-use planning, concrete implementation and management strategies are often ignored. The absence of concrete guidelines coupled with budget constraints has left local managers ill-equipped to address these complex issues.

The current integrated policy advocates a dual function for the corridor areas of the Greenbelt. Recreational opportunities and ecological conservation efforts are supported in these areas. Despite significant promise, the 'real world' benefits of these policies have yet to be fully demonstrated. The widespread wave of enthusiasm surrounding this approach in planning and policy circles has left a fundamental concern unanswered. Does this strategy really work? Improved evaluation methods are necessary to determine whether or not multi-use corridors can effectively balance the complex demands placed on shared resources. The present study will explore the following research question:

Research Question:

Are multi-use corridors an effective strategy for balancing ecological preservation and recreational landscape demands?

1.3 Research Objectives

Develop a decision support system (DSS) to evaluate the proposed multi-use corridor policy.

Failure to provide management guidelines jeopardizes the practical implementation of corridor conservation strategies. Identifying the sensitivities and demands within park areas allows managers to consider tradeoffs and develop targeted site design and recreation policies to facilitate multi-use corridor management. Emerging spatial technologies promise to overcome the limitations of traditional management systems in this regard.

Recent research in the fields of landscape and recreation ecology reflects a growing interest in the concept of equipping managers with a 'spatial analysis toolkit' (Bishop and Hulse, 1994; Bishop and Gimblett, 1999; Cohen, 2002, among others). Advanced research in these fields supports the use of a decision support system (DSS). The functional linking of an integrated framework (e.g. multi-use corridor policy) and spatial analysis tools (e.g. Geographic Information Systems, GIS) in a DSS offers an enhanced decision-making tool to address complex management issues. DSS models recognize the importance of visible tradeoffs between ecological, recreational and management attributes in the evaluation of landscape design alternatives (Shin et al., 2001).

The practical utility of a DSS in 'real' world applications is highly dependent upon the appropriate pairing of model functions and practical objectives. The present study develops a corridor conflict simulation model (CCSim). The developed decision support model serves the following research objectives:

- Identify critical conservation sites within the corridor areas of the Greenbelt. A GIS-based Ecological Sensitivity Model predicts the spatial distribution of ecological sensitivities within the study area indicating conservation priorities.
- Identify and predict the impact of recreational stress within corridor areas of the Greenbelt. Results of a field-based trail survey are integrated in a GIS Recreational Impact Model to determine the spatial distribution and extent of trail degradation in the corridor network.
- Identify potential conflicts or 'hot spots' where severe recreational impacts encroach on fragile corridor environments. The Corridor Conflict DSS predicts corridor sites where tradeoffs between conservation and recreation goals may be necessary. The ability to effectively balance demands within the study site is critical to the success of the proposed multi-use corridor strategy. Current management recognizes that the existing corridors may fall short of proposed policy goals. An optimal corridor scenario will be evaluated to predict the long-range feasibility of this planning policy.

Prior knowledge of potential conflicts between recreational use and sensitive environmental areas may assist managers in developing practical strategies to avoid costly damage to key site values (Manning, 2003). Preventative strategies including sensitive site design and controlled access to fragile ecological areas can then be implemented to preserve the integrity of the resource base. These responses may mitigate negative impacts and encourage the compatible use of the shared resource base.

1.4 Chapter Outline

The growing popularity of multi-use management calls for improved design and evaluation methods. Recent advances in the fields of landscape and recreation ecology explore the use of emerging decision support technologies to improve the management of complex human-environment settings. Chapter two reviews recent research stemming from recreation and landscape ecology concerning the use of decision support systems in multi-use management.

Complex systems are difficult, if not impossible to predict. Diverse data and spatial analysis 'tools' were assembled in this study to provide a practical tool for the planning and management of multi-use corridors. Chapter three will outline the various methods and tools that comprise the decision support system (CCSim) developed in this research.

The CCSim was applied to evaluate the multi-use corridor policy proposed for the Ottawa Greenbelt. The incidence of identified conflicts between competing recreation and environment demands point to the overall effectiveness of this planning strategy. Chapter four examines the results of this application and discusses implications for the local planning environment.

The model developed in this study is forwarded as a prototype tool to assist multi-use management. The ability to predict complex human-environment interactions in the evaluation of management alternatives promises numerous benefits for modern park management. Concluding remarks will address the broader implications of this research for multi-use management and point to future avenues of research in this field.

CHAPTER 2: LITERATURE REVIEW

Multi-Use Corridor Planning and Management

2.1 Introduction

Problem

Modern society places complex demands upon an increasingly burdened shared resource base. The capacity for human alteration of natural areas has become exceedingly apparent. Rapid change in the structure and functioning of the ecological landscape threatens both biotic and ecosystem functioning. Unforeseen and undesirable outcomes including environmental degradation, biodiversity loss and habitat fragmentation pose serious challenges to modern planners (Collinge, 1996). Research indicates that the preservation of corridors between otherwise isolated habitats may modify the negative impacts associated with habitat fragmentation and restore ecological functioning (Taylor et al., 1993).

Unique and often fragile natural areas are popular destination spots for recreationists. Increased mobility, income and leisure time has fostered a growing demand for outdoor recreation. Diverse forms of recreation, such as mountain biking, hiking and cross-country skiing, place varied demands on natural areas. The growing demand and complexity of outdoor recreation threatens not only ecological integrity, but recreational quality. In a recent poll of National Park Service (NPS) managers ecological trail impacts were identified as a primary concern. **Social impacts**, including aesthetic quality loss, user crowding and conflicts emerged as a second major concern (Ballinger and Marion, 1996 in Manning, 1999).

Threats of ecological degradation and recreational quality loss underscore the need for creative approaches to sustainable management. The growing popularity of lineal, passive recreation activities (e.g. hiking, cross-country skiing) may serve as the engine for future conservation efforts.

Park managers are challenged to devise strategies that encompass economic, political, social and ecological concerns. A set of comprehensive management tools is required to identify and evaluate critical tradeoffs amongst these variables. A limited number of management systems effectively address this need. Conventional strategies remain focused on single-attribute concerns, failing to effectively balance ecological and social demands.

Proposed Solution

Growing ecological and social concerns will shape the future of natural area management. Improved understanding and communication of trade-offs represent an essential step forward in the management of complex systems. Recent policy shifts acknowledging this need increasingly advocate integrated management frameworks, including amendments to the National Trail Systems Act (1993), Parks Canada National Park Policy (2003) and National Capital Commission Greenbelt Master Plan (1996). An integrated management framework addresses the following factors:

- (1) biophysical constraints and ecological impacts
- (2) recreational impacts upon the functionality of a shared resource base
- (3) diverse user group demands
- (4) ecological and social susceptibility

(Manning, 2003)

Recent trends and policy shifts have left managers facing a wide range of problems and an even wider range of potential solutions. Integrated or multi-use corridors, linking otherwise isolated natural areas, offer an innovative approach to balancing diverse ecological and recreational landscape demands. Initial enthusiasm surrounding this concept masks underlying doubts concerning the utility of this approach in practical management. Proposed benefits have yet to be

fully demonstrated in 'real world' applications. The purpose of this research, therefore, is to investigate the following question:

Are multi-use corridors an effective strategy for balancing ecological preservation and recreational demands?

The growing popularity of this approach calls for improved corridor design and evaluation methods. Despite a recognized urgency, the conceptual framework and practical tools required to address this issue are still in their infancy. Recent advances emerging from the fields of landscape ecology and recreation ecology offer renewed promise in this regard. Both landscape ecology and recreation ecology study human-dominated landscapes. Landscape ecology studies the spatial distribution of natural areas (Collinge, 1996), while recreation ecology studies the distribution of recreation impacts in these settings (Cole, 1989).

Advanced research in these fields supports the functional linking of an integrated framework and spatial analysis tools in a decision support system (DSS). Decision support systems provide dynamic, spatially explicit tools to develop and evaluate alternative management options. By testing various 'what if' scenarios, a DSS can improve decision-making in complex multi-use environments. The potential exists for these advances to overcome the limitations of conventional methods in the evaluation of novel management approaches (Bishop and Gimblett, 1999).

This chapter will review research contributing to multi-use corridor design and evaluation. A review of conceptual and methodological advances in the fields of landscape and recreation ecology provides the context of this study. Multi-use resource management is not a novel concept. To understand the potential advances afforded by recent research first requires an understanding of previous obstacles encountered in the broader geographical context of integrated resource analysis.

2.2 Broad Geographical Context: Early Integrated Resource Analysis

'To understand resources one must understand the relationship that exists between man and nature.'

- Zimmerman, 1951

Recent shifts in resource research, policy and practice reflect the importance of balancing ecological and human systems in the design and management of complex environments. A comprehensive theory must underlie the planning and prediction of these systems. Models provide a means of informing theory, quantifying complex system processes and exploring alternative management options. Various integrated modeling systems have been developed to address this challenge.

Several early advances in the study of human-environment interactions underlie the development of the first fully operational integrated models in the early 1980s. The early 20th century marked a period of considerable transition in the field of geography. Consideration of human-environment relationships became increasingly prevalent as the research focus shifted from biocentric theories of environmentalism to a broader understanding of humans as both products and producers of their environment (Pattison, 1964).

Growing social concerns surrounding resources and a shift from private to public planning cultivated a significant change in resource policy during this period. Resource analysis and management, previously bound to the natural sciences, broadened to encompass a social science perspective. A more holistic definition of resources emerged, adopting the concept of human and cultural resources (e.g. health and freedom) in addition to narrowly defined physical resources (e.g. coal, iron). Policies were expanded to reflect the critical role social objectives would play in shaping the future of resource management (Zimmerman, 1951). Despite critical advances, failure

to effectively represent complex human-environment dynamics plagued early policy and research efforts. Practical methods and models fell prey to similar criticisms.

In the last decade, integrated modeling approaches have been advanced as a tool for linking complex biophysical and human systems. This is not a novel idea. The emergence of this concept can be traced back to the 1960s. The 'quantitative revolution' marked a transition from qualitative methods to statistical and mathematical means of analysis. The first generation of computer models emerged in a period dominated by the idea that scientific methods could be extended to the realm of human study.

Prior to further examination of this issue it is important to define several key concepts. For the explicit purposes of this research, the term 'model' is used to refer to the data-handling process prior to representation, that is, the internal representation or data structure that provides the source of cartographic representations. Cartographic representations refer to the transformation and display of information in a form that encourages interpretation and visualization of spatial structure and functioning (MacEachren, 2001). In summary, models are the internal representations of 'real world' spatial information, which are subsequently transformed into cartographic displays for effective visualization, interpretation and/or analysis (Fairbairn, 2001; Lawson et al., 2003).

Early integrated models were inundated by both conceptual and practical flaws, and as such yielded disappointing results. More concerned with the application of scientific methods than practical utility, initial models lacked complexity. Poorly understood human and environmental variables were oversimplified to such a point that they no longer accurately represented complex systems. Additional limitations stemmed from the purely mathematical basis of these models, noticeably lacking the spatial component of contemporary models. Technological constraints, imposed by large data requirements and limited computer resources, posed a significant barrier to model operationalization and signaled the end of this overly-optimistic period (Kammeier, 1999).

Recent theoretical and practical advances in the fields of landscape and recreation ecology offer renewed promise in integrated resource analysis. New conceptual frameworks linked to advanced spatial analysis tools progressively acknowledge the complexity of human-environment interactions in natural area management. However, the difficulty of integrating social and ecological systems is exposed in the limitations of these approaches. The final section of this paper will examine advanced research and practice in the field of integrated modeling and decision support systems (DDS) as a promising solution to this 'age old' problem.

2.3. Landscape Ecology: Ecological Assessments

2.3.1 Emergence of Landscape Ecology: The Role of Corridors in Conservation

In the last two decades, principles of landscape ecology have been progressively employed to delineate key corridor sites and to determine the conservation priorities for these areas.

Landscape ecology is defined by Collinge (1996) as 'a study of the spatial distribution of natural areas in a human dominated ecosystem; the flow of plants and wildlife, nutrients and water, among these natural areas and the temporal changes in the ecology of the landscape'. Landscape ecology is accredited with the ability to balance human and biophysical system demands in complex environments. The demonstrated potential of this field in real world planning has yet to be seen. An early ecological focus in corridor research and practice has contributed to an inherent bias in this field. Failure to effectively integrate social concerns in landscape ecology models has hindered the practical utility of this approach.

Corridor conservation strategies first emerged in the early 20th century in response to growing demands for game species preservation. The use of corridors for channeling faunal movement between natural areas became a popular conservation technique in North America during this period. In the 1960s, theories of island biogeography and metapopulation dynamics furthered the

study of corridors by examining their role in improving species persistence through enhanced flora and faunal dispersal. Although a detailed discussion of these theories is beyond the scope of this study, notable contributions to the field of landscape ecology have stemmed from these approaches (Hess and Fischer, 2001).

Landscape ecology is advanced as an integrated approach to the management of human dominated landscapes. However, nearly two decades after the emergence of this field critics point to a limited ability to effectively incorporate human landscape components and a subsequent failure to represent the complexity of human-environment interactions (Nassauer, 1995). Early predecessors in corridor research have contributed to the ecological focus of this field.

Key Concepts and Components

As previously noted, landscape ecology is defined as 'a study of the spatial distribution of natural areas in a human dominated ecosystem; the flow of plants and wildlife, nutrients and water, among these natural areas and the temporal changes in the ecology of the landscape' (Collinge, 1996, p. 60). Three critical aspects of this definition (Figure 2.1) are identified as follows:

1. **Structure:** Spatial patterns and the relationship between landscape elements. Key structural components include size, shape and juxtaposition (Collinge, 1996).
2. **Function:** Ecological flows and biotic movement between landscape elements (Whitford et al., 2001, Hobbs, 1997).
3. **Change:** The alteration of the structure and function of landscape elements over time (Hobbs, 1997).

Spatial patterns are the keystone of landscape ecology. The structure of the landscape is a major determinant of both functioning (ecosystem and biotic) and of changes in form and flows over time. Landscape functioning and change in turn operate as feedback mechanisms influencing

the structure of the landscape (Forman and Godron, 1986, O'Neill et al., 1988, Collinge, 1996).

Debates exist within the literature regarding the emphasis placed upon structure over function in landscape management. These issues will be explored in the following section.

Figure 2.1: Landscape Ecology Key Components

Source: Hobbs (1997), p. 4

Proponents of landscape ecology argue that human dominated landscapes are most effectively managed by maintaining large-scale ecological connectivity through preserving a network of natural areas and corridors (Forman, 1995, Hobbs, 1997, Collinge, 1996). Connectivity can be defined as the degree to which the landscape facilitates biotic movement and ecosystem dynamics and processes between natural areas (Taylor et al., 1993). This definition reflects the dependence of movement and function upon landscape structure. Structural landscape indices, including cover, habitat and minimum corridor width were employed to define viable corridors in the present study.

A conceptual landscape model composed of patch, corridor and matrix elements provides a tool for the design and management of fragmented environments. Key elements of this model are defined as follows. The matrix is the most extensive and connected landscape element and as

such exerts a primary influence upon the structure and functioning of the encompassed landscape elements. A patch is defined as a non-linear area embedded within a matrix. The remnant patch, which is significant in the context of this study, is defined as an isolated natural area created by a large-scale disturbance of the surrounding matrix (Forman and Godron, 1986).

Corridors represent a small, but critical area with regard to ecological function and consequently provide the primary focus of this research. Forman and Godron define corridors as narrow ribbons of land differing from the matrix on either side (Forman and Godron, 1986). Remnant corridors, which are important to this study, link otherwise isolated patches. In designing corridors for ecological purposes at least one of five basic functions is served. Ecological functions may include: (1) conduit (facilitate biotic movement), (2) habitat (species production and reproduction site), (3) filter (sediment, pollutant or invasive species buffer), (4) barrier (vegetation gaps as barriers to species dispersal) and (5) source (reproduction exceeds mortality) and sink (mortality exceeds reproduction). To date studies have focused primarily on the function of corridors as conduits for faunal movement. Comparatively limited research efforts have addressed alternative ecological functions (Lowrance et al., 1984 and Curatolo and Murphy, 1988 in Beier and Noss, 1998, Harris and Scheck, 1996).

The maintenance of landscape connectivity, through the preservation of corridors between isolated fragments, is critical to both the structure and functioning of the landscape. Despite disparate research efforts, corridor design reflects a focus upon improved connectivity and resulting enhancements to large-scale ecological processes (e.g. species mobility, nutrient cycling, hydrology flows and other related processes).

The complementary use of corridors to meet diverse social demands has been suggested in related research. Numerous authors (Saunders and Hobbs, 1991; Bennett, 1996; Fahrig, 2000; Hess and Fisher, 2001) acknowledge a growing confusion regarding the definition and intended

function of corridors. The term 'corridor' is currently used differentially across a number of disciplines including landscape ecology, conservation biology, recreation ecology and landscape architecture. Corridor functions range from ecological preservation to multi-use resource management. The absence of a well-defined goal in corridor design and evaluation often leads to disappointing 'real world' results. Prior to further examination of this broader debate in the literature, the following section will outline debates raised within the field of landscape ecology.

2.3.2 Landscape Ecology Debates: Defining Corridors and Connectivity

Failure to provide a consistent terminology in the study of corridors has plagued the field of landscape ecology. Several key debates have evolved regarding the intended function and utility of corridor conservation strategies. This section will critically examine the key arguments presented in the following debates:

1. native vs. wildlife definitions
2. species-specific vs. demographic studies
3. structural connectivity vs. functional connectivity
4. ecological vs. multifunctional corridors

Native vs. Wildlife Definitions

In the design and evaluation of corridors, Forman (1996) argues that wildlife must be distinguished from native fauna. Conservation of native fauna—defined by Forman (1996) as organisms that are characteristic of a defined area—should be the goal of corridor systems. Supporting research evidence indicates that invasive or non-native species negatively impact both biotic and ecosystem functioning (Crumpacker, 1998). Biotic functioning is threatened by the characteristic range expansion of broadly adapted non-native species, which may ultimately lower the adaptive capacity of the native community. Furthermore, non-native species are largely ineffective in the regulation of ecosystem processes (Crumpacker, 1998). An increase in overall

wildlife (i.e. native and invasive species) abundance often occurs at the cost of native biological diversity. Other studies (Low, 1996 and Wheeler, 1996, among others) fail to acknowledge this distinction and instead focus upon the general function of wildlife conservation.

Species-Specific vs. Demographic Studies

Divergent viewpoints in the literature often relate to the following question: Should corridors function to enhance overall biological diversity (i.e. species demographic approach) or protect threatened species (i.e. species-specific approach)? Proponents of the species-specific approach contend that landscape patterns represent distinct and different levels of connectivity for different species (Tischendorf and Fahrig, 2000). Connectivity measures, therefore, must address the movement of a particular species. Threatened or endangered species, generally considered conservation priorities, often serve as target species. Fragmentation-sensitive species are also employed in this approach (Beier and Noss, 1998). A divergent viewpoint contends that corridor design must necessarily address and preserve a broad array of species to provide effective guidelines for practical management across species and landscapes (Hobbs, 1997). The latter stance is adopted in the Ottawa Greenbelt corridor strategy (NCC, 1996).

Structural vs. Functional Connectivity

The term 'connectivity' is used interchangeably in the landscape ecology literature to refer to either functional or structural connectivity. The concept of functional connectivity first emerged during the 1950s in the field of game preservation and later in theories of island biogeography and metapopulation dynamics. Functional connectivity measures the behavioral response and movement of biota between natural landscape elements. This definition has recently been expanded to incorporate ecological flows and processes (Taylor et al., 1993). Taylor defines functional connectivity as the degree to which the landscape facilitates biotic movement *and* ecological processes between natural areas (Taylor et al., 1993).

Not all authors adhere to this relatively narrow definition of connectivity. The concept of structural connectivity emerged in early spatial models of landscape ecology. The basic structural definition of a corridor is a linear landscape element differing from the matrix on either side (Forman and Godron, 1986). This concept is often equated with landscape and habitat continuity.

Structural corridor attributes, including presence or absence of gaps, width, length, edge, and interior habitat area provide quantitative measures to further define this concept. Structural connectivity measures are widely adopted in landscape ecology research (Forman and Godron, 1986; Noss and Harvey, 1986 in Beier and Noss, 1998). Research supporting the use of structural indices points to the high level of interaction between landscape structure and function achieved through a complex series of feedback mechanisms. Evidence obtained in these studies indicates that structure exerts a significant influence upon the ecological functioning of the landscape (Noss and Harvey, 1986 and Turner and Gardner, 1990 in Beier and Noss, 1998; Forman, 1996).

The need for concise, practical methods in corridor planning and design lends further support to this argument (Forman, 1996, Turner and Gardner, 1990 in Beier and Noss, 1998). Structural connectivity measurements allow operationalization of model concepts and quantification of spatial landscape attributes. The relative stability of landscape structure vs. landscape function over time and the overall suitability of methods to broadly defined management goals enhance the practical utility of this method. In summary, the concept of structural connectivity provides a practical framework for the design and evaluation of corridor systems.

Divergent research (Baudrey and Merriam, 1998 in Hess and Fischer, 2001; Bennett, 1996 and Fahrig, 2000) stresses the importance of functional connectivity in corridor design. Baudrey and Merriam (1998) distinguish between structural 'connectedness' (i.e. continuity of spatial landscape elements) and more precise measurements of functional connectivity (i.e. biotic behavioral responses to landscape elements). Critics argue that linear landscape elements, which appear to

connect patches from a human perspective, do not necessarily improve connectivity for other species (Fahrig, 2000). Structural indices are based on the false assumption that connectivity can be viewed as a generalized feature of landscape. In summary, critics argue that popular measurements of structural connectivity alone are insufficient and are of little to no conservation value to specific species. Measurements of connectivity must address the requirements and behavioral responses of target populations and species. This observation leads to a critical question: how do you measure and design a system of connected corridors if connectivity varies for each species?

Currently the term 'corridor' is used to define both structural and/or functional attributes of linear landscape features. An emphasis on either structural or functional connectivity varies across a range of diverse disciplines. Ultimately, the selection of appropriate connectivity indices is dependent on the intended function of the corridor system. Corridor conservation strategies may serve either very specific or very broad management goals. Bennett (1996) notes that evaluating connectivity in the absence of a functional context is meaningless (Bennett, 1996 in Fahrig, 2000). Recent research points to the need to define connectivity and design corridors in accordance with their intended function in the landscape. Having established the intended function of a corridor, these terms acquire meaning and can then be evaluated in the context of predefined management goals.

As previously noted, this research will focus on the design and evaluation of multi-use corridors. These corridors attempt to balance various ecological and social landscape demands. Hess and Fischer (2001) argue that multi-use corridors require multiple measures to evaluate complex recreational and ecological functions. A critical question is raised by this argument. Should ecological or social objectives be prioritized in the planning and design of corridor conservation strategies?

Ecological Function versus Multifunction Corridors

Effective design and evaluation of corridor systems first require clear and concise statements of intended function. This seemingly simple solution is the source of further confusion and debate. Despite recent interest in the social function of corridors, landscape ecology research remains largely focused on ecological goals. Research supporting this position maintains that a single attribute, ecological focus, is required to ensure the conservation value of corridor systems (Saunders and Hobbs, 1991, Beier and Noss, 1998). In this rather narrow view, corridors are defined as a 'linear habitat, embedded in a disturbed matrix that connects two or more larger blocks of habitat and will enhance or maintain the viability of specific wildlife populations in habitat blocks' (Beier and Noss, 1998, p. 1240). Simberloff (1990) further argues that human presence in these areas will impede the ecological function of the corridor for several species. In summary, proponents of this viewpoint contend that competing social objectives hinder the ecological function and conservation value of corridor systems.

The reality remains that corridors will, in all probability, serve more than one function in the landscape. Nausseur (1995) argues that by focusing on ecological function alone 'real world' interactions between ecological and social values are obscured. Humans construct and manage landscapes on the basis of multiple objectives including political, economic, aesthetic and recreational demands, as well as ecological needs. In this view, people are inseparable from ecosystems and, as such, must be considered in any attempts to effectively manage natural systems (Crumpacker, 1998). Furthermore, research indicates that corridors designed to accommodate non-intensive recreational activities (e.g. hiking, cross-country skiing), which preserve or restore the structure and function of natural ecosystems, may in fact enhance species movement and persistence (Forman, 1996). Recent policy shifts recognize the need to move from

single attribute to multi-value resource management. Despite the popularity of this approach, conventional landscape ecology methods remain focused on ecological concerns, failing to effectively balance ecological and social landscape demands.

2.3.3 Landscape Ecology: Design and Evaluation Methods

Ecologically defined corridor systems adhere to common goals of species and biodiversity conservation. Beyond this point, minimal agreement can be found in the vast array of corridor studies. Two general approaches can be discerned amongst divergent research designs (1) **field-based assessments** and (2) **computer-based models**. Debates concerning the effectiveness of these evaluation methods are found throughout the literature. Inherent tradeoffs must be considered in the selection of appropriate methods. Field-based studies provide accurate site-specific information; however, large time and cost demands placed on scarce management resources restrict overall feasibility. Recently, advanced models have received substantial attention as a means of overcoming the limitations of traditional methods. Initial enthusiasm surrounding this approach may mask underlying concerns regarding the accuracy and practical utility of these models in 'real world' management applications. Knowledge of specific management objectives may ultimately prove the most important factor in determining appropriate evaluation methods.

The diverse nature of research designs has limited the comparison of findings across studies. The following section will outline relevant findings and trade-offs amongst these distinct approaches to corridor design and evaluation. Concluding remarks will address the restrictive nature of a single attribute, ecological approach to corridor design.

2.3.3.1 Field-based Assessments

Varied field-based methods have yielded a wide range of findings across a diverse range of settings. Field-based studies are broadly categorized as follows:

Experimental Studies

Species-specific or species demographic parameters are tested to assess corridor function in a series of randomized experiments. Experimental field studies manipulate real landscapes or artificially created landscapes to provide control (fragmented landscapes) and test conditions (corridor connected landscapes) (see table 1, appendix). Few experimental studies have addressed the evaluation of species demographics ((Mansbergh and Scotts; 1989; Machtans et al. 1996; Shmeigelow et al., 1997) in Beier and Noss, 1998). The results of these studies point to overall improvements in population structure, survival rates and a lower species turnover rate. Despite promising findings, the ability to extrapolate these results to actual landscapes is highly questionable. Experimental findings regarding species-specific mobility ((Merriam, 1990; Rosenberg, 1994; Andreassan, 1996) in Beier and Noss, 1998) are equally uncertain beyond the original species and site studied.

Observational Studies

Observational studies of species demographics and species-specific parameters study the observed effect of corridors in 'real-world' fragmented landscapes. The majority of observational studies demonstrate the beneficial role of corridors in species demographics, including improved species abundance, colonization and immigration rates and species diversity (see table 2, appendix). A primary focus on bird populations, however, raises questions concerning the applicability of these findings to other species. Species-specific observational studies ((Bennett, 1990; Lindenmayer et al., 1993, Vermeulen, 1994) in Beier and Noss, 1998) have focused on a wide array of variables including both conduit and habitat corridor functions. These studies assume that corridor benefits established for fragmentation-sensitive or threatened species can be used to infer net benefits for all species. Observational evidence has generally supported the

positive impact of corridors in facilitating species' mobility. However, failure to provide comparative studies of species mobility in the outlying disturbed matrix and a high risk of confounding variables (e.g. differential corridor quality) have raised doubts concerning the reliability of these findings.

Advocates of these approaches maintain the accuracy of findings beyond the original study. The high risk of confounding variables, however, has raised serious questions regarding the validity of this assumption. Time and cost intensive field methods place high demands upon scarce resources and are, therefore, often limited in practical utility. Necessary tradeoffs exist between the accurate representation of complex systems and the practical utility of field-based methods.

2.3.3.2 Computer-Based Models and Spatial Analysis

Field studies possess a limited ability to predict ecological responses to landscape modification. As a result, traditional management strategies have relied upon time and cost intensive 'trial and error' approaches. Computer-based models have recently been advanced to address this limitation (Schuur, 1994; Gardner et al., 1996). The present research explores the practical utility of advanced technologies, including GIS modeling, in the prediction of ecological landscape response to alternative corridor design.

Recent advances in computer-based modeling and spatial analysis 'tools' (e.g. GIS, autonomous agent models, and visualization) provide an improved basis for the understanding and prediction of complex ecological systems. The emergence of new technologies in landscape design and management was precipitated by two major advances; (1) lower cost computer hardware and related gains in efficiency and user-operability and (2) the emergence of GIS and the 'routinization' of computer analysis tasks (Brail, 1987). Advanced technologies offer improved information acquisition, integration and decision support tools to assist managers in the practical design and management of corridors. Novel applications of these technologies range from species dispersal simulations to the identification of optimal corridor conservation sites. Important

conceptual and practical advances in ecological modeling underlie recent applications of this technology.

Early Ecological Models

A shift from qualitative to quantitative methods in the 1960s sparked a renewed interest in the field of ecological modeling. This trend coupled with improved computational capacity spawned the first generation of computer-based ecological models. Systems science provided a sound underlying theory contributing to the increasing popularity of modeling tools in environmental management. The popularity of this approach, however, was quickly overshadowed by the failure of several large, cost-intensive computer models. Early computer modeling efforts were flagged as “data-hungry”. Inadequate computer resources contributed to the oversimplification of complex system dynamics and imposed limits on the accuracy of model outcomes. Lacking both ubiquity and a spatial component the practical utility of early models was limited and resulting failures soon signaled the end of this overly optimistic period of modeling (Wu and Marceau, 2002).

State of the Art Ecological Models

Growing interest in quantitative, spatially based approaches to ecology (e.g. patch dynamics) has fostered a renewed interest in computer-based modeling. Advanced technologies, including GIS, autonomous agent modeling and visualization tools, offer significant promise in the improved understanding and prediction of complex ecological systems. However, underlying concerns in many cases remain unresolved. The ability to accurately represent and predict complex systems presents a challenge to both the past and the present. Predicting complex systems becomes even more complex when human actions are explicitly considered.

The growing diversity of model designs and functions reflects the complex challenges facing modern managers. Emerging technologies have recently been applied to corridor design and evaluation problems ranging from species dispersal patterns to optimal landscape connectivity

models. An extensive list of model functions, ranging from simple information acquisition tools to more complex predictive capabilities have developed to address these problems.

Yu (1996) developed a GIS-based species dispersal simulation model. **Simulation models** are 'the imitation of real-world processes or systems over time' (Wang and Manning, 1999).

Model outcomes include detailed species-specific responses to alternative landscape patterns. Information acquired in this research may be used to map strategic corridor routes for targeted species. Proposed benefits of this approach include the ability to predict behavioral responses across a range of scales. However, questions concerning the accuracy of these methods beyond the initial species and scale of analysis remain unanswered. A limited number of simulated modeling studies have been conducted. Future research is required to develop consistent modeling assumptions and parameters in order to allow cross-comparisons with field-based findings.

Related research targets the need for practical methods to predict the impact of future land use changes on biodiversity (Crist, 2000). The Biodiversity Expert Systems Tool (BEST) combines existing data in a GIS to predict an array of species-specific responses to proposed land use change. Model parameters include habitat and resource requirements, as well as sensitivity to human 'interference'. Model design reflects the need for widely accessible, time and cost effective approaches to management problems. However, highly oversimplified and subjective assessments of complex species behavior raise serious concerns about the practical utility of this model in 'real world' landscapes.

The practical demand for tools to assess biodiversity is similarly targeted in a recent study (Bjorn et al., 2002). The GIS model developed in this study employs a species-demographic approach to identify critical ecological sites or 'biotypes' necessary to ecosystem functioning. The resultant biotype distribution map integrates a wide array of ecological data sets (e.g. wetlands,

riparian habitats, cover type etc.) to predict and evaluate alternative corridor strategies. Practical application of this model may provide a critical tool for the effective evaluation and of alternative management scenarios. Enhanced decision support and communication of management alternatives are among the proposed benefits of this approach. Various elements of this model were incorporated in the corridor conflict simulation model (CCSim) developed in this study.

Computer-based models may represent a critical step toward closing the gap that currently exists between landscape ecology research and 'real world' practice. Several fundamental obstacles have impeded the application of this approach. Models designed for wide accessibility across diverse user groups require the oversimplification of ecological systems and processes. Consideration of human systems further complicates this picture. Oversimplified and narrowly defined ecological models possess a limited ability to accurately represent the complex interactions between ecological and social values in 'real world' management (Nassauer, 1995, Hobbs, 1997).

Advanced policy and research reflect a shift from single attribute to multiple value resource management. Landscape ecology is advanced as an integrative approach to the practical planning and management of complex corridor systems. However, nearly two decades after the emergence of this field, critics argue it has failed to meet these objectives (Hobbs, 1997). Questions concerning the utility of models that fail to consider 'real world' objectives and limitations have been raised.

Recognizing this limitation, recent studies have outlined the need for an integrated, interdisciplinary approach to landscape planning and management (Nassauer, 1995, Hobbs, 1997, Burger, 2000). The field of recreation ecology that has emerged as a potential solution to this problem may ultimately suffer similar criticisms related to the complex nature of human-environment interactions.

2.4 Recreation Ecology: Recreation and Social Assessment

“...it soon became obvious that the resource-orientated point of view must be augmented by consideration of human values.”

–Wagner in Pattison, 1964

2.4.1 Emergence of Recreation Ecology Research

Increased mobility, income and leisure time have fostered a growing demand for outdoor recreation. Recent research indicates that environmental impacts, as well as social crowding and conflict problems negatively influence the quality of recreational experiences (Floyd et al., 1997). Growing threats of ecological degradation and recreational quality loss underscore the need for practical strategies to effectively balance social and ecological concerns.

The field of recreation ecology has emerged in response to these concerns. Recreation ecology has been defined as the study of recreational impacts on the environment. Recreation-related impacts range from soil compaction to displacement of native vegetation. Significant research efforts have focused on the development of field-based trail impact assessment (TIA) methods (Cole, 1989; Mortensen, 1989; Lajeunesse et al., 1997; Kutiel et al. 1999). **Trail impact assessments** examine the type, severity and extent of recreation related impacts to identify trends and avoid irreversible damage to the trail resource.

A recent criticism has addressed the relatively limited scope of this research (Leung, 1996). A focus on ecological impacts alone may obscure the interrelationships between recreationists and the environment. Recent research reflects a broader conceptualization, in which recreation ecology is defined as the study of ‘reciprocal ecological influences and interactions between humans and the environment in recreation contexts’ (Leung, 1996). Emerging research has focused on ways in which recreational use and behavior affects and is affected by environmental attributes.

Non-intensive recreation has been proposed as a vital and complementary use of corridor conservation areas. Recreation ecology promises practical strategies to address growing demands upon a shared resource-base. Realization of this goal hinges upon the ability to identify critical tradeoffs amongst the ecological, social and management components of these systems. As witnessed in the field of landscape ecology, however, the study of complex human-environment interactions often presents a unique challenge to both research and practice.

Conventional strategies remain focused on single dimensions or attributes of recreational concerns, failing to explicitly address competing ecological and social demands (Manning, 1999). A narrow focus, coupled with a reliance on costly field methods, including trail impact assessments, visitor counts and surveys, possesses limited ability to address the complex nature of human-environment interactions in diverse recreational settings. Emerging spatial technologies may offer new promise in overcoming these limitations. The following section will review field-based assessment methods, prior to examining recent advances in the field of computer-based recreation modeling.

2.4.2 Recreation Ecology: Design and Evaluation Methods

2.4.2.1 Field-Based Methods

Trail Impact Assessments

A large body of research is dedicated to field assessments of recreation related environmental impacts. Corridors represent a small, but critical area in the preservation of ecological systems. The limited spatial extent of corridors heightens vulnerability to recreation impacts and may result in the loss of connectivity. In the last three decades, worsening trail conditions have prompted a growing concern amongst park managers. Trail impact assessment (TIA) methods have developed to address this concern.

TIA studies have typically employed either a **sampling** or **census** field survey approach, with few studies combining both. Ecological indicators, ranging from general visual assessments to more specific quantitative measures, are common amongst approaches. Common indicators are summarized in the following table.

Table 2.1: Trail Impact Assessment Indicators

<i>Indicators</i>	<i>Significance</i>
Trail Width	indicates spatial extent of impacts
Tread Incision	indicates soil erosion
Access and/or Multiple Treads	increases the spatial extent of impacts
Soil Compaction	Contributes to increased run-off and erosion, poor root respiration and water infiltration. Represents barriers for certain species, may decrease functional connectivity
Vegetation Density and Diversity	loss of density and soil stability contributes to displacement of native vegetation by invasive species

Adapted from: Kutiel et al, 1999, Lajeunesse et al. 1997, Mortensen, 1989, Patel and Rapport, 2000

Although this list is by no means exhaustive, it provides an indication of the range of potential indicators available. Indicators yield practical information concerning existing trail conditions to managers. The utility of this approach is highly dependent on the appropriate pairing of selected indicators and management objectives.

The field method employed is equally dependent on pre-defined management objectives. **Point sampling** methods provide an average estimate of trail condition via measurement of indicators at systematic intervals along the length of a trail (Leung and Marion, 1999b, Kutiel et al., 1999). The accuracy of this approach is largely determined by the sampling interval. Leung and Marion (1999a) argue that a sampling interval of less than 100m provides an accurate assessment (i.e. 10

% accuracy loss) of trail impacts; however, limited time and cost resources may restrict the feasibility of this approach. Time and cost efficient intervals ranging from 100 to 500 m, however, yield considerably lower accuracy levels (i.e. 50% accuracy loss). Practical needs and resource limitations should determine the appropriate balance between accuracy and efficiency.

Census-based approaches provide a more detailed account of trail condition via measurements of the location, severity and lineal extent of impact indicators. Census-based survey methods may be: (1) sectional evaluations (i.e. detailed trail census conducted in equal area segments) or (2) trail problem assessments (i.e. detailed trail census of pre-defined problem areas) (Farrell and Marion, 2001; Hawes, 1996 in Leung and Marion, 1999a). A **stratified-point sampling** method offers a hybrid approach, permitting variation of sampling design (e.g. indicator type and sampling interval) across various strata defined by relative susceptibility to degradation. Trail susceptibility is determined by several factors including trail width, cover type, and type and level of recreational use (Lajeunesse et al., 1997). This method offers a flexible design, yielding information ranging from general trail condition to detailed impact assessments at pre-defined problem areas or 'hot spots'. Variable study designs and settings have limited comparison of findings across studies. Despite this limitation, the prevalence of localized recreational impact areas or 'hotspots', has been noted across studies (Leung and Marion, 1999a).

A stratified point sampling method was employed in this study. High accuracy demands and a limited spatial extent determined the selected 50 m sampling interval. The selected methods employed in this research reflect both practical needs and available resources.

Tradeoffs are inherent in field assessments of recreation-related impacts. General indicators (e.g. wet soils) which provide an easy, rapid indication of overall trail condition are insufficient in assessing the magnitude and severity of trail degradation. More specific, quantitative indicators

(e.g. vegetation density and diversity indices) yield highly detailed measurements of trail conditions, although they require substantial resource investments.

Tradeoffs are equally apparent in the choice of assessment method. Effective trail management requires accurate, timely and cost-effective methods. Point-sampling methods can be universally applied and reduce time, cost and personnel demands. Assessment accuracy, however, is highly dependent upon the choice of indicators and sampling interval. Census-based approaches offer highly detailed, accurate assessments, although the required investment of limited resources restrict feasibility (Lajeunesse et al., 1997, Patel and Rapport, 2000).

Trail degradation not only threatens ecological integrity, but also detracts from aesthetic and recreational values. Research in this field is limited by a failure to address the underlying causes of trail degradation. TIA studies have largely excluded social variables such as aesthetic preferences and recreational demands in trail evaluations. The effective integration of these diverse landscape demands represents a critical step forward in multi-use resource management.

Aesthetic Preference Assessment

The growing popularity of multiple use landscapes has encouraged consideration of social preferences in park management decisions. As a result, significant research attention has focused on the importance of aesthetic landscape preferences. Research in this field has covered a wide range of issues ranging from forest stand preferences (Ribe, 1989) to the importance of riparian viewsheds (Xiang, 1998). Equally diverse are the wide array of methods employed in these studies. Two general approaches can, however, be identified; **field-based assessments** and, more recently, **computer-based modeling approaches**. The following section will provide a cross-section of field-based approaches to aesthetic preference research. The limitations inherent in these approaches point to the need for creative solutions. The application of advanced technologies in this field will be further addressed in subsequent sections of this chapter.

The need for quantitative measures of landscape aesthetics has emerged in response to the demand for public accountability in resource management decisions. Early empirical research addresses the need to devise standardized measures of aesthetic preference across diverse user groups. The Scenic Beauty Estimation (SBE) method represents one of the first attempts to address this need. The SBE provides an interval scale of shared scenic landscape values derived from on-site assessments or via photographic representations (Manning, 1999). Subsequent research in this field has successfully identified several common indicators of aesthetic landscape preference. Aesthetic preferences include: water, contrasting landforms, vegetation and stand diversity, low groundcover and high distance and depth of view (Kaplan and Kaplan in Hull and Stewart, 1995; Ribe, 1989; Xiang, 1998).

The evaluation of negative aesthetic impacts has yielded less consistent results. Several studies have demonstrated that environmental degradation has minimal impact upon scenic landscape valuations (Helgath, 1975 in Manning 1999, Merriam and Smith, 1974 in Floyd et al, 1997). For example, a survey of backcountry hikers reported a high satisfaction with trail conditions despite severe trail erosion (Helgath, 1975 in Manning, 1999). More recent studies, however, have indicated that recreational users not only observe, but are negatively influenced by evidence of environmental degradation such as tree and vegetation damage (Roggenbuck et al., 1993 in Floyd et al., 1997).

Lack of consistency across studies may be attributable to variable research designs. Field-based approaches to aesthetic preference research include (1) survey and sampling methods and (2) direct user observation. Survey methods sample visitor populations to provide estimates of average user preferences via various mediums such as random point surveys and participant photography. Direct user observation provides detailed accounts of user preference across varied settings through direct observation of individual behavior. Common findings point to the problem of

confounding variables associated with these methods. Recreational activity, level of experience and context have been shown to significantly influence aesthetic preferences. Patey and Evans (1979) found that experienced wildlife specialists demonstrated a significant preference for landscapes with higher habitat values (Patey and Evans, 1979 in Floyd et al., 1997). Contextual influence was similarly demonstrated in a study conducted by Anderson (1981) where similar stands were attributed with higher aesthetic values if they were previously identified as park or wilderness areas as opposed to resource extraction areas (Anderson, 1981 in Ribe, 1989).

Field assessments are limited by inherent trade-offs in accuracy and feasibility. Sampling methods permit a rapid assessment of overall aesthetic preference; however, the accuracy of this approach is often called into question. Varied sampling and survey designs limit reliable cross-comparisons and extrapolation of findings across studies. Uniform user groups and minimal landscape types employed in these studies raise additional doubts concerning the validity of findings (Ribe, 1989). Direct-user observation yields highly accurate information, but the extensive resource investments required are beyond the feasible limits of most practical applications. Confounding variables linked to individual user perceptions further restrict the generalization of results across studies and between natural areas. Faced with growing recognition of aesthetic preferences in policy and decision-making, managers often lack effective practical assessment methods. Conventional field-based methods are plagued by problems of accuracy, validity and feasibility (Manning, 1999).

Crowding and Conflict Assessment

Recreationalists are drawn to ecologically valued natural areas. A growing demand for recreation threatens to degrade both the ecological and recreational quality of these areas. As a result, extensive research has focused on setting acceptable limits of use (Cole and Stewart, 2002).

The number and type of user encounters provide an indicator of recreational quality in these studies. Estimates of appropriate user thresholds are frequently determined on the basis of this model (Figure 2.2). Recent studies, however, have questioned the accuracy of this model, casting doubt on the use of related findings in defining appropriate use levels (Cole and Stewart, 2002).

Figure 2.2: Visitor Use and Satisfaction Model

Adapted from Alldredge (1973) in Manning, 1999

Recreational quality is a highly subjective measure. Various confounding variables undermine the reliability of this model. A recent survey of backcountry hikers demonstrated the impact of situational variables on overall ratings of satisfaction. Both temporal and spatial inconsistencies in user-defined standards of acceptable encounter levels were revealed (Cole and Stewart, 2002). Diverse user groups further question the accuracy of single aggregate measures of recreational satisfaction. Heightened sensitivity to encounters has been demonstrated in experienced hikers and between different user types (McKay, 1976 in Manning, 1999). Inconsistent findings of

acceptable crowding norms are attributed to situational attributes, personal attributes or attributes of those encountered.

In response to this critique, a divergent area of research has addressed the impact of encounter type on acceptable crowding norms (Manning, 2003). Conflict studies focus on the underlying causes of heightened sensitivity to crowding; primarily incompatible uses, motives, values and experience ((Clark et al., 1971, Jackson and Wong, 1981 and McClaran, 1991) in Manning, 1999). Although detailed examination of these issues is beyond the scope of this paper, management implications are clear. Failure to consider user conflicts may limit the effectiveness of recreation management strategies.

Numerous field assessment methods have been employed to identify crowding impacts and determine acceptable use levels. Methods range in type and complexity from simple field counts to detailed visitor surveys (Cole and Stewart, 2002, Manning, 2003). Tradeoffs in accuracy and efficiency are equally evident in these studies. In spite of questionable accuracy, visitor counts are widely used as an indicator of overall recreational quality (Manning, 2003). The use of simple point sampling methods to obtain coarse measures of overall satisfaction is equally upheld. The accessibility and flexibility of these methods across diverse settings has contributed to the wide adoption of these approaches.

Numerous studies target the limitations of these methods. Universally high measures of recreational satisfaction point to various methodological shortcomings, including a consistent failure to consider potential tradeoffs between multiple values indicative of recreational satisfaction. Recent research (Cole and Stewart, 2002) has advocated a shift from simple, aggregate satisfaction ratings to more complex, multiple measures of recreational quality. The latter determines the extent to which recreational opportunities meet pre-defined management

objectives. The use of multiple quantifiable indicators provides a more accurate basis to establish various standards of recreational quality (i.e. minimum acceptable condition of indicators) (Manning, 1999).

2.4.2.2 Recreation Ecology Models and Spatial Analysis

Information concerning use levels, distributions and conflicts must be coupled with spatially-explicit ecological data to improve the practical utility of these approaches. Conventional field methods possess a limited capacity to link these components. Multi-use corridor management requires a framework that considers both recreational user benefits and the ecological integrity of the resource (Shin et al., 2001). Advanced technologies offer significant promise in this regard. Important conceptual and practical advances in recreation modeling underlie recent applications of this technology.

Early Recreation Ecology Models

Resource intensive, trial and error field methods often fall short of corridor management objectives. Accuracy and level of detail are often compromised in practical applications requiring accessible and efficient assessment methods. Realization of these limitations coupled with improved computational capacity sparked an early interest in computer-based recreation ecology models.

Recreation ecology is advanced as an applied science addressing complex human-environment interactions in recreation contexts (Leung, 1996). Applied models require a strong underlying framework and a practical means of quantifying complex system processes and exploring management alternatives. Both conceptual and practical limitations have hindered early modeling attempts in this field.

Ecological processes and interactions were the primary focus of early computer models. By comparison, few models addressed concerns and fewer still attempted to integrate complex spatial and temporal human-environment interactions (Goodchild et al., 1993 in Gimblett, et al., 2001). The Wilderness-Travel Simulation Model (WSM), introduced in the mid 1970s, represents one of the first attempts to integrate the social and environmental dimensions of recreation management. Model inputs included visitor survey data and spatial trail and campsite location information. Model outputs included the number, type and location of user encounters presented in a series of summary tables. These results provided the necessary information to design and implement a trailhead quota system to limit user conflicts in the original study area.

Despite early signs of success, the WSM rapidly fell into disuse. Limited representational and analysis capabilities hindered the practical utility of this model. In addition to problems of oversimplification, high costs associated with limited computer accessibility and capacity restricted the use of this model in 'real world' applications. The WSM was subsequently adapted for use in Grand Canyon River rafting management, although outputs were equally restricted to highly oversimplified, aggregate summaries of user encounters (Roberts et al., 2002). Common criticisms plagued other early model efforts and ultimately proved to be insurmountable obstacles (VanWagtendonk, 2003).

State of the Art Recreation Ecology Models

What has changed since the 1970s? Some argue, very little. Underlying concerns in many cases remain unresolved. Others point to the potential of innovative spatial technologies to address key criticisms and advance the field of computer-based recreation models (Bishop and Karadaglis, 1997, Gimblett et al., 2001, Roberts, et al., 2002, Wang and Manning, 1999). What remains clear is that understanding complex systems and deriving effective solutions to multi-use resource problems presents a challenge to both the past and the present.

Advanced technologies have yielded innovative tools for modeling recreation environments. As a result, a second generation of modeling systems has emerged rendering the WSM relatively obsolete (Bishop and Hulse, 1994, Haider and Hunt, 1997, Harris et al., 1995, Wang and Manning, 1999, etc.). These models are explicitly designed to provide managers with enhanced tools to inform decisions in dynamic, complex environments. Novel spatial analysis tools, including autonomous agents, GIS, and visualization tools, offer a new approach to enduring management problems. The Grand Canyon River Trip simulator (GCRTSim) provides an interesting example of the role of recent advances in modeling complex systems. New technologies are incorporated in a revised model of Grand Canyon River rafting. A flexible, spatially explicit design fosters the consideration of numerous parameters (e.g. user group diversity, environmental conditions and management guidelines) to predict responses to various 'what-if' scenarios. Although significant challenges remain, emerging technologies have shown significant promise in the representation and understanding of complex systems.

Recreation models address a wide array of issues ranging from aesthetic preference evaluations to the predication and assessment of management alternatives. Model functions are equally varied and include information acquisition, integration and decision support. Although well documented in research, the benefits of these approaches have not been fully realized in 'real-world' applications. Realization of the full potential of these models is highly dependent on the appropriate pairing of model design and complexity with management objectives. These issues will be explored in the following examples.

Advanced spatial technologies may provide managers with the necessary information to make effective decisions in multi-use corridor environments. The following examples demonstrate the advantages offered by these technologies in determining aesthetic preferences (Bishop and Hulse,

1994, Floyd et al., 1997, Haider and Hunt, 1997) and acceptable visitor encounter levels (Wang and Manning, 1999).

Model estimates of aesthetic preferences may yield practical guidelines for corridor site planning. Numerous approaches have been developed to evaluate aesthetic landscape preferences. A recent study conducted by Haider and Hunt (1997) uses existing forestry data to simulate landscapes and determine scenic preferences along a trail system. Consistent responses obtained in a comparative study of field and model-derived estimates highlight time and cost benefits to be gained through the use of existing data in predictive models (Haider and Hunt, 1997).

Related research (Bishop and Hulse, 1994, Floyd et al., 1997) explores the use of existing data and GIS tools in assessing aesthetic landscape indicators. In the former study consistent results were obtained between expert field evaluations and model predictions of scenic values. Results obtained in the latter study demonstrated significant variation amongst users and across study sites. Divergent research results should serve as a cautionary note to managers. Efficiency gained through the use existing data in advanced models must be balanced against potential losses in reliability. Model validation and required tradeoffs must be addressed prior to implementation. Further research addressing the impact of model design and parameters upon yielded results may improve the future reliability of these approaches.

Field-based methods remain limited in the ability to accurately predict recreational demand. Complex variables and interrelationships are further defined in state of the art modeling environments. Advanced functioning in this regard may improve the predictive ability of recreation demand models. A recent model to predict visitor levels at a national park demonstrates this point (Lovett and Fjelda, 1997). A relatively simple model design was used to integrate field-derived survey data in a GIS environment to inform demand predictions. Consistent results obtained across

contrasting sites demonstrate the extrapolation potential of this model. However, limited consideration of more complex system variables illustrates the necessary tradeoff between model complexity and generalization. Potential exists for model outcomes to be incorporated with additional studies to provide a more comprehensive picture of recreational demands and related impacts.

Wang and Manning (1999) advocate the use of simulation models and visualization tools to overcome the limitations of resource intensive field methods in establishing social carry capacity thresholds. Complex visitor travel and encounter simulations provide an effective means of predicting visitor experiences and implementing existing policies. In this example, oversimplification of complex recreation behavior is weighted against efficiency gains within modeling environments.

The selected examples demonstrate the potential benefits of applied recreation modeling in management. Efficiency gains derived through the use of generic modeling tools may offer a unique alternative to costly trial and error field methods. Despite noted advantages, recreation models remain limited in scope. The integration of complex variables poses a significant challenge to the design of both ecological and recreational frameworks. Models developed to address key social concerns possess a limited capacity to represent complex environment variables, often resulting in the use of single, aggregate measures. The environmental complexity underlying recreation behavior is, therefore, poorly represented. Similarly, complex recreation behavior is poorly represented in ecological models.

Innovative research seeks to incorporate advances in these fields within the singular framework of an integrated modeling system or Decision Support System (DSS). The following section will review the conceptual and practical basis of these systems prior to examining their role in this study.

2.5 Decision Support Systems in Corridor Management

2.5.1 Challenges

Previous limitations demonstrate the need for an integrated, interdisciplinary approach to landscape design and management (Meekes, 1999). Parallel advances in conceptual and methodological frameworks promise to assist managers in balancing complex demands in corridor environments.

As previously noted, recent policy initiatives reflect a shift from single attribute to multi-value corridor design and management. Growing recreation demands, threats of ecological degradation and increasingly scarce resources have challenged managers to find innovative solutions to pressing planning problems. An integrated approach to the design of corridor networks, incorporating recreational and ecological landscape demands, may yield complementary solutions to these problems (Harris and Scheck, 1998). New integrated frameworks (Figure 2.3) recognize the importance of visible tradeoffs between ecological, social and management attributes in the formulation and evaluation of alternative landscape design (Shin et al., 2001)

Figure 2.3: Three Components of Integrated Assessment

Adapted from Manning and Lime (1996) in Manning, 1999

To effectively navigate complex tradeoffs between these components managers must equip themselves with a new set of tools. Multi-value resource assessment is still often beyond the scope of conventional management strategies. Integrated modeling or decision support systems provide a means of structuring complex spatial analysis procedures, providing a functional linkage between various components. A DSS provides an interface for the synthesis of conceptual frameworks and advanced spatial analysis tools. The flexibility and complexity afforded in this system offers significant advantages over previous approaches to examining complex human-environment interactions. Advances in this field may represent critical steps toward improved understanding complex management tradeoffs (Ervin, 2001).

A rapid policy shift towards multi-use resource management has occurred. A gap exists between the design and practical evaluation of these policies questioning both the feasibility and effectiveness of novel landscape management approaches. Harris and Beatty (1993) argue that an effective management framework must meet two critical requirements; (1) integration of multiple variables and feedback mechanisms to generate management alternatives and (2) tools for determining the impact of these alternatives (Harris and Beatty, in Hopkins, 1999). A spatial decision support system promises to meet these goals.

The resurgence of modeling across disciplines reflects both advancing technology and the growing urgency of complex management challenges. What are these new 'tools' and what, if anything, has changed following early failures in this field? The following section will outline the various components of a decision support system (DSS) and review potential benefits and remaining challenges in this field. The role of DSS technologies in applied research and more specifically within the current study will be examined in the final section of this chapter.

2.5.2 Decision Support Solutions: Concepts and Components

Decision support systems (DSS) provide a means of structuring complex spatial analysis procedures, providing a functional linkage between various components. A DSS is defined as the underlying structure, which links conceptual frameworks, GIS and visualization tools, in a manner that enables data transactions to pass transparently between the various components of this system (Bishop and Gimblett, 1999). Figure 2.4 provides a schematic representation of an *ideal* DSS. The flexible design of a DSS enables the integration of diverse data sources and various model subsystems. Complex user-defined variables and relationships are processed through this system to predict the social and ecological impacts of alternative management options. Proposed management strategies are evaluated and adjusted on the basis of these outcomes prior to implementation.

Figure 2.4: Conceptual Decision Support System

Adapted from Alberti, (1999)

The flexibility and complexity afforded in this system begins to break down previous barriers encountered in the prediction and management of human-environment systems. The application

of this model to a wide range of ecological and recreational management issues is enabled by the use of tools largely relevant to any spatial system. The *ideal* DSS offers a new approach, where spatial analysis tools are applied in response to a problem rather than as a function of model characteristics or data restrictions. The selection of appropriate tools is determined by the required model output as defined by precise management objectives. A strong conceptual framework, outlining management objectives, must therefore underlie any attempt to effectively model complex human-environment systems.

Multi-use Corridors: A Conceptual Framework

Numerous frameworks have developed in response to demands for new tools to manage shared resources. Development of these frameworks is driven by a common goal – to balance ecological integrity and recreational quality in a comprehensive land use plan (Lawson et al., 2003, Pavlikakis and Tsihrintzis, 2003). Newly advanced multi-use corridor strategies, such as the Ottawa Greenbelt corridor strategy, are representative of this shift towards integrated resource management. Diverse objectives, including species and ecosystem protection and recreational and aesthetic goals, fall underneath the umbrella of this framework.

Growing environmental concerns coupled with increased recreational demand have popularized this strategy. Corridors designed to maintain landscape connectivity can provide a cost-effective complement to larger conservation reserves, accommodating both ecological and social quality concerns (Noss, 1987). The strength and design of this framework is highly dependent on clear and explicitly stated objectives concerning the intended functions of corridors in the landscape. Individual corridor strategies are largely defined by site-specific management objectives. A succinct definition of this concept is therefore difficult. Broadly defined, multi-use corridors integrate ecological, social and management attributes in a comprehensive framework to address a wide range of objectives. Potential functions are outlined in table 2.2

Emerging research supports and defines the role of multi-use corridors in conservation and recreation management. However, the proposed benefits and utility of this strategy has yet to be demonstrated in any real detail. A lack of practical evaluation tools is often targeted as the reason for this shortcoming. The advanced flexibility and complexity of novel decision support systems offer significant promise in this regard. An integrated modeling system or DSS comprises the following tools.

Table 2.2: Multi-use Corridor Functions

<i>Objective</i>	<i>Description</i>
Recreation and Tourism	Growth trends in passive, linear recreation provide a potential funding source and complimentary corridor use (Burger, 2000).
Education and Research	Foster public education and research to enhance understanding of human environment interactions (Searns, 1995).
Cultural Preservation	Cultural and heritage features are often incorporated in corridor systems.
Hydrology	Riparian corridors control water quality, erosion and potential flood damage
Ecological Function	A wide range of ecological functions including species and biodiversity conservation, ecosystem preservation etc.

GIS

A geographic information system (GIS) provides a computerized map overlay system for the storage, retrieval, analysis and display of spatial attribute data. GIS models range from habitat diversity assessments (Wright and Tanimoto, 1998) to recreation and environment conflict mapping (Harris et al., 1995). Multi-use resource management requires the integration of large arrays of diverse data lacking common measurement parameters. Spatial relationships define and link complex data sets in a GIS environment to provide managers with a cost-effective and timely means to predict and evaluate landscape management alternatives. The necessary abstraction and thematic classification of GIS data, however, limits the representation of

dynamic processes. A GIS is often paired with additional spatial technologies such as automatic agent (AA) modeling to overcome this limitation (Bishop and Gimblett, 1999).

Autonomous Agent (AA) Models

AA models are computer simulations, incorporating advances in Artificial Intelligence and object-orientated programming. Initially developed to model spatially explicit ecological processes, AA models have recently been applied to simulate recreational use in complex settings. AA recreation simulation paired with a virtual GIS environment enables the analysis of dynamic human-environment processes (Bishop and Gimblett, 1999).

Visualization and 3-D Representation

Visualization refers to the interactive visual representation of data to enhance understanding and communication of spatial contexts and to make problems more visible (MacEachren, 2001). Applied visual technologies range from automatic landscape generation to interactive virtual trail environments. The addition of visualization tools, including 3-D models and animation, in a DSS extends the flexibility, interaction and representation of spatial information. Improved visibility, understanding and communication of potential tradeoffs amongst policy-makers, managers and the public represent potential benefits to management.

As previously noted, a DSS provides an underlying structure linking conceptual frameworks and spatial technologies, thus creating a unified interface between the user and complex subsystems. In an ideal system, spatial technologies are selectively employed to meet diverse management objectives allowing improved flexibility and understanding in the prediction and evaluation of management alternatives. Although tradeoffs remain, numerous benefits are extended in decision support models.

Predictive Capability

Complex relationships between management decisions and ecological and social impacts are difficult, if not impossible, to predict. Advanced technologies offer practical benefits in the development and testing of 'what if' scenarios. Decision support systems provide spatially explicit tools to systematically investigate the impact of various management alternatives prior to actual implementation (Alberti, 1999).

Dynamic Change

Object-orientated AA models and associated visualization tools enable the depiction of dynamic change in complex systems. These advanced technologies allow managers to overcome the spatial and temporal limitations of static maps and advance the analysis of dynamic, probabilistic change inherent in human-environment systems (MacEachren, 2001).

Generalization

Field-based approaches have been highly criticized for their limited ability to extrapolate methods and findings beyond the initial study site. The flexibility of DSS design and technologies offer renewed promise in the provision of generic modeling tools for practical management. A high degree of accuracy and interactivity in complex models requires detailed site-specific data resulting in a relatively narrow model scope. Prior consideration of tradeoffs between the realistic representation of complex systems and the ability to extrapolate results will determine the effectiveness of a DSS in individual applications. Enhanced model complexity must be weighed against the need for universal methods and results (Bishop and Gimblett, 1999, Bishop and Hulse, 1994, Floyd et al., 1997).

Accessibility, Time and Cost

The proposed time, cost and accessibility benefits of a DSS are highly debated. Proponents of these technologies point to the enhanced 'visual thinking', user interaction and operability

benefits afforded by the use of visualization tools. These improvements foster better understanding, communication and visibility of management alternatives between diverse user groups, including policy-makers, researchers, managers and the public.

Faced with limited resources, the ability to adapt existing models to diverse management problems is equally attractive. Additional value resides in the ability to predict management outcomes prior to the commitment of scarce resources. The unforeseen negative aesthetic impact of recent boardwalk construction across fragile areas of the Skyline Trail in Cape Breton illustrates the importance of this issue (Manning, 2003). The questionable accuracy of these models beyond the intended application, however, must be considered. Tradeoffs in representational accuracy vs. time and cost efficiency should be considered in the light of management demands and available resources.

Data Requirements and Model Validity

Advances in geospatial information acquisition and spatial technologies have improved both the quantity and quality of data available for use in complex models. In spite of these advances, the restrictive costs and accessibility of data often result in the use of existing, rather than optimal data sets. Given the complexity of recent models, efforts must be taken to determine the accuracy of underlying data. Model validity depends largely on the extent to which errors in source data are addressed (Meitner and Daniel, 1997).

Integration of Complex Systems

One of the most promising advantages of a DSS system is the potential to link disparate data and complex sub-systems (ecological, social and managerial). Advanced technologies, including GIS and autonomous agent modeling, are well suited to integrate complex data sets and simulate human-environment interactions. However, the idea of linking complex processes in a comprehensive model that can be readily applied across diverse recreation settings has yet

to be fully realized. Tradeoffs must be addressed to forge operative linkages between management objectives and applied DSS technologies.

Practical Utility

The extent to which the above issues are addressed in initial model design largely determines the practical utility of a decision support system. Model structure is highly reliant upon desired outcomes as defined by clear, concise management objectives. The analysis of complex interactions requires some level of abstraction. Tradeoffs between available resources and accuracy requirements must be informed by specific management goals. Critical questions including: what is being measured; what level of analysis is required; and what resources are available; should be addressed prior to the implementation of an effective decision support system. The proposed benefits and future utility of a DSS are demonstrated in the following applied research studies.

2.5.3 DSS 'Real World' Applications

The complex nature of multi-use resource management provides an effective forum to demonstrate the utility of decision support systems in fostering sustainable recreation in fragile environments. Many argue that managers are ill-equipped to make effective decisions concerning necessary tradeoffs in the management of shared resources. The objective of a DSS is to provide (1) methods for the integration of social and biophysical data, (2) to predict human-environment interactions and (3) to facilitate the evaluation and communication of management alternatives (Bishop and Gimblett, 1999).

Several critical assumptions underlie the development of these models. Models assume that the spatial patterns of ecological impacts and sensitivities can be mapped and that recreational demands and values can be accurately represented. Bishop and Gimblett, (1999), propose a DSS model where management options are simulated to determine social and environmental impacts

via GIS, AA models and 3-D visualization. A specific application of this model uses spatial analysis tools to display and evaluate alternative trail designs. Uncertainty surrounding the simulation of complex recreation behavior and the validity of human responses to virtual environments question the validity of underlying model assumptions. Assumptions reflect the necessary simplification of complex systems in the pursuit of practical tools for 'real world' management applications. Remaining uncertainties must be addressed but this should not obscure the immediate need for practical management tools.

Efforts to expand the scope of DSS models to reflect complex tradeoffs amongst ecological, social and managerial resources are addressed in the following case studies. Figure 2.5 illustrates a GIS model combining social and biophysical data to address potential conflicts between recreationists and sensitive wildlife species (e.g. bighorn sheep). This model provides managers with a practical tool for mapping potential conflict areas. Model outcomes are subsequently employed to devise effective management strategies, such as limiting trail access. Ecological, social and management components are effectively integrated; however the relatively limited scope of this model limits broader applications.

Broad management objectives for multi-use corridor networks provide the context for related research conducted by Cohen (2002). A GIS-based model is developed to identify and evaluate alternative corridor routes in central Israel. Corridors were delineated on the basis of predefined management objectives to provide a preserved network of connected open spaces servicing local ecological and social demands. Large-scale corridors with minimal environmental disturbance and high historic values were identified using land use/ land cover data. Least-cost path analysis, a GIS tool, generated alternative corridor routes meeting specific ecological (e.g. habitat suitability) and social (historically significant site) criteria. The use of existing, standard databases and the extrapolation potential of this relatively simple model demonstrate the practical benefits of a DSS.

The valid extrapolation of this model to more complex environments remains untested and may ultimately negate the proposed benefits of this model (Cohen, 2002).

Figure 2.5: Integrated GIS Conflict Model

Adapted from Harris, et al., (1995)

Broad planning goals equally provide the context for this study. This research integrates field-derived trail impact data and ecological suitability mapping in a GIS environment to determine potential conflicts and evaluate the effectiveness of proposed multi-use corridor strategies. Decision support technologies including GIS and visualization tools are utilized to evaluate and communicate critical tradeoffs between recreational trail demands and ecologically sensitive areas. The effective use of these technologies in this study hinges on the appropriate pairing of model design and management objectives.

Recent management objectives reflect the need to consider complex tradeoffs between ecological and social values in multi-use resource planning. Efforts to link analysis 'tools' with clear,

concise management goals represent a critical step forward in the implementation of DSS technologies and the development of practical methods for the evaluation of novel multi-use resource policies.

CHAPTER 3: METHODOLOGY

Multi-use Management and Decision Support Systems

3.1 Introduction

3.1.1 Broad Research Goals and Objectives

Mounting environmental concerns coupled with intensive demands for recreational opportunities pose a unique challenge to the design and management of natural areas. Negotiating the intricate balance between ecological preservation and recreational will require innovative approaches and tools.

Integrated management strategies, such as multi-use corridors, have been forwarded as a policy solution to the complex problems facing park management. Multi-use corridor strategies share a common optimistic goal – to balance ecological integrity and recreational uses in a comprehensive land use plan. Although the wave of enthusiasm surrounding these strategies may be masking a critical question: do they work?

For such a seemingly simple question, there is no easy answer. Lack of clear and consistent methods has hindered corridor design and evaluation, often yielding disappointing results in 'real world' applications (Saunders and Hobbs, 1991; Bennett, 1996 and Fahrig, 2000; Hess and Fischer, 2001). Corridor design must be premised on an explicit statement of intended function as defined by management goals. Recreation, wildlife conservation and water quality protection are the goals of the Ottawa corridor network as defined in recent National Capital Commission policy (NCC, 1996). The present study addresses the current gaps between policy and practice and poses the following question:

Are multi-use corridors an effective strategy to balance ecological preservation and recreational demands?

Practical implementation is limited by a lack of management 'tools'. Conventional, field-based evaluation methods suffer from large time, cost and personnel requirements, rendering them largely obsolete (Roberts, et. al, 2002). As previously noted, the ability to negotiate key tradeoffs between ecological and recreational values is critical to the success of a multi-use corridor strategy. Decision support technologies, including GIS and visualization tools, offer unique advantages in the negotiation of complex human-environment interactions. The capacity to integrate large amounts of disparate data in a GIS environment may provide a potentially powerful management tool.

A two pronged approach is taken in the present study to examine: (1) ecological sensitivities and constraints and (2) recreational demands and impacts. A decision support system (DSS) is developed to evaluate visible tradeoffs between these values. The objectives of a comprehensive DSS model are to provide: (1) methods for the integration of social and biophysical data, (2) to predict human-environment interactions and (3) to facilitate the evaluation and communication of potential management alternatives (Harris and Beatty, in Hopkins, 1999).

Figure 3.1 provides a schematic representation of the decision support system developed in this study. The corridor conflict simulation model (CCSim) links ecological and recreational model components and relevant spatial data and analysis tools in a decision support system. Existing tools and data are utilized to provide an accessible and accurate means of identifying and predicting use conflicts across a range of management settings. The primary components of this system are:

1. Ecological sensitivity assessment model
2. Recreation impact model
3. Integrated corridor conflict model

This chapter describes the various components of this system. Section two will outline indicators and analysis procedures employed in the identification of ecologically sensitive areas. Section three of this chapter will outline trail impact assessment methods used to determine recreation demands and impacts. The integrated analysis and communication of ecological and recreational model outputs in the decision support system will be outlined in section four.

Practical methods to evaluate multi-use corridor strategies are lacking. The model developed in this study is forwarded as a prototype tool to assist multi-use management and decision making by linking diverse data and model components. The proposed flexibility of this model, however, requires a certain degree of abstraction to effectively link 'real world' objectives and models. Concessions in the realistic representation of complex systems are necessary to provide managers with accessible and easy to use tools.

Figure 3.1: Decision Support System – Corridor Conflict Simulation Model

3.1.2 Model Assumptions

Fundamental assumptions underlying the DSS developed in this study include (1) the ability to map spatial patterns of ecological sensitivities and (2) the ability to accurately represent recreational demands and impacts. Models of complex human-environment interactions require some level of abstraction. In light of pressing management demands and scarce resources the ability to evaluate and test management alternatives prior to the commitment of resources is assumed to outweigh representational accuracy concerns.

3.2 Ecological Sensitivity Model

Broad management objectives for the study area outline the desire to maintain ecosystem integrity through a connected system of protected natural areas. Corridors are intended to facilitate the movement of flora, fauna and water between protected areas (NCC, 1996). The methodological framework for the present study rests on the assumption that landscape structure acts as a major determinant of ecological function and overall landscape conservation value (Forman and Godron, 1986; Forman, 1996). The concept of structural connectivity provides a practical framework for the design and evaluation of corridor systems. Structural landscape characteristics (e.g. land use, land cover) act as the basis for both the present research design and current Greenbelt policy.

Attainment of ecological management goals hinges on the ability to identify and protect key ecological values in corridor environments. The ecological sensitivity model developed in this research defines conservation priorities by identifying ecologically sensitive areas in the corridor study area. Recreational access to these fragile areas must be regulated to protect ecological values and minimize the risk of impacts. Various biophysical data were required to effectively delineate key sites.

3.2.1 Ecological Database

Numerous studies support the use of computer-based models to provide an improved basis for the understanding and prediction of ecological responses to corridor landscape patterns ((Donovan et al., 1987; Ornsby and Lunetta, 1987 and Stutheit, 1989) in Harris and Scheck, 1996). Beyond this point of agreement, minimal consensus exists regarding whether corridors should function to enhance overall biological diversity or protect threatened species. Corridors cannot secure the persistence of all species, although a broadly defined corridor system begins to address the diverse ecological demands of a complex landscape (Hector et al., 2000). Both this study and existing NCC policy adopt the viewpoint that corridor design must address and preserve a broad array of species and ecological components to provide planning guidelines for management across species and landscapes (NCC, 1996). A land use/land cover (LULC) approach is adopted in the construction of the ecological database used in this study to reflect the broad nature of these goals (Figure 3.1).

Existing data and analysis tools were adapted to the present study to provide managers with an efficient means to design and evaluate corridor systems. These tools include:

Landscape Analysis Tools – Woodland Evaluation System: Developed by the Eastern Ontario Model Forest organization, this system provides a comprehensive method to evaluate woodland significance. It allows users to simulate potential impacts of future changes to the landscape. Structural landscape indices (e.g. connectivity, forest interior) are operationalized to evaluate the relative ecological value of landscape patches. Various indices and analysis methods developed in this system were adapted to the present study (Rowse, 2003).

Wildlife Analysis Tools – Landscape Analyst ©: The Landscape Analyst allows users to assess the current ecological conditions of regions both visually and quantitatively. It also

allows users to simulate potential impacts of future changes to the landscape. Wildlife analysis tools provided in this software were adapted to the present study. Landscape attributes critical to species preservation (e.g. forest interior habitat, relative road density) are analyzed to determine the relative habitat value of landscape patches (Canaan Valley Institute, 2001).

Together these tools provide the basis for the **ecological sensitivity model** developed in the present study. The land use/land cover database developed for use with this model adheres to the requirements of these tools as described in the following section.

Landscape Analysis – Woodland Evaluation System

Analysis is conducted at the level of a **landscape** patch. A patch is defined as an isolated natural area created by a large-scale disturbance of the surrounding matrix (Forman, 1986). Woodland patches provide the primary unit of analysis for this study, reflecting both the ecological and recreational significance of these areas. **Woodland patches** provide ecological and social benefits including erosion prevention, water retention, habitat provision and recreational opportunities (OMNR, 2000).

The woodland patch data layer was derived from the NCC Regional Vegetation layer (NCC, 1995) in adherence to Ontario Ministry of Natural Resources guidelines for designated woodland areas (OMNR, 2000). Included are all woody vegetation such as forests, forested wetlands and plantations. Thirteen classes of woodland patches are distinguished and account for 20 km².

Although not recently updated, this layer represents the most current data set with continuous coverage for the study area. The accuracy of the data is consistent at 5 – 10 m. NCC orthographic air photos taken in 1998 at a 1 m resolution were used as a secondary data source to validate uncertain woodland boundaries. Time restrictions limit the complete validation of all boundaries in study area.

As noted in chapter one, recent NCC Greenbelt policy defines three land use categories; core natural areas, natural area buffers and natural area linkages or corridors. Corridor sites, as designated by the NCC, provide the study area boundary for this analysis. Boundaries have been updated as recently as 2002 and have an accuracy of 5 -10 m.

Landscape analysis tools integrate diverse data to measure the overall ecological value of woodland patches. Various structural indices (table 3.1) are used to quantify spatial landscape attributes and operationalize ecological goals defined for the study area. Research supporting the use of structural indices points to the high level of interaction between landscape structure and function via various feedback mechanisms. All data layers (tables 3.1 and 3.2) were supplied by the NCC in a vector format at a scale of 1:25,000. Map layers were compiled from 1:50,000 air photos taken in 1988 (MTM – NAD 27) with some data updated in 1995. Accuracy is consistent at 10 m.

Wildlife Analysis tools integrate diverse data to measure overall habitat suitability and level of human disturbance. Extensive preprocessing was required to adapt wildlife analysis tools available within the Landscape Analyst © software to this study. Data layers were combined in a knowledge-based classification to provide an updated LULC raster grid for the study area (table 3.2). Land use/land cover was reclassified to adhere to standardized land use categories defined for use with this software (table 3, appendix).

The lack of a comprehensive, updated database for the study area poses a major barrier to both current research and practical management. Current data are critical to effective decision making. Results of this analysis are subject to change every time a woodland patch is removed or altered. Accurate delineation of environmentally sensitive areas is limited to the validity of the underlying data.

Table 3.1: Landscape Analysis Database

<i>Criteria</i>	<i>LULC Data Layers</i>	<i>Format</i>	<i>Scale</i>
Forest Interior	Woodland Patch	Vector	1:25, 000
Connectivity	Woodland Patch	Vector	1:25, 000
Riparian Areas	Woodland Patch, Rivers ² , Aquatic habitat	Vector	1:25, 000
Proximity to Wetlands	Woodland Patch, Wetlands	Vector	1:25, 000

Table 3.2 Wildlife Analysis Database

<i>Criteria</i>	<i>LULC Data Layers</i>	<i>Format</i>	<i>Scale</i>
Bird Community Index (BCI)	Woodland Patch, Vegetation, Greenbelt Sectors, Rivers, Wetlands, Roads, Existing Land Use, Existing Study Area Boundary	Raster	1: 25, 000
Relative Road Density	Roads, Existing Study Area Boundary	Vector	1: 25, 000

The NCC recognizes that the current corridor system falls short of several of the goals outlined in the recent Master Plan for the Greenbelt (1996). Forward looking, preventative planning measures are encouraged to achieve these goals over the course of the next 20 years. Changes to both the quality and quantity of corridor sites are required to meet management goals and preserve ecologically valued components of the Greenbelt.

²Rivers data layer contains streams, creeks, lakes and rivers

Widely supported corridor design principles were used to construct an 'optimal' corridor scenario. Changes to both the quantity and quality of corridor sites are required to achieve broad biodiversity and ecosystem conservation goals in the future. An optimal corridor scenario is used to predict the impact of future corridor design and management options.

Identification of optimal corridor sites was a complex procedure requiring consideration of multiple data sources. The Ecological Analysis of the Greenbelt (NCC, 1991) provided a strong starting point for determining critical habitat areas and ecologically viable areas. Additional guidelines were established based on a thorough review of corridor research. Optimal corridors were designed to enhance the structural connectivity of the landscape for a wide range of species and ecosystem processes. Structural connectivity is widely accepted as critical conservation design principle (Harris and Scheck, 1996; Beier and Noss, 1998). The following section outlines general guidelines and criteria for defining optimal corridors established through a comprehensive review of the literature.

1. Widen existing corridors to provide linkages that maintain habitat and ecosystem connectivity and buffer riparian and wetland areas. Site specific variations will exist; however, general guidelines suggest a corridor width of 500m to several kilometers for landscape corridors (Kubes, 1996; Conner and Rudolph in Harris and Scheck, 1996). Suggested riparian corridor widths are equally diverse. A 100 m corridor width is adopted in this study to represent an average estimate of suggested corridor widths (Harris and Scheck, 1996).
2. Forest cover, habitat and wetland boundaries provide a structural guideline for delineating optimal corridor boundaries. Revised boundaries reflect ecosystem boundaries, not administrative boundaries (Hector et al., 1999; Saunders and Hobbs, 1991).

3. Revegetate internal corridor gaps exceeding 500 m to maintain continuous forest cover and enhance structural connectivity. Both ecological and species mobility are enhanced by connected forest habitat. (Bennett, 1996; Kubes, 1996; Hctor et al., 1999; Cook, 2002; OMNR, 2000).
4. Place all roads on one side of the corridor where possible to minimize interior habitat disruption (Cohen, 2002, Algonquin to Adirondack Conservation Society, 2003).

These general guidelines were used to predict an optimal corridor network for the study region.

Parallel landscape and wildlife analyses were conducted to identify and predict existing and future ecological sensitivities. The following section will describe the indicators and analysis tools employed in this study.

3.2.2 GIS Landscape and Wildlife Analysis

General Framework

The GIS-based ecological sensitivity model links diverse landscape and wildlife data and relevant spatial analysis tools. Adapted landscape and wildlife analysis tools comprise the ecological component of the DSS developed in the present study (see Figure 3.1).

Limited attempts have been made to forge operational linkages between quantitative ecological criteria and targeted planning goals (Rowsell, 2003). The ecological sensitivity model is intended to provide managers with a highly accessible and operable tool to identify key corridor conservation sites. Limited management resources should not restrict the use of this model in practical corridor evaluations.³

³ Alternative modeling approaches ranging from simplified Boolean models to highly detailed quantitative models were deemed inappropriate to the specific objectives of this research.

The ecological sensitivity model employs an equal ranking system. In this system, a common ranking scheme is applied across several ecological indices to provide an aggregate score for individual landscape patches. Information was insufficient to justify variable weighting. Therefore an equal weighting scheme was adopted. Thresholds for each indicator are consensus values derived from average estimates of suggested thresholds as presented in existing corridor research. Rank scores, ranging from 0 – 4 were assigned in accordance with the specific thresholds defined for each indicator. A score of 4 signifies high ecological value while a score of 0 indicates low ecological value with respect to the criteria employed in this study. This model provides means of quantifying structural landscape attributes critical to stated ecological objectives. Functional linkages are forged between quantitative ecological indices and targeted management goals.

A comprehensive review of relevant research led to the selection of indicators used in this model. A diverse range of ecological indicators was selected to determine conservation priorities and reflect the broad nature of the planning goals addressed in this study. Indicators range from simple forest interior measurements to more complex habitat suitability analysis. Despite diversity, two general indicator and analysis categories can be distinguished: (1) Landscape Analysis and (2) Wildlife Analysis. Analysis procedures are further defined in the following section.

1. Landscape Analysis

Intended ecological functions, as defined for the study area, are to provide a connected system of natural areas and maintain a functioning ecosystem. Selected indicators measure woodland patch significance with respect to this goal. No standard exists which defines a 'significant' woodland. Identification and evaluation of these areas varies across management areas with available resources, access to information, development pressures and natural area allocations. A lack of consistent data and evaluation tools has hindered management efforts. Evaluation tools should be adoptable and adaptable across management and natural settings.

For the purpose of this study significance is measured in terms of the impact of landscape structure upon the overall quality of the natural area environment. As previously noted, evidence illustrating the high levels of interaction between landscape structure and function is often cited to support the use of structural indices in landscape design and management. Selected structural indices provide a generalized method that uses available data and resources to accurately delineate priority conservation areas.

Connectivity

Landscape connectivity, through the preservation of corridors between isolated natural areas, is critical to both the structure and functioning of the landscape. Both large scale ecological processes (e.g. nutrient cycling, hydrology flows, etc.) and species mobility are enhanced by connected forest habitat. Research evidence indicates that continuous forest cover enhances species mobility and habitat (Cook, 2002). Fahrig (2000) further demonstrates the role of connected corridors in improved species persistence and stability in the Ottawa region. Despite considerable debate concerning appropriate connectivity measures, the benefits of connected habitat patches for species in 'real' landscapes is widely supported (Beier and Noss, 1998). Additionally, continuous forest cover has been shown to be equally important to recreational functioning (Cook, 2002).

The proximity of adjacent patch edges provides a quantitative measure of structural connectivity in this study. Consensus values derived from existing research were used to establish the thresholds used in this study (table 3.3). An upper threshold limit of 500 m between adjacent woodland patch edges corresponds to loss of connectivity for numerous interior species (e.g. fisher) (Kubes, 1996, Fedowick, 1993, Bennett, 1996). A lower threshold limit of 40 m between adjacent woodland patch edges corresponds to connectivity loss for small

mammals (Kubes, 1996). Remaining thresholds were established based on similar work conducted by the City of London (2000).

Table 3.3: Connectivity Thresholds

Rank Score	Thresholds
4	< 40m to the nearest patch boundary
3	40 – 100m to the nearest patch boundary
2	100 – 250m to the nearest patch boundary
1	250 – 500m to the nearest patch boundary
0	>500m to the nearest patch boundary

The connectivity criterion was calculated using the woodland patch layer. The Nearest Feature extension for Arc view 3.2 © was used to calculate the distance between adjacent patches. The resulting distances were reclassified and assigned a rank score in accordance with the thresholds outlined in table3.3. As previously noted, rank scores provide a means of quantifying structural landscape attributes critical to overall ecological functioning. Ranked vector-based woodland patches were converted to a 10 meter resolution raster grid to reflect the accuracy of underlying data⁴. The need to accurately target key problem sites necessitates the use of a fine-scale resolution. A high level of detail enables the accurate analysis and display of critical ecological sites. Analysis output is presented in a map of assigned rank values for all woodland patches in the existing and optimal corridor network.

Forest Interior

Forest interior is defined as a core habitat area sheltered from forest edge habitat and other conflicting land uses. Highly dependent on patch size and shape, interior habitat is recognized as a strong indicator of overall ecological health (OMNR, 2000). Numerous bird community

populations are dependent on forest interior habitat. Included amongst these are threatened local species⁵ such as the red-shouldered hawk, Acadian flycatcher and hooded warbler. Various common bird species (e.g. Canada warbler, wood thrush) and other interior species (e.g. fisher) are equally dependent upon forest interior habitat. In summary, large blocks of continuous forest support a higher diversity of native interior forest species, whereas small, disconnected patches support larger numbers of invasive, edge-dwelling species (Forman, 1986). Invasive species negatively impact both biotic and ecosystem functioning (Crumpacker, 1998).

The threshold for this indicator was woodlands with a minimum of 2 hectares of remaining interior after the removal of successive edge habitat ranging from 200 to 50 m (table 3.4). To meet this criterion interior habitat must be continuous and not the sum of multiple detached cores. These thresholds were based upon related research conducted by the Rowsell, (2003) and OMNR, (2000).

The forest interior criterion was calculated using the woodland patch layer. Successive edge areas ranging from 200 – 50m were removed to identify remaining forest interiors or 'cores' of 2 hectares or larger. Rank scores were calculated for individual woodland patches in accordance with the criteria outlined in table 3.4. Ranked woodland patches were converted to a 10 m resolution raster grid. Analyses output is presented in a map of assigned rank values for all woodland patches within the existing and optimal corridor network.

Riparian Forests - Proximity to Water

Riparian areas include habitats or ecosystems that are associated with bodies of water (Fry et al., 1994). Riparian areas are small, highly productive areas, supporting a wide array of

⁴ Refers to both GIS and field trail survey data

⁵According to Canada's national species at risk (OMNR, 2000)

Table 3.4: Forest Interior Thresholds

Rank Score	Threshold
4	> 2 ha remaining after 200m edge removed
3	> 2 ha remaining after 150m edge removed
2	> 2 ha remaining after 100m edge removed
1	> 2 ha remaining after 50 m edge removed
0	< 2 ha remaining after 50 m edge removed

distinct species and ecosystem functions and as such should be considered a conservation priority. Woodlands serve multiple functions in riparian areas.

Providing protective forest cover along critical migration routes, pollution control along watercourses and reducing erosion potential through rain interception and reduced overland flow, riparian forests are recognized as a key component in a healthy ecological network. The role of riparian areas in providing passive recreation and aesthetic opportunities has been equally noted (Fry et al., 1994).

Riparian forest thresholds were established on the basis of existing research. An lower threshold of 100m is required to protect interior bird species and vegetation (Harris and Scheck, 1996). An upper threshold of 10 m is required to enhance large (deer, fox, coyote) and small (hares, voles) mammal dispersal along riparian corridors. Similar studies conducted by the City of London (2000) and the Regional Municipality of Halton (2001) were used to determine the remaining threshold levels.

The riparian forest criterion was calculated using the woodland patch layer and hydrology layers (rivers and aquatic habitat). The woodland patch layer was first queried to identify woodland patches within a specified distance range of water bodies (lakes, ponds etc.).

Table 3.5: Riparian Forest Thresholds

Rank Score	Threshold
4	<10 m from a water features ⁶ shore
3	10 – 30 m from a water features shore
2	30 – 50 m from a water features shore
1	50 – 100 m from a water features shore
0	>100 m from a water features shore

A second query identified woodland areas in a specified distance range of lineal water features (rivers, streams etc.). Identified woodland patches were assigned a rank score in accordance with the thresholds outlined in table 3.5. Ranked woodland patches were converted to a 10 m resolution raster grid. Analysis output is presented in a map of assigned rank values for all woodland patches in the existing and optimal corridor network.

Proximity to Wetlands

Wetlands represent a high conservation priority in the study area. As such, wetlands were distinguished from other aquatic habitat features to reflect their importance to the regional ecosystem. Wetlands are critical to both ecosystem functions, including watershed management and flood control and species conservation, as habitat for diverse flora and fauna. Three provincially important wetlands (Shirley's Bay, Stony Swamp and the Mer Bleue bog) are located in the study area. Mer Bleue has been further distinguished as an internationally significant wetland under the United Nations RAMSAR Convention (1996).

The proximity to wetlands criterion measures the distance between adjacent woodland and wetland patch edges. Thresholds and analysis for this criterion parallel those outlined for connectivity measures and therefore will not be repeated in this section (table 3.6).

Table 3.6: Proximity to Wetlands Thresholds

Rank Score	Thresholds
4	< 40m from wetland boundary to the nearest patch boundary
3	40 – 100m from wetland boundary to the nearest patch boundary
2	100 – 250m from wetland boundary to the nearest patch boundary
1	250 – 500m from wetland boundary to the nearest patch boundary
0	>500m from wetland boundary to the nearest patch boundary

2. Wildlife Indicators

Management objectives for the study area are to provide a connected system of natural areas and maintain a functioning ecosystem. NCC management objectives further outline the intended function of corridors in facilitating the movement of flora and fauna between otherwise isolated patches (NCC, 1996). The study area provides a rich habitat for a variety of native species of flora and fauna. Several local species are currently listed on the Canadian Species at Risk list (Environment Canada, 2003). Adapted wildlife indicators provide a mechanism to operationalize management goals. The importance of these indicators to the preservation of local flora and fauna are outlined in the following section

Preservation of biodiversity plays a critical role in maintaining a vital ecosystem. The following wildlife analysis tools were adapted to the present study to evaluate the relative habitat value of landscape patches located in the study area (see Figure 3.1).

Relative Road Density

Major roads disrupt biotic functioning by acting as a primary source of fragmentation and posing a barrier to species dispersal. Additionally, roads provide access to natural areas and hence are a strong indicator of human presence and activity. Numerous species are sensitive

⁶ Water features include rivers, streams, creeks and lakes as identified by the NCC (2003)

to the disruptive impacts (e.g. noise pollution, increased run off, intensive human activity etc.) of road systems.

Calculation of relative road density assumes a standard 30 m road width. Thresholds for this indicator are based on similar work conducted by the Algonquin to Adirondack Conservation Society (2003) and the Canaan Valley Institute, (2001). A medium threshold of 4.5-6.5percent was defined in numerous related studies (Jenson, 1986 and Fuller et al., 1992 in Algonquin to Adirondack Conservation Society, 2003). Remaining thresholds are established on the basis of work conducted by the Canaan Valley Institute (2001).

Table 3.7: Relative Road Density Thresholds

<i>Ranked Score</i>	<i>Thresholds</i>
4	0 – 2.6 % Road Density
3	2.7 – 4.4 % Road Density
2	4.5 – 6.5 % Road Density
1	6.6 – 10.9 % Road Density
0	11 – 66 % Road Density

Relative road density was calculated using the road systems and study area boundary layers. Calculation of relative road density assumes a standard 30 m road width to allow a faster calculation of results. The vector-based road data were converted to a 30 m resolution raster grid. Road density was summarized for each cell using a moving window technique with a 1 km square spatial filter. Calculated road densities were reclassified and assigned a rank score in accordance with table 3.7. Analysis output is presented in a 30 m resolution raster-based map of assigned rank values for all cells in the existing and optimal corridor network.

Bird Community Index (BCI)

The BCI measures habitat suitability by relating the type of bird community inhabiting an area with the surrounding land cover (e.g. forest, wetlands, built environment etc.). Originally developed as part of the U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program, (EMAP) this modeling tool has been adapted to current research. Comparable model inputs support the valid extrapolation of the BCI to the study area. Over 300 songbirds were indexed in the initial study, of which all but three can be found in the Ottawa region (Ottawa Bird Inventory, 2003).

The BCI examines the relative proportion of specialist and generalist species characteristic of various structural and functional ecosystem components to provide a composite measure of ecological condition. Bird community composition reflects landscape dynamics and structural complexity and configuration characteristics. High scores indicate areas of high habitat requirements, where specialists are well represented relative to generalists (O'Connell et al., 1998).

Songbirds were selected as a target species based on the following traits: species vary in sensitivity to ecological stresses, life history characteristics can be linked to multiple environmental components, relative ubiquity and availability data sources and strong aesthetic appeal. Numerous studies ((Noss, 1990; Karr and Chu, 1997 and Croonquist and Brooks, 1991) in O'Connell et al., 1998) have supported the use of this target species as an effective indicator of general biotic and habitat integrity. Thresholds used here reflect those established in the initial study (O'Connell et al., 1998). Scores are weighted to provide an equivalent to the common ranking system used in this study.

Table 3.8: BCI Thresholds

<i>Ranked Score</i>	<i>Threshold</i>
4	2 = Excellent habitat condition
2	1 = Fair habitat condition
0	0 = Poor habitat condition

The BCI is calculated using a composite LULC raster grid of the NCC planning region (see table 3.2) and study area boundary layers. A standardized LULC scheme is applied identifying forested, wetland and forested wetland cover types. Analysis extends to an area of 1000 m beyond the defined study area boundaries to identify adjacent land use impacts. Several intermediate grids are produced during a complex computation that spans several days. BCI integer scores ranging from 0 to 2 are calculated for each cell. BCI scores were weighted and assigned a rank score in accordance with table 3.8. Output for this analysis includes a raster-based map depicting assigned rank values for all cells in the existing and optimal corridor network.

3.2.3 GIS Ecological Sensitivity Map

A GIS-based ecological sensitivity model was developed to identify key corridor conservation sites in both the existing and optimal corridor network. The aggregation of numerous indicators and metrics provides a robust assessment of ecological conditions in the study area to evaluate the feasibility of stated management objectives.

Model output depicts the combined equal weighting scores of indicators in a composite GIS ecological sensitivity map for existing and optimal corridor networks (see Figure 3.1). Analysis outputs for each of the pre-defined ecological indicators were summed to produce a cumulative score for each cell of the study area. Cumulative rank scores range from 0 – 24. A score of 24

signifies high ecological value while a score of 0 indicates low ecological value. The resulting ranked map depicts the spatial distribution of ecologically sensitive areas in the corridor network.

A GIS environment provides an effective platform to integrate diverse data and criteria to evaluate and predict ecologically sensitive areas. The addition of recreation impact data to this equation further complicates the picture. This issue will be further explored in the following section.

3.3 Recreational Impact Model

Humans construct and manage landscapes on the basis of multiple objectives. This model integrates recreation management goals into ecological conservation efforts to evaluate the compatibility of these objectives. Recreation management objectives for the study area are to provide recreational opportunities and protected views (NCC, 1996). To meet growing demands for passive recreation in the planning environment the NCC has committed to continued development of a trail network linking key components and attractions of the park system (NCC, 1993). A recent visitor survey equally reflects demands for an improved trail system, while recognizing the need to regulate access to fragile environments (NCC, 2003).

Corridors represent a small, but critical, area in the preservation of ecological systems. Questions concerning the ability to balance recreational trail use in fragile corridor environments remain unanswered (Simberloff et. al, 1992 in Hess and Fischer, 2001). Heightened impacts may degrade the quality of recreational experiences and result in the loss of ecological connectivity. Trails provide access and recreational opportunities, while concentrating recreation related impacts (Leung and Marion, 1999 b). Balancing ecological and recreational demands in multi-use corridors is assisted by identifying the spatial distribution of ecologically sensitive areas and concentrated recreational impact areas. Identifying the key sensitivities and impacts within corridor areas allows managers to consider tradeoffs and develop effective site design and recreation management policies.

3.3.1 Trail Impact Assessment – General Framework

A large body of research is dedicated to field assessments of recreation related environmental impacts. Relatively fewer studies address the use of advanced spatial technologies in modeling recreation environments (Cole, 1989). This study integrates ecological data with recreation use and impact distributions in a computer-based model to identify potential conflicts. Conventional field methods are paired with emerging technologies to provide a practical tool for corridor design and evaluation.

Field-based trail impact assessment methods have typically employed either a sampling or census survey approach, with few studies combining both. Point sampling methods provide an average estimate of trail condition via measurement of indicators at systematic intervals along the length of a trail (Cole, 1989, Leung and Marion, 1999a, Kutiel et al., 1999). Census-based approaches provide a more detailed account of trail condition via measurements of the location and severity of impact indicators.

The recreation impact model developed in the present study employs a stratified-point sampling method. This method offers a hybrid approach, permitting variation of sampling design across various strata defined by relative susceptibility to degradation. Stratified point sampling employs a two tiered approach, where trail segments susceptible to degradation are first predicted using available trail data. Detailed field surveys of trail impacts are then conducted in these predicted problem areas. This approach yields information ranging from overall trail condition to detailed assessments of potential problem areas. A global positioning system (GPS) was used during trail assessments to determine the spatial distribution of recreation impacts. Spatially explicit recreation data were linked to ecological sensitivity data in a corridor conflict simulation model (CCSim). This process will be further defined in section four of this chapter.

The utility of this approach is highly dependent on the appropriate pairing of method design and management objectives. An expansive study area and limited resources present a challenge to both practical management and current research. The challenge in developing this methodology was to devise a means to evaluate the entire trail network with sufficient accuracy and limited time and financial resources. Prior identification of trail areas susceptible to degradation provides an efficient, yet accurate means of evaluating recreation impacts by focusing efforts on areas of higher risk.

3.3.2 Trail Susceptibility Assessment

Trail susceptibility to degradation is determined by several factors including trail location and function, cover type and level and type of recreational use (Miller et al., 1998; Lajeunesse et al., 1997). Table 3.9 outlines parameters used to evaluate relative susceptibility to degradation. For all parameters higher values correspond to higher risk areas. Parameters and rationale are based on previous studies (Miller et al., 1998 and Lajeunesse et al., 1997). Miller, Collins, Steiner and Cook (2002) developed a method to identify and evaluate areas suitable for greenway development. In this study, areas with the highest recreation capabilities are determined via linkage function (i.e. connected trail system) and level of use (i.e. surrounding commercial/residential land use). Additional parameters, including cover type and type of use, are derived from a recent study conducted by Lajeunesse, Domon, Bouchard and Cogliastro (1997). The previously defined stratified-point sampling method was developed in this study to evaluate and monitor the impacts of recreational use in urban natural areas.

With the exception of use levels, underlying data for trail susceptibility analysis was obtained from the existing NCC recreational trails database (2002). Recent visitor counts within corridor trail areas have not been conducted. Level of use was therefore predicted in a GIS environment using the aforementioned database and the existing NCC land use database (1995). Land use within a

1km radius of individual trail areas was selected and classified as either commercial/residential or other. Percentages of area for each land use category were calculated and ranked according to the thresholds established in table 3.9.

Table 3.9 Trail Susceptibility Rating

<i>Parameters</i>	<i>Criteria</i>	<i>Score</i>	<i>Rationale</i>
Cover	• Stone dust	1	Trails with stone dust or gravel are considered less susceptible than bare soil or vegetation.
	• Coarse Gravel	2	
	• Bare Soil	3	
Type of Use	• Single Use	1	Single use trails are considered less damaging in terms of extent of impact
	• Multiple Use	2	
Linkage	• Not connected to trail network	1	Higher user levels and impacts are associated with linked trail systems
Function	• Connected to local trail network	2	
	• Connected to regional trail network	3	
Level of Use	• <5% commercial/residential land use within 1km radius	1	Higher levels of use are anticipated within higher concentrations of commercial and residential land use.
	• 5-25% commercial/residential land use within 1 km radius	2	
	• >25% commercial/residential land use within 1km radius	3	

Cumulative scores for all trail areas were calculated and used to identify areas subject to recreational stress. Final scores exceeding a value of 5 of a possible 11 point score were

considered to represent high risk areas. Identified problem areas served as the focus of a field-based survey of recreation impacts. Analysis of trail susceptibility uses existing data to predict areas at high risk of trail degradation. Field-based trail impact surveys require substantial time and cost investments. Prior identification of problem areas allows managers to effectively allocate limited resources to predicted problem areas. Focusing efforts in high risk areas may assist managers in the practical management of extensive trail networks.

3.3.3 Trail Impact Analysis

The objective of a trail impact assessment (TIA) is to determine the spatial distribution of impacts and general trail conditions. Priority is assigned to trails classified as susceptible to degradation. Trail impact assessments within predicted problem areas provide detailed information concerning recreation impacts using a relatively simple, rapid survey method (see Figure 3.1).

Sampling was conducted at 50 m intervals along 34 km of predefined problem areas. A hand held GPS, accurate to an average 7 m resolution, was used to measure the sampling interval and provide spatial coordinates for each of the 690 sampling points. Trail condition was evaluated within a 1 –2 m radius of the sampling point. The accuracy of this approach is largely determined by the sampling interval. Leung and Marion (1999a) argue that a sampling interval of less than 100 m provides an accurate⁷ assessment of trail impacts. A 50 m sampling interval was selected in this study to accurately define highly degraded trail segments. Trail surveys were conducted in late summer following the high use season. Trail surveys are intended to provide a ‘snapshot’ of the upper extent of trail degradation within the study area (Hammit and Cole, 1987 in Cole 1989). Resource constraints limit consideration of change over time; this issue will be further addressed in the following chapter.

⁷ A 10% accuracy loss in point-based trail surveys was noted when compared to a base dataset consisting of complete trail census results.

Trail impact indicators yield practical information concerning existing trail conditions to managers. Ecological indicators, ranging from general visual assessments to more specific quantitative measures were used in this study. The choice of indicators is highly dependent on management objectives and resources. The choice of indicators in this study reflects both sustainable tourism concerns and practical constraints (e.g. time, cost, expertise).

The following indicators were used in this study: trail width, wet soils, tread incision, access and/or multiple treads and soil compaction (table 3.10). Numerous research studies support the use of these indicators and provide the underlying rationale for this selection (Kutiel et al, 1999, Lajeunesse et al. 1997, Leung and Marion, 1999a, Mortensen, 1989, Patel and Rapport, 2000). For all parameters higher values correspond to more severe degradation. Threshold values represent a summary of average estimates derived from existing research.

Table 3.10: Trail Impact Analysis Indicators

<i>Indicators</i>	<i>Criteria</i>	<i>Rank Score</i>	<i>Rationale</i>
Tread Incision Segment eroded past initial trail surface	◆ Low 1-15 cm	1	Soil erosion
	◆ Medium 15 – 30 cm	2	
		3	
	◆ High >30 cm		
Access and/or Multiple Treads	◆ None	1	Spatial extent of impacts, increased fragmentation
	◆ 1-2 treads	2	
	◆ 2+ treads	3	

Wet Soils	◆ none	1	Soil erosion, increased
Wet soil covering more than half the trail width	◆ < 0.5 trail coverage	2	incidence of multiple
	◆ > 0.5 trail coverage	3	treads, negative recreation and aesthetic impact
Tree Root Exposure	◆ 0 – 30%	1	Increased tree mortality
Tops and/or sides of root exposed ^a	◆ 30 – 60 %	2	and reduced vigor
	◆ 60%	3	Negative aesthetic impact
Soil Compaction	◆ 1 – 1.5 kg/cm ²	1	Increased run-off and
Measured mid, left and right of trail using a penetrometer.	◆ 1.5 – 3 kg/cm ²	2	erosion, poor root
	◆ 3-4.5 kg/cm ²	3	respiration and water infiltration. Barriers for certain species.

¹ To retain consistent scoring, areas devoid of forest cover were assigned tree root exposure scores derived from a regression analysis of tree root exposure and correlated soil compaction data.

A measure of degradation for each sampling point is calculated by summing rank scores for each of the indicator variables. Cumulative sampling point scores can be used to identify areas of concentrated recreation impacts. Overall measures of degradation are represented by the mean value of all sampling points along a trail segment. Cumulative scores range from 0 – 15, where a score of 15 signifies highly degraded trail areas.

3.3.4 GIS Recreation Impact Map

Point-based trail degradation scores were registered in a digital database according to latitude and longitude coordinates. Having defined spatial coordinates, recreation trail data were then transferred to a GIS environment. Model output is a GIS recreation impact map depicting the spatial distribution and relative severity of recreational impacts in the existing trail system (see Figure 3.1). Prior knowledge of highly concentrated recreational impact areas may assist managers in developing targeted site design and recreation management strategies to avoid unacceptable risks to valuable ecological and recreational resources.

The objective of this study is to evaluate and predict the effectiveness of multi-use corridor strategies. Field-based methods have limited ability to predict recreational impacts. A relatively simple model was developed, integrating field derived trail data in a GIS environment, to predict future recreational impacts. Recent NCC policy outlines plans for a multi-use trail (i.e. The Spine Trail) connecting the various natural areas located in the Greenbelt. Partial construction of this proposed trail network is already underway. Average trail scores derived from completed trail segments were used to predict potential impacts along the proposed Spine Trail route. Trail characteristics, including trail width, cover type and type of use, were employed to further inform impact predictions. The resulting map depicts predicted trail degradation along segments of the proposed trail located in the corridor study area.

Limited consideration of more complex variables (e.g. predicted recreation and urban growth trends) represents a limitation of this method and further illustrates the necessary tradeoff between model complexity and predictive capability.

Despite noted limitations, the practical utility of this model rests in the ability to accurately and efficiently evaluate and predict the spatial distribution of potential recreational impacts. A simple,

flexible model design provides a practical tool for managers faced with threats of ecological and recreational degradation within a shared resource base. The ability to identify and predict conflicts between fragile environments and high use recreational areas represents an invaluable and necessary tool in the effective management of multi-use environments. The following section will outline the integration of ecological and recreational components in a spatial decision support model (DSS).

3.4. Decision Support System – Corridor Conflict Simulation Model

3.4.1 Corridor Conflict Analysis

Growing recreation demands, threats to ecological quality and scarce resources challenge managers to devise creative solutions to balance competing demands in shared resource management. Demands for integrated, interdisciplinary approaches to corridor design and evaluation are increasingly recognized in natural areas planning policies. The widespread popularity of this approach has left managers with a heavy burden. Practical implementation and evaluation tools are lacking, causing many to argue that today's managers are ill-equipped to handle the complex demands of multi-use management (Bishop and Hulse, 1994; Bishop and Gimblett, 1999; Cohen, 2002). While many remain pessimistic, others point to new hope stemming from recent advances in spatial technologies.

This study integrates diverse data in a decision support system (DSS) to evaluate feasibility of stated management goals. A DSS provides a means of structuring complex spatial analysis and linking diverse model components to evaluate management alternatives with limited resource investments. The flexibility of this system enables the integration of disparate recreational impact and ecological sensitivity data and subsystems. DSS model output is a series of maps depicting conflicts between recreational trail use and critical conservation areas.

Maps depicting ecological sensitivities and recreation trail impacts were combined in a GIS environment to identify existing and potential use conflicts or 'hotspots' (see Figure 3.1). By examining the spatial patterns of trail degradation against a backdrop of ecologically significant areas it is anticipated that potential conflicts will become apparent. A query of the newly integrated database identified areas of concentrated recreation impacts within a 50 m radius of ecologically sensitive sites. Existing research indicates that a 100 m buffer is required to maintain visual aesthetics and minimize species disruption in highly concentrated impact areas. Although sensitivity levels vary, a 100 m buffer is often adequate to shield both humans and wildlife from disruptive impacts (Brunson, 1996; Xiang, 1998).

Trail degradation and ecological sensitivity thresholds were derived from similar research in this field (Lajeunesse et al., 1997, Rowsell, 2003). Highly degraded trail segments possess cumulative scores exceeding a value of 8 out of a possible 16. Similarly, ecological sites were considered highly sensitive when exceeding a cumulative value of 15 of a possible 24. Conflict areas or 'hot spots' occur when these thresholds are surpassed within the predefined 100 m buffer area.

A similar method was used to predict future conflicts in the study area. A map of predicted ecologically sensitive areas within the optimal corridor network was integrated with a map of predicted trail degradation scores for the proposed Spine Trail. The resulting map was used to identify potential future conflicts or 'hotspots' in the optimal corridor network. The ability to predict and balance future ecological and recreational demands will determine the long-term feasibility of this planning strategy.

Considerable confusion surrounds the role of corridors in landscape management. Understanding complex relationships between the recreational and ecological use of these areas is critical to management efforts. Improved decision-making is highly dependent on the extent to which these relationships can be explicitly and quantitatively defined (Meitner and Daniel, 1997).

Conflict analysis may assist in identifying management strategies to reduce degradation without restricting recreational use, including diverting trails around sensitive areas or improving the durability of concentrated impact areas (Harris et al., 1995). Improved trail design and management represents a cost-effective, long-term sustainable tourism strategy.

3.4.2 Visualization of Results

Improved understanding and prediction of multi-use environments is only half the battle. Publicly accountable decision-making requires effective communication of management alternatives. Visualization is the interactive representation of data to enhance understanding and communication and make problems more visible (MacEachren, 2001). The addition of visualization tools in the form of an animated map sequence enhances the visibility and understanding of conflict analysis results. Visualization tools can equally support the communication of results amongst diverse user groups in the planning environment (e.g. government, researchers, public).

A critical question remains: what is the most suitable method of representation? Various visualization tools have been used to facilitate decisions concerning management problems and solutions (Fairbairn, 2001). In the present study, cartographic zoom tools were used to adjust the level of detail in map displays. Conflict analysis maps for the existing and optimal network were transferred to a standard image format (JPEG). Animation software was used to pan across the Greenbelt and 'zoom in' to predicted 'hotspots.' Better communication of problem areas and site specific 'hotspots' could assist managers in developing guidelines and targeted strategies. Tradeoffs between competing uses are often necessary; the ability to clearly communicate alternatives may foster public support and awareness of sustainable recreation and tourism efforts.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

Growing outdoor recreation demands in the Ottawa region have placed new pressures upon park resources. A multi-use corridor strategy has received wide support from the local planning community, researchers and the general public as a potential policy solution to existing recreation management problems (NCC, 1993). Understanding the interaction between recreation and conservation priorities is essential to the effective design and management of these natural areas.

Use conflicts threaten the effectiveness of this policy. The National Capital Commission (NCC) acknowledges the shortcomings of the existing corridor system, recognizing the need for site specific management plans (NCC, 1996). The success of this policy hinges on the ability to negotiate potential conflicts and tradeoffs in future planning decisions.

Advanced spatial technologies are applied here to explore complex human-environment interactions within the Ottawa Greenbelt. The decision support model developed in this study integrates environment and recreation data to identify and communicate potential conflicts amongst key site values. Results of this study may assist local planning authorities in developing targeted strategies and guidelines for corridor management. The potential exists to apply this model to broader issues facing multi-use management.

Applied model results are presented in several sections. In the first section, results obtained in the ecological assessment of the study area are presented. The second section presents results obtained in the recreational impact analysis. Pulling these threads together, the third section will examine the distribution and implications of use conflicts in the NCC Greenbelt corridors. The corridor conflict simulation model (CCSim) is forwarded as a tool to assist the design and management of shared resources. Concluding remarks will examine remaining limitations and point to the potential benefits of this model in the study of complex human-environment systems.

4.2 Ecological Sensitivity Model Results

4.2.1 Ecological Sensitivity Model: General Framework

NCC ecological goals outline the intended role of corridors in facilitating flora, fauna and water movement and maintaining the healthy diversity of natural areas within the Greenbelt. The ecological component of this system (see figure 3.1) was designed to identify key conservation sites critical to the attainment of this goal. Existing GIS 'tools' were adapted for use with this model. Raster (Figure 4.1) and vector (Figure 4.2) processing of diverse land use and landcover data was performed to predict the ecological value of individual landscape patches.

Structural indices were used to quantify spatial landscape attributes and operationalize stated ecological goals. A common ranking scheme is applied across all indicators. Analysis results for individual indices are examined prior to exploring how these pieces fit together to predict conservation priorities in the Greenbelt corridors.

4.2.2 Ecological Sensitivity Model: Results by Indicator

Connectivity

Corridors of continuous forest cover, which represent structural connectivity, between otherwise isolated natural areas enhance both species persistence and large-scale ecosystem processes (Wegner and Merriam; 1979 in Fahrig 2000; Cook, 2002). The proximity of adjacent woodland boundaries was used to quantify structural connectivity in this study. Rank values were assigned to individual patches in accordance with previously defined thresholds (table 3.3). Analysis results are presented in a raster-based map depicting the spatial distribution of connected patches in the study area (Figure 4.3).

High levels of connectivity were found across the study area. High ecological values were assigned to approximately ninety-five percent (19 km²) of all woodland areas (20 km²) located in the study area.

Figure 4.1: Ecological Database - Raster

Figure 4.2: Ecological Database - Vector

Figure 4.3: Spatial Distribution of Forest Connectivity and Forest Interior

A large forested tract extends from Shirley's Bay to Stony Swamp providing a critical linkage between these two core areas. Populations are often healthier in areas where forested patches are grouped closely together. The close proximity of woodland patches in this area offers significant habitat potential for a variety of forest-dependent bird populations (OMNR, 2000). The major highway corridor traversing this corridor, however, largely restricts opportunities for mammal dispersal, although a railway overpass that traverses the highway corridor may serve as an alternative dispersal route.

Part of the same general highway corridor, much farther to the east, disrupts a block of continuous forest cover extending from Pine Grove to Mer Bleue. Use of this dispersal route, extending from Pine Grove to Mer Bleue, is primarily restricted to bird populations. Lack of forest cover in the Black Rapids Creek and Airport corridors restricts the ecological function of these areas. Resulting threats to water quality and wildlife habitat will be further discussed in the following sections.

Forest Interior

Forest interior habitat supports a wide diversity of wildlife and is consequently recognized as a strong indicator of overall ecological health (OMNR, 2003). The persistence of rare local species, including the red shouldered hawk and the river otter, is highly dependent on the preservation of interior habitat (Environment Canada, 1998 in Rowsell, 2003). Forest interior was quantified by removing successive edge areas to reveal remaining 2-hectare forest 'cores'. Rank values were assigned in accordance with previously defined thresholds (table 3.4). Analysis results are presented in a 10 m resolution raster-based map depicting the spatial distribution of forest interior habitat in the study area (Figure 4.3).

Minimal forest interior habitat is predicted in the Greenbelt corridors. Medium to high ecological scores are assigned to less than five percent (0.6 km²) of woodlands in the study

area. Remaining sites, for the most part, fall far below this threshold. Infrastructure corridors, servicing expanding satellite communities, traverse the Greenbelt resulting in severe habitat fragmentation. For example, a major transportation route (Carling Avenue), servicing an outlying community (Nepean), transects a forested tract in the Shirley's Bay corridor significantly reducing forest interior area. A similar example is found in the Mer Bleue corridor where a major road (Anderson Road) transects a large forested tract. Increasing fragmentation of the Greenbelt accounts for the low occurrence of forest interior habitat.

Despite increasing fragmentation, significant forest interior areas are scattered throughout the study area. Small forest interior patches, located adjacent to Shirley's Bay wetland and Stony Swamp, provide important extensions of adjacent habitat areas. Provincially rare forest interior bird species (e.g. northern goshawk) have been identified in these areas (NCC, 1991). Concentrated areas of forest interior adjacent to the Mer Bleue Bog are identified as the sole habitat area for numerous provincially significant bird species (e.g. hermit thrush) in the Greenbelt. Isolated patches of forest interior are also found in the south-west corner of the Black Rapids Creek corridor, although the nature of forest cover in these areas (i.e. intolerant hardwoods and pine plantations) restricts the ecological value of this site (NCC, 1991). Small forest fragments, characteristic of this area, may limit the reproduction of forest-interior bird species (Harris and Scheck, 1996).

Riparian Forests

Riparian forests are a highly valued component of the Greenbelt ecological network extending numerous benefits including erosion and flood control, water quality preservation and protected dispersal corridors for select species (Fry et al., 1994). Previously defined rank values were assigned to woodland patches indicating the relative proximity of these areas to streams,

rivers and lakes (table 3.5). Analysis results are presented in a 10 m resolution raster-based map depicting the spatial distribution of riparian forests in the study area (Figure 4.4).

High priority riparian forests comprise over 10 percent (2.5 km²) of the total study area. Riparian areas are critical to the persistence of numerous wildlife species (Wright and Tanimoto, 1998). A minimal 10-m corridor width is required to support the dispersal of large and small mammals. Conservation priorities are therefore assigned to woodlands located within 10 m of a water feature. These areas are located adjacent to Shirley's Bay wetland and Mer Bleue Bog and within Pine Grove.

The notable absence of forest cover in the Black Rapids Creek and Green's Creek riparian corridors has been cited as a contributing factor to poor water quality and habitat damage in these areas (NCC, 1991). Water quality is often improved by riparian forests, which remove nutrients from the soil and in the process remove various pollutants such as nitrates and heavy metals (Harris and Scheck, 1996). Increasing nutrient input and erosion linked to livestock operations in the Green's Creek area threaten water quality and significant fish habitat. Riparian forests also trap sediment, reducing sediment loads and turbidity in watercourses. Increased silt loads, associated with expanding development in the Green's Creek area, threaten significant fish habitat. The limited spatial extent and generally high economic land value of riparian corridors may present an obstacle to the conservation of these areas.

Wetland Forest Buffers - Proximity to Wetlands

The Greenbelt houses two provincially significant wetlands in Shirley's Bay and Stony Swamp and an internationally significant wetland in Mer Bleue. Critical ecosystem functions including watershed management, flood control and species habitat provision are supported by these wetlands.

Figure 4.4: Spatial Distribution of Riparian Forests and Wetland Forest Buffers

The conservation of these areas represents a major priority for local management authorities. Previously defined rank values were assigned indicating the relative proximity of adjacent woodland and wetland boundaries (see table 3.6). Analysis results are presented in a 10 m resolution raster-based map depicting the spatial distribution of woodlands in close proximity to these wetland areas (Figure 4.4).

Conservation priority sites correspond to areas located within 40 m of a wetland boundary. Less than 10 percent of the total study area (1.6 km²) is considered to represent a high conservation priority with respect to this indicator. As would be expected, these areas are located adjacent to identified wetland habitats. Although limited in spatial extent, these sites serve a critical function. Forested areas provide a protective buffer for highly valued wetland habitats. As previously noted, numerous rare plant and animal species are housed in the wetland habitats of the Greenbelt. Forested buffers are critical to the persistence of species requiring large wetland areas to sustain existing populations (e.g. least bittern, spotted turtle etc.).

Forested buffers are well distributed throughout corridor areas, as well as other protected areas (i.e. core and buffer areas) surrounding the Mer Bleue wetland. Private ownership of areas outside of the Greenbelt may pose problems in the future. If developed, resulting changes to water levels could affect a significant proportion of the wetland habitat. Forested buffers are notably absent in the Shirley's Bay corridor. The absence of a forested buffer along the southern boundary of Shirley's Bay poses a significant threat to sensitive wetland species (e.g. loggerhead strike) within in the area.

Relative Road Density

Relative road density measures the level of human disturbance and associated habitat disruption (table 3.7). Major roads pose a significant barrier to the dispersal of numerous

species. The preservation of continuous habitat, protected from the disruptive impacts of major road systems, is critical to local conservation efforts. Assuming a standard road width of 30m, relative road density was calculated using a moving window technique with a 1km² spatial filter. Analysis results are presented in a 30-m resolution raster-based map depicting the spatial distribution of road density in the study area (Figure 4.5).

Major road systems transect all corridors in the Greenbelt. Numerous transportation routes servicing outlying satellite communities disrupt habitat and ecosystem continuity. Concentrated areas of high road densities are noted north of Stony Swamp and between Pine Grove and Mer Bleue Bog, where a major highway corridor is located. Corresponding habitat areas and linkages are effectively severed for species sensitive to the disruptive impacts of road systems.

Roadways, which fragment otherwise connected habitat, serve as a barrier in numerous ways. Changes in humidity, wind speed, evaporation rates and noise levels may cause sensitive species to avoid roadside environments. Studies show the effects that roads have on the movement and mortality of wildlife (Forman, 1996; Harris and Scheck, 1996). Associated noise levels have been shown to negatively affect birds (reduced nesting, etc.). Additional disruption stems from the introduction of invasive species in roadside environments (Harris and Scheck, 1996). Roads traversing the Shirley's Bay and Mer Bleue corridor serve as a major source of habitat disruption and species mortality for numerous rare species located in the adjoining habitat areas.

Bird Community Index

The Greenbelt provides a diverse habitat for a variety of species, several of which are currently listed amongst the Canadian Species at Risk (OMNR, 2000). The Bird Community Index relates the type of bird community inhabiting an area with the surrounding land use. Songbirds represent the target species for this analysis.

Numerous studies support the use of songbird populations as an effective indicator of habitat values important for various wildlife populations ((Noss, 1990; Karr and Chu, 1997) in O'Connell, et al., 1998; etc.). Rank values are assigned based on previously defined thresholds (table 3.8). Analysis results are presented in a 30-m resolution raster-based map depicting the spatial distribution of valued habitat areas (Figure 4.5).

Predicted areas of high habitat suitability comprise approximately thirty-five percent (7 km²) of the total study area. Valued habitat sites located adjacent to Shirley's Bay wetland support numerous nationally, provincially and regionally rare bird species (e.g. evening grosbeaks, pine warbler, etc.), as well as providing significant fish and wildlife habitat. The significance of these sites for migratory bird populations and regionally rare wildlife species (e.g. map turtle and river otter) has been noted in previous studies (NCC, 1991). High habitat values are additionally predicted in sites abutting Stony Swamp and Mer Bleue Bog. The diversity of habitats and close proximity of woodlands in these areas are considered to be of significant habitat value providing nesting sites for a number of threatened species (e.g. henslow sparrow) (NCC, 1991).

Predicted habitat values in the Pine Grove area are of questionable reliability. Although this area supports numerous bird populations, limited potential exists for broader habitat uses. The predominance of young pine plantations explains the relatively limited presence of wildlife in this area. Critical distinctions in forest stand properties, including age and species type, are not considered in the Bird Community Index. Failure to address these factors represents a major limitation of this analysis and raises broader concerns regarding the accurate prediction of habitat suitability.

Figure 4.5: Spatial Distribution of Habitat Areas - Relative Road Density and Bird Community Index

4.2.2.1 Ecological Sensitivity Model: Composite Results

The ecological sensitivity model provides a means to assess broad ecological conditions across diverse environments. The results of individual indicator analyses were combined in a composite GIS-based map to accurately predict critical conservation priorities in the corridor network. The contribution of individual indices to cumulative ecological scores varies significantly. While connectivity values indicate a high percentage of priority conservation sites (95%), forest interior values are considerably lower (5%). All remaining indicators exhibit a relatively equal distribution of high to low ecological scores.

Despite considerable variance amongst individual indicator results, a persistent spatial pattern begins to emerge where high priority conservation sites (i.e. ecologically sensitive areas) are consistently identified adjacent to Shirley's Bay, Stony Swamp and Mer Bleue Bog. Conservation priority is assigned to areas of medium-high to high ecological values considered sensitive to further disruption and/or degradation.

As previously noted, the purpose of the ecological sensitivity model is to identify conservation priorities within the corridor network. Analysis outputs for each of the pre-defined indicators were assigned equal weightings and combined to produce a cumulative ecological score⁹ for all cells in the study area. The resulting map (Figure 4.6) depicts the spatial distribution of predicted ecologically sensitive areas located in the study area. As noted in the previous section, key ecological sites are concentrated in areas adjacent to Shirley's Bay, Stony Swamp and Mer Bleue Bog. The site-specific significance of these areas with respect to both ecological functioning and wildlife preservation has been well documented in this chapter.

⁹ Cumulative scores range from 0 to 24, where a score of 17-24 signifies a high ecological value, a score of 9-16 indicates an average score and a score of 0 -9 indicates a low ecological value

Figure 4.6: GIS Ecological Sensitivity Map

Management goals outline plans to maintain ecosystem functioning through a connected system of natural areas. Corridors are intended to facilitate the movement of flora, fauna and water between significant natural areas both within and outside of the Greenbelt (NCC, 1996). Shortcomings of the existing corridor network have been acknowledged by the National Capital Commission (NCC, 1996). Important wildlife dispersal routes, habitat areas and ecosystem processes are often placed at risk of degradation within existing corridors. Both roadways and forest clearances constitute major sources of habitat fragmentation in the study area. The absence of forested buffers surrounding significant riparian and wetland environments poses an additional threat to species persistence and water quality. Sites of significant ecological value are sparsely distributed throughout the existing corridor environment. To meet stated management goals limitations of the existing corridor network must be addressed in future planning and management decisions.

Changes to both the quality and quantity of corridor sites are required to meet management goals and preserve ecologically valued components of the Greenbelt. Widely supported corridor design principles (see section 3.2.1) were used to construct an 'optimal' corridor scenario. Numerous factors and data sources were considered in the design of this system. Guidelines were established based on a thorough review of corridor research. Optimal corridor design enhances the structural connectivity¹⁰ and viability of the landscape for a wide range of species and ecosystem processes. Ecological viability and resilience are enhanced through extended riparian buffers, increased corridor widths and the removal of existing gaps and barriers. An optimal

¹⁰ The use of structural indices in conservation design is widely supported in research (Harris et al., 1996; Beier and Noss, 1998).

corridor scenario is used to predict the impact of future corridor design and management alternatives. Figure 4.7 depicts an optimal corridor design for the NCC planning environment.

Figure 4.7: Optimal Corridor Design

The previously noted absence of forest cover along critical riparian corridors threatens both water quality and species persistence in the Greenbelt. Potential exists to develop riparian vegetation within corridors located along the Ottawa River, Rideau River, Jock River and Black Rapids Creek. Where possible a 50 m buffer¹¹ should be established on either side of these watercourses. The numerous benefits of riparian forests in terms of water quality and species mobility have been previously documented in this chapter. Protected riparian corridors may also enhance landscape connectivity by connecting core natural areas in the Greenbelt with significant outlying natural areas (e.g. Marlborough Forest, Osgoode Bog and Cumberland Forest).

Additional changes include adjustments to the boundaries of existing core natural areas. Boundaries should be extended to include previously identified priority conservation sites adjacent to Shirley's Bay, Stony Swamp and Mer Bleue Bog. Suggested changes in forestry practices within Pine Grove, whereby coniferous plantations would eventually be converted to mixed hardwood stands, may also improve the ecological potential of this area (NCC, 1991).

Changes in corridor design and management demonstrate the potential to yield significant improvements over the existing corridor system. Parallel landscape and wildlife analyses were conducted to identify and predict existing and future ecologically valued areas. Analysis outputs for each of the pre-defined ecological indicators were summed to produce a cumulative score for each cell of the study area. Cumulative rank scores range from 0 – 24.

Figure 4.8 compares ecological values across the various landscape and wildlife indicators used in this study. Improvements in both corridor quality and quantity are evident. The addition of critical riparian buffers and extended corridor boundaries account for a fifty percent increase in corridor areas. Medium to high value ecological areas are predicted to increase significantly with

¹¹ Riparian buffer widths may vary in accordance with existing land use (e.g., natural vegetation boundaries, existing urban land use, etc.)

respect to both riparian forests and forest connectivity in the optimal corridor network. Continuous forest cover and riparian buffers provide significant ecological benefits. Improvements in corridor design may enhance the movement of flora, fauna and water in the study area. A general increase in corridor quality, evident in improved ecological scores across indicators, is additionally noted.

Figure 4.8: Existing vs. Predicted Ecologically Valued Areas

Required changes often fall outside of the NCC planning jurisdiction. The overall feasibility of this scenario is challenged by current land use and ownership issues. For example, recent plans to extend the Shirley's Bay and Mer Bleue Bog areas by approximately 700 hectares to reflect natural watershed boundaries are complicated by private ownership of these areas (NCC, 1999). Despite remaining challenges, an optimal scenario provides a valuable starting point for future ecological management plans.

Previous efforts to link quantitative ecological criteria and targeted planning goals have been limited. The ecological sensitivity model offers a generic modeling tool to identify critical conservation sites. The use of this model to assist existing and future corridor planning strategies is suggested in this study. Identifying conservation priorities is only half the battle. In addition to local conservation initiatives, outdoor recreation is highly encouraged in Greenbelt corridors. Growing recreation pressures challenge managers to find new ways to balance competing ecological and recreational demands. Identifying potential conflicts between recreators and ecologically sensitive areas represents a critical step forward in the successful implementation of a multi-use planning policy.

4.3 Trail Impact Analysis Model

4.3.1 General Framework

Recreational stress associated with high use trail networks threatens both ecological and aesthetic site attributes. Examining degraded trail sites against a backdrop of ecologically sensitive areas assists in identifying critical use conflicts. The trail impact analysis (TIA) model employs a stratified sampling design to evaluate trail conditions within predicted high-risk areas. Detailed surveys of numerous impact indicators (e.g. multiple treads, tread incision, wet soils, tree root exposure and soil compaction) were conducted at 50 m intervals in predicted problem areas

following a high use season. Model output is a vector-based map depicting the spatial distribution of recreation impacts within the trail network of the study area.

4.3.2 Trail Susceptibility Assessment

Prior identification of high-risk impact areas provides an efficient means of surveying trail conditions across an extensive study area with fixed resources. Susceptible trail areas are defined as areas at high risk to degradation. Several indicators have proven useful in identifying these areas (e.g. cover type, type of use, level of use and linkage function) (Lajeunesse et al., 1997). Trail susceptibility was evaluated on the basis of these indicators using readily available trail data.

Predicted use levels required the consideration of both recreational trail data and urban land use data. Research indicates that high use recreational areas are concentrated in commercial and residential areas (Lajeunesse et al., 1997). The percentage of commercial and/or residential land use within a 1-km radius of trail areas was used to predict recreational use levels within the study area. Figure 4.9 depicts the results of this analysis. High levels of use are predicted in the Shirley's Bay and Green's Creek areas, where adjacent commercial/residential land uses account for 26% and 11% of the total land use respectively.

Cumulative rank scores across all indicators were calculated to predict trail susceptibility. Table 4.1 provides a summary of results for predicted high-risk trail segments. Predicted high risk areas¹² correspond to the following trail characteristics: regionally connected all season trails with bare soil cover located in concentrated areas across the study area.

¹² High-risk areas are defined for trail segments where cumulative scores exceed a value of 6 of a possible 11 point score.

Figure 4.9: Predicted Level of Trail Use – Adjacent Commercial and Residential Land Use

Table 4.1: Trail Susceptibility

Trail Number (NCC)	Length (m)	Width (m)	Sector	Level of Use Score	Trail Cover Score	Trail Type	Linkage Score	Total Susceptibility
a-10	4171	0.3 - 1.4	Shirley's Bay	1	3	2	1	7
b-11	2780	0.8	Shirley's Bay	1	3	2	2	8
b-12	1489	0.8	Shirley's Bay	1	3	2	1	7
a-11	860	1.7	Shirley's Bay	1	2	2	2	7
a-12	1950	0.5	Shirley's Bay	3	3	2	2	10
l-40	800	.8-4	Pine Grove	2	3	1	1	7
l-41	1710	0.8	Pine Grove	2	3	1	1	7
l-42	974	0.8	Pine Grove	2	3	1	1	7
o-50	4570	2.7	Mer Bleue	1	3	2	2	8
o-51	3300	0.2-3.6	Mer Bleue	1	3	2	2	8
o-52	2910	1.7-2.7	Mer Bleue	1	3	2	2	8
s-61	1.05	1.3	Green's Creek	2	3	2	2	9
s-62	100	N/A	Green's Creek	2	3	1	2	8
s-63	250	N/A	Green's Creek	2	3	1	2	8
s-64	1000	3.5	Green's Creek	2	1	2	2	7
s-65	1250	3	Green's Creek	1	2	2	2	7

The accuracy of predicted trail susceptibility is highly dependent upon the validity of underlying data and relevance of selected indicators. Predicted high-risk areas largely correspond to identified areas of actual trail degradation with the exception of trails located in the Green's Creek area. Despite predicted high trail risk in this area, minimal site degradation was identified in subsequent trail surveys. Further discussion of limitations related to predictive capability is undertaken in the concluding remarks of this chapter. Despite noted limitations, trail susceptibility predictions provide an efficient means of targeting recreation impacts in an extensive trail system.

4.3.3 Trail Impact Analysis

Visitor perceptions of site degradation often remain fixed long after restoration efforts are complete. The purpose of a field-based trail impact survey is to locate recreation impacts within predicted problem areas. Detailed field surveys were conducted in problem areas employing numerous indicators of trail condition. A hand held GPS was used to define the spatial coordinates for each sampling point. Geospatial coding allowed survey results to be transferred to a GIS environment for subsequent analysis. Identified spatial patterns of recreation impact may assist managers in devising preventative strategies to avoid further loss of ecological and recreational site values in these areas.

Prior to examining broader recreation impact distributions, it is first important to understand the underlying causes of trail degradation in these areas. Figure 4.10 displays the contribution of individual indicators to cumulative trail degradation scores. Across all trail areas a consistent pattern emerges where soil compaction is found to be a major contributor to trail degradation. Environmental impacts associated with recreational activity are often first revealed in damaged soil conditions (Kutiel et al., 1999). Higher risks of degradation are associated with bare soil trail cover, relative to coarse gravel, stone dust or asphalt cover. Soil compaction readings were taken in the upper soil layer. Soil compaction reduces the organic matter and litter in the upper soil layer and contributes to increased runoff and erosion and poor root respiration and water infiltration.

Highly compacted trail segments may additionally pose a barrier to sensitive species. Microclimatic changes such as increased sunlight and wind and altered temperature regimes have been documented within the edges of forests adjacent to clearings. Similar impacts may occur along a forest trail wide enough to open up the canopy (Cole, 1989). These microclimatic alterations could disrupt both plant species and wildlife. Negative impacts on breeding birds have been caused by recreational trails as narrow as 1-3m wide in forested areas (Miller et al., 1998).

Negative impacts may include a decline in nesting near trails, altered bird species composition near trails, and increased nest predation by cowbirds, skunks, raccoons and foxes using the clearings as dispersal routes. Bare soil trails may also impede wildlife dispersal for sensitive species that are reluctant to cross openings (Saunders and Hobbs, 1991).

Figure 4.10: Trail Impact Scores: Contribution by Indicator

Notably lower soil compaction levels were found in the Pine Grove area. Organic soil matter is largely related to surrounding vegetative cover. Pine Grove is heavily populated with early pine plantations. Upper soil layers associated with these stands generally contain a high concentration of lignin and a thick layer of litter making them particularly resistant to decomposition. Soils found in these areas are, therefore, more resilient to recreational stress associated with soil compaction than soils associated with broad-leaved mixed or deciduous stands (Doubleday, 2004; Kutiel et al, 1999). Future studies targeting the specific impacts of recreation stress on soil and vegetation

properties (e.g. cover, height, species richness and diversity) would provide a future complement to this research. Recreation impacts linked to individual indicators are otherwise evenly distributed across the study area.

Cumulative degradation scores for each sampling point were calculated and transferred to a GIS environment. TIA model output is depicted in Figure 4.11 displaying the spatial distribution of trail impacts across the study area. A summary of mapped information is provided in Figure 4.12. While average trail scores tend to mask details concerning concentrated impact areas, maximum impact scores reveal a different story. Maximum impact figures reveal a high concentration of severe trail degradation in the Mer Bleue Bog area, where trail scores frequently climb into the upper ranges of the scoring system indicating major degradation at these sites. To a lesser extent, degraded trail sites were also concentrated in areas adjacent to Shirley's Bay and Stony Swamp core natural areas. High maximum impact scores found in these areas correspond to results obtained in previous studies where increased demand for recreational opportunities in the Greenbelt has been targeted as a primary concern within existing natural areas (OMNR, 2000).

The TIA model developed for this study provides a snapshot of existing trail conditions. Field based methods possess limited ability to predict future recreation impacts. To overcome this limitation a relatively simple GIS based model was developed to predict the impact of the planned multi-use pathway for the study area. Construction is already underway on a 56-km trail connecting various natural areas and trail systems in the Greenbelt. Aligned within the current corridor system the Spine Trail is intended to provide sustainable tourism opportunities and alleviate increasing recreational pressures in the area. Figure 4.13 displays the planned route and potential impacts¹³ of the Spine Trail. Although detailed predictions are beyond the scope of this

¹³ Predicted trail impact scores range from 4 to 7 as depicted in figure 4.13

model, broad inferences can be drawn. Minimal degradation is likely to be associated with the planned trail, largely due to proposed trail construction and design.

Figure 4.11: Spatial Distribution of Recreation Trail Impacts

Coarse gravel and stone dust will be used to reduce degradation linked to soil compaction and tread incision. A wide, well-defined path minimizes, and may additionally reduce, the incidence of multiple treads and access trails. Predicted high-risk areas correspond to existing patterns of degradation where recreational stress is highly concentrated in high use areas adjacent to Shirley's Bay and Stony Swamp.

Figure 4.12: Recreation Trail Impact – Greenbelt Sector Summary

Results obtained in this study demonstrate the practical utility of a TIA model. Benefits are derived from the provision of a simple, yet accurate tool to target sites of high recreational stress. Having identified ecologically sensitive areas and recreational pressures within the study area, one critical step remains. Multi-use planning policy seeks to balance these demands in a comprehensive land use plan. Judging the relative success or failure of this plan requires

assembling ecological and recreational information to reveal a broader pattern of either compatibility or conflict.

Figure 4.13: Predicted Recreation Impact of the Planned Trail System

4.4. Decision Support Systems – Corridor Conflict Model

The corridor conflict model (CCSim) is advanced as a prototype tool to assist shared resource management by identifying conflicts between recreators and key ecological values. Maps depicting spatial distributions of ecological sensitivities and recreational trail impacts were combined in a GIS environment to identify existing and potential use conflicts or 'hotspots'. By examining trail impacts against a backdrop of ecologically sensitive areas it is possible to identify areas where recreational activity encroaches upon sensitive environments. Critical habitat and ecological functions are jeopardized by excessive recreational trail use. Improved site design and recreation management strategies are required to mitigate ecological and aesthetic quality losses in conflict areas.

Results of the conflict analysis (Figure 4.14) depict an increasingly familiar pattern. User conflicts are highly concentrated in areas adjacent to the Mer Bleue Bog, with a lesser concentration occurring in areas adjacent to Shirley's Bay Wetland and Stony Swamp. High use trails exert significant pressure on ecologically valued sites located in the Mer Bleue area. Highly degraded trail segments possess cumulative scores exceeding a value of 8 out of a possible 16. Similarly, ecological sites were considered highly sensitive when exceeding a cumulative value of 15 of a possible 24¹⁴. Conflict areas or 'hot spots' occur when these thresholds are surpassed within the predefined 100 m buffer area.

In total, 21 hotspots fall within this relatively confined area accounting for approximately two thirds of all predicted conflict areas (Figure 4.15). Unique environments draw increasing numbers of outdoor recreationalists. A recent NCC survey indicates that visitor satisfaction is most strongly related to natural environment features (e.g. wildlife viewing opportunities).

¹⁴ Trail degradation and ecological sensitivity thresholds were derived from previous research studies (Lajeunesse et al., 1997, Rowsell, 2003).

Figure 4.14: Spatial Distribution of Recreation and Ecological Conflicts - Hotspots

Over 85% of trail users surveyed support restricted access to fragile ecological areas when deemed necessary to preservation efforts (NCC, 1999). The Mer Bleue area is highly susceptible to recreation-related impacts. As previously noted, this area is a valuable component of the existing ecological network supporting numerous plant, animal and bird communities of national, provincial and local conservation significance. Critical ecosystem functions, including watershed management and flood control, are additionally dependent upon the preservation of this area.

Failure to effectively monitor and respond to mounting conflicts within this site may ultimately extract a heavy price. High costs are associated with site restoration. Poor site design and visitor management policies can result in serious damage to valued ecological and social assets. Failure to effectively address these problems through targeted management strategies raises doubts concerning the future success of proposed multi-use policies.

'The levels at which loss of valued attributes of the environment begin to occur clearly depends on the planning and management of the site' (Manning, 2003). NCC rules and regulations are intended to secure the future viability of natural areas and ensure a high quality visitor experience. Existing site design and regulations in identified hotspots fall short of necessary measures. Regulations, including restricted access for domestic animals during the winter season, are primarily designed to prevent user conflict rather than ensure site conservation. Sparse boardwalks located along segments of the Mer Bleue trail system do little to protect the surrounding environment. The intermittent nature of these protective measures and lack of monitoring efforts has contributed to the poor performance of recreation management strategies in this area.

Figure 4.15: Corridor Conflicts – Greenbelt Sector Summary

Sensitive trail alignment, construction and zoning restrictions can assist in providing safe and ecologically sound access to these areas. Reduced conflicts are largely the result of zoning measures, where recreational access to ecologically valued sites is controlled or restricted (e.g. domestic animal restriction, boardwalk construction, trail closure). Proposed trail routes are also realigned to avoid sensitive habitat areas. Recently adopted NCC guidelines are reflective of this type of forward thinking, where all areas deemed to contain ecologically significant features are designated as Valued Ecosystem Components (VEC). Recreation and tourism activities are subsequently controlled and/or restricted in these areas. The benefits of these proposed measures remain uncertain, as practice lags significantly behind policy.

Results of this study indicate a heightened threat to key resource values in areas where recreational pressures exceed natural thresholds. The successful implementation of a multi-use corridor policy is jeopardized by the absence of effective monitoring and management strategies in the study area. Devising new management 'tools' to improve the understanding and communication of inherent tradeoffs in complex systems represents a necessary step forward in park management.

An integrated DSS, linking emerging technologies in a 'spatial analysis toolkit', provides managers with the necessary resources to make effective decisions regarding shared resources. An ideal model linking complex systems that can be readily applied across diverse settings does not exist. As such, the CCSim remains limited by several conceptual and technical issues outlined in the following section

Complexity vs. Generalization

A model that defines interactions between diverse variables can facilitate the management of complex systems (Gimblett et al., 2001). The CCSim is forwarded as a prototype tool to assist managers by linking diverse data and model components. The flexibility afforded in this model requires a certain degree of abstraction to effectively link 'real world' objectives and adapt tools to management problems beyond the initial application. The complex nature of visitor and species travel patterns has a significant effect on the distribution of recreation-related impacts in corridor systems. Consideration of these variables requires extensive, site-specific social and ecological information. Failure to consider complex variables concerning user preferences and species-specific behavior may limit the effectiveness of this model. Concessions in the realistic representation of complex systems are necessary to provide the widely accessible tools advanced in this research.

Accuracy vs. Accessibility

Tradeoffs in required accuracy and time and cost efficiency are tied to the above issue. NCC managers cite fixed budgets as a major concern (NCC, 1999). Development of a comprehensive database requires a large initial investment. Although recent initiatives, such as the Southern Ontario Land Resource Information System (SOLARIS), are underway to develop a current land use database, existing data are often lacking (Rowse, 2003). Existing data and tools were adapted in this study to provide managers with an accessible modeling tool to manage multi-use environments. The lack of updated data raises concerns regarding the validity of model outputs. Analysis results are affected every time a woodland patch is altered.

Accuracy concerns extend to the use existing tools (e.g. Bird Community Index tools) beyond the intended application. Given unlimited resources, this model would benefit from detailed field surveys to compare model predictions with actual site characteristics. Failure to address these issues may ultimately affect overall model validity. Errors in underlying data are inevitable (Wright and Tanimoto, 1998). Although limitations are inherent in the design of this study, accuracy concerns must be balanced against efficiency gained through the use of accessible resources.

The above issues were considered in initial model design. Critical decisions concerning tradeoffs between available resources and accuracy requirements were made on the basis of current research and management goals for the study area. The CCSim is intended to provide a cost-sensitive approach to multi-use management. Existing data and tools were adapted in this model to provide an accessible tool for multi-use park design and management.

Some questions still remain concerning the effectiveness of multi-use corridors, but the results of this study offer several signposts to guide the effective design of Greenbelt corridors

in the future. Concluding remarks will explore the potential benefits of this study in terms of both local corridor planning and broader multi-use management policies.

CHAPTER 5: CONCLUSIONS AND FUTURE RESEARCH

5.1 Research Findings and Implications

The growing popularity of outdoor recreation tests the ability of managers seeking to provide the desired benefits, without incurring the costs of continued park use. Newly advanced multi-use park policies attempt to balance ecological benefits with sustainable recreational use. The rapid shift towards multi-use management has left critical questions unanswered. Perceived policy benefits have yet to be fully realized in day-to-day park management. The following question is posed in this research: **Are multi-use corridors an effective strategy for balancing ecological preservation and recreation landscape demands?**

The answer to this question hinges on the successful negotiation of several key issues. Outdoor recreation can support local conservation efforts but only if existing management challenges can be met. Faced with a growing range of problems and an even wider range of possible solutions, many argue that managers may be ill equipped to meet the challenges of multi-use management. Failure to effectively balance the competing demands placed on valued park resources may ultimately result in long term damage.

The current study evaluates proposed plans for a multi-use corridor strategy in the Ottawa Greenbelt. Urban growth coupled with changing recreation trends has placed significant pressure on valued resources housed in the Greenbelt. A recent visitor and management survey (NCC, 1999) highlights concerns surrounding the continued ability of the Greenbelt to accommodate recreational pressures, while preserving fragile environments. Recreation, wildlife conservation and water quality protection comprise the goals proposed for the Ottawa corridor network. Defining goals is only the beginning; meeting these goals may prove challenging. Failure to establish

effective guidelines for the design and management of corridors places the future of these efforts in peril.

Conservation and recreation goals are often pitted against one another as resource pressures increase. To ensure that carrying capacity is not exceeded managers must consider tradeoffs between competing demands and site sensitivities (Manning, 2003). Consideration of wide ranging values in park management decisions often exceeds the capabilities of conventional management systems. For this reason, a secondary goal of the present study was to develop a decision support system to facilitate multi-use corridor management. Decision support systems, linking integrated frameworks and relevant spatial analysis tools, are proposed as an effective tool for the management of complex systems. 'Real world' losses may be avoided by identifying the benefits and risks associated with different management options prior to implementation.

Diverse indicators were used to identify the ecological sensitivities and recreational demands within the study area. Multi-use corridor management requires the integration of large arrays of diverse data lacking common measurement parameters. Spatial relationships are used to define and link these complex data sets in the corridor conflict simulation model (CCSim). This model is intended to provide managers with a cost-sensitive approach to the design and management of multi-use environments.

Application of this model within the study area yields critical information concerning the spatial distribution of recreational impacts and ecological sensitivities. 'Hotspots' refer to sites where recreational use encroaches on sensitive environments. Model results point to a high concentration of hotspots within the Mer Bleue trail system. Signs of severe degradation in the form of soil compaction, erosion and tree root exposure were noted at numerous sites. Conservation priorities assigned to critical habitat and ecological functions are jeopardized by

excessive recreational trail use in the area. Targeted management strategies are required to restore these sites and avoid further loss of valued park resources.

The Ottawa Greenbelt corridor strategy (NCC, 1996) is indicative of a broader shift in the planning community from single attribute to multi-use management. In the rapid shift toward multi-use management, the development of concrete guidelines for park management is often ignored. The results of this study are intended **to assist managers in developing targeted strategies for implementing multi-use policies.**

The CCSim is proposed as a management tool to evaluate necessary tradeoffs in multi-use management. Model outcomes explore the impact of various management responses to corridor conflicts. Management strategies, including zoning restrictions and sensitive trail routing are predicted to reduce existing conflicts and help preserve ecological values in the study area.

5.2 Implications for Multi-use Management

Today's park systems, for the most part, play a dual role. In addition to conservation goals, natural areas often provide the backdrop for a wide range of recreational pursuits (Manning et al., 1996). These goals often conflict. Better guidelines and codes of practice are required to avoid costly damage to park resources.

As previously noted, various potential solutions are available to combat the range of problems associated with multi-use management. Management strategies seek to improve the durability of the site and/or regulate access to the site. Potential strategies include:

- **Physical Site Management:** The severity of site degradation is often dependent on the design and management of the area. Boardwalks, trail hardening and sensitive trail routing minimize and concentrate impacts permitting controlled access to maintained sites.

- **Quotas and Use Limits:** Zoning strategies and quota systems have been widely applied in park settings to control and/ or limit access to fragile or sensitive areas. Numerous park systems now limit the number of people allowed access to a site at a given time. Spatial and temporal distancing of visitor use can alleviate both recreational crowding and conflict problems and ecological pressures.

The consequences of these strategies are often hard to predict. Model simulations may prove to be of real value in this context. Emerging technologies offer critical advances in the following areas:

Predictive Capabilities

As recreational demands grow in scale and complexity managers are increasingly challenged by the need to predict and evaluate the outcome of alternative strategies. Decision support technologies offer practical benefits in the development and testing of 'what if scenarios'. The unforeseen consequences of proposed management options may be avoided through prior evaluation of potential outcomes.

Generalization

Traditional management approaches have been highly criticized for their limited ability to extrapolate methods and findings beyond the initial study site. The potential to extend this model to a wide range of management problems and settings is made possible by a flexible design and the use of tools largely relevant to any spatial system. Generic modeling tools represent a critical step forward in the broad implementation of multi-use policies.

Accessibility and Time and Cost Efficiency

The CCSim was designed for easy use by park managers. A simple GIS-based model supplies a widely accessible platform and may foster improved understanding and communication amongst diverse user groups including policy makers, park managers and the public.

Conventional field-based methods often place considerable strain on fixed management

budgets. The use of existing tools and data provides a rapid, cost-sensitive approach to the evaluation of management options.

Integration of Complex Systems

One of the most promising advantages of DSS technologies is the potential to link disparate data and complex subsystems. GIS environments provide an effective platform to integrate biophysical and social data for the purpose of identifying and predicting complex human-environment interactions. The analysis of complex interactions requires some level of abstraction. Tradeoffs between available resources and accuracy requirements must be informed by explicit management goals.

The practical use of modeling tools in 'real world' management is limited by underlying uncertainties. The ability to accurately represent complex recreation behavior and ecological system responses remains questionable (Gimblett, 1999; Bishop and Gimblett, 1999). Emerging research may help resolve these concerns.

5.3 Future Research

Complex models become even more complex when human behavior is explicitly considered. Recreation impacts are not limited to environmental degradation. Visitor crowding and conflict concerns further complicate multi-use management. The CCSim remains limited in the consideration of complex recreational behavior and use patterns.

Advanced technologies, such as autonomous agent (AA) modeling offer significant promise for exploring the consequences of management decisions upon visitor behavior. AA models are computer simulations, incorporating advances in Artificial Intelligence and object-orientated programming, to simulate recreational behavior (e.g. visitor encounters, travel patterns, etc.). Potential linkages between existing models and ancillary recreation simulation models require further study.

To date, park management efforts have focused largely on strategies to minimize environmental damages resulting from overuse. Additional research is required to establish the relationship between site design and management and recreational quality among diverse user groups. The improved accuracy of complex models hinges on both conceptual and practical advances in this area.

Uncertainties underlie fundamental model assumptions raising broader concerns regarding the validity of this model. Critical questions remain regarding the valid extrapolation of model outcomes to 'real world' landscapes and the subjective assessment of model parameters, relationships and outcomes (Ervin, 2000, Lange and Bishop, 2001). Questions concerning whose reality is represented via spatial information manipulation and output are often ignored. Selected management strategies often reflect the weighted nature of decisions concerning competing resource demands (Manning, 2003). Exploration of these issues is required to ensure the effective use of decision support models and technologies in multi-use management.

The uncertainties which plague complex models may be difficult, if not impossible, to resolve. Improved understanding and communication through decision support systems is, however, still possible. Efforts to link analysis tools with clear, concise management goals represent a critical step forward in the resolution of these issues. The temptation to blindly apply technologies must be avoided.

Growing ecological and recreational concerns will shape the future of park management. The extent to which 'real world' demands for improved management guidelines are addressed will determine the fate of multi-use policies. A 'balancing act' is required to sustain recreational use in fragile environments. Maintaining this fine balance in the future will require innovative tools and creative strategies.

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APPENDIX

APPENDIX - TABLE 1: OBSERVATIONAL CORRIDOR STUDIES

Study	Type of corridor use documented; measure of use	Documentation for (lack of) movement through matrix
1. Beier 1995. Dispersal of juvenile cougars in endangered habitat	Juvenile dispersal; fraction of dispersers making passages and number of passages per corridor	Radio tagged animals never crossed urban matrix
2. Bennett et al. 1994. Corridor use and the elements of corridor quality chipmunks and fencerows in farmland mosaic	presence; number of captures in fencerows	Not addressed
3. Bennett 1990. Habitat corridors and the conservation of small animals in a fragmented forest environment	Presence, residence, and movements between patch and corridor; number of marked animals caught in both patch and corridor	Not addressed, but deemed improbable
4. Bentley & Catterall 1997. Use of brushland corridors and linear remnants by birds in southeastern Queensland Australia	Presence; number of birds detected in corridor and in intact habitat	Not addressed
5. Downes et al. 1997a. Use of corridors by mammals in fragmented Australian eucalypt forests	Presence and residence; relative abundance, sex ratio, and body mass in corridor, patches, and matrix	Nine native species did not use matrix (pasture), based on same sampling procedure used for corridor patch
6. Henderson et al. 1985. Patchy environments and species survival: chipmunks in an agricultural mosaic.	Presence and residence; number of marked animals caught in both patch and corridor	Not addressed, some animals moved via matrix
7. Heuer 1995. Wildlife	Passages via corridor to other	Deep snows and cliffs probably preclude

	corridors around developed areas in Banff National Park (wolf, lynx, and cougar, winter only)	patches; number of passages per corridor (winter only)	movement outside of corridors
8.	Johnsingh et al. 1990. Conservation status of the Chila-Motichur corridor for elephant movement in India.	Passage via corridor to other patches; not quantified (implied that passage was frequent)	Not addressed
9.	Lindenmayer et al. 1993. Presence and abundance of arboreal marsupials in wildlife corridors within logged forest.	Presence and residence; abundance of animals in linear habitats	Not addressed
10.	Lindenmayer et al. 1994. Patterns of use and microhabitat requirements of mountain brush-tail possum in wildlife corridors.	Presence; number of detections in corridor	Not addressed
11.	Mock et al. 1992. Baldwin Otay Ranch wildlife corridors studies (deer, bobcat, and cougar).	Presence; number of detections in corridor	Not addressed; urban matrix likely impenetrable to bobcat and cougar
12.	Ruefenacht & Knight 1995. Influences of corridor continuity and width on survival and movement of deer mice.	Travel across midpoint of corridor (aspen stringers in sage brush matrix) by displaced mouse; number of midpoint crossings	Not addressed
13.	Suckling 1984. Population ecology of the sugar glider in a system of habitat fragments.	Juvenile dispersal; fraction of dispersers using corridor for at least part of dispersal	At least 5 of 15 dispersals involved extra-corridor movement
14.	Sutcliffe & Thomas 1996. Open corridors appear to facilitate dispersal by ringlet butterflies between woodland clearings.	Passage via corridor to other patches; number of marked insects caught in both patch and corridor	Indirect evidence suggests that less than 2% of movement occurs outside corridors

15. Tewes 1994. Habitat connectivity: importance to ocelot management and conservation	Passage via corridor to other patches; not quantified (implied that passage was frequent)	Not addressed
16. Vermeulen 1994. Corridor function of road verge for dispersal of stenotopic heathland ground beetles (nonvolant)	Residence and movement; number of recaptures at various distances	Apparently no movement via matrix, using same procedures as corridor
17. Wegner & Merriam 1979. Movements by birds and small mammals between a wood and adjoining farmland habitats	Presence and residence; number of marked animals caught in both patch and corridor	Not addressed; some animals necessarily moved via matrix

APPENDIX - TABLE 2: EXPERIMENTAL CORRIDOR STUDIES

Study	Type of corridor use documented; Measure of use	Documentation for (lack of) movement through matrix
Andreasssen et al. Optimal width of movement corridors for root voles	Optimal width travel through 300-m-long artificial corridor by displaced voles; maximum distance, speed, and number of complete corridor transits	Not addressed
Forney & Gilpin 1989. Spatial structure and population extinction: a study with <i>Drosophila</i>	Transits via pinholes allowing movement between half-pint plastic bottles ("patches"); not quantified (flies not individually marked)	Not addressed (no matrix available)*
Merriam & Lenoue 1990. Corridor use by small mammals: field measurements for three types of <i>Peromyscus leucopus</i>	Presence in fencerow corridors by displaced radio-tagged mice released in farm fencerows; percentage of time traveling for 48 h, and total distance traveled in 48 h	Not addressed; no corridorless landscape studied

Rosenberg 1994. Efficacy of biological corridors (for immigration movements by salamander)	Travel through 40-m-long artificial corridor by displaced salamanders (released into 3 x 3-m patch); number of complete corridor transits	As many passages via matrix as via corridor
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TABLE 3: ECOLOGICAL DATABASE LAND USE RECLASSIFICATION

Raster Database Reclassification				
Value	Count	NCC class	Emcxwalk	Reclass
1	1217873	revegetation		2 Forest
2	2201955	thicket swamp		15 Other vegetation
3	653961	open water		16 Other
4	4009435	coniferous early successional		7 forest-coniferous
5	8887736	coniferous unknown successional		7 forest-coniferous
6	1961786	marsh		15 Other - vegetation
7	2736733	deciduous swamp		8 forested wetland
8	4660186	hardwood unknown successional		2 Forest
9	3211215	deciduous unknown successional		2 Forest
10	6600746	mixed early successional		2 forest
12	9393755	deciduous early successional		2 forest
13	1194528	scrub/thicket		15 other vegetation
	1			
14	525441	rock/sand barren		13 barren

15	541123 mixed late success ional	2 forest
16	8316284 meadow	15 other vegetation
17	921771 hedgerow	15 other vegetation
18	2915976 coniferous	7 forest-coniferous
19	1402679 mixed swamp forest	8 forested wetland
20	392 other	16 other
23	462484 mixed unknown success ional	2 forest
30	60757 wetland non-typed	9 wetland
101	5005713 deciduous late success ional	2 forest
121	1173525 coniferous swamp	8 forested wetland
128	179694 mixed	2 forest
129	142054 deciduous	2 forest
131	99670 coniferous late success ional	2 forest
201	718049 provincially sig. Wetland	9 wetland
202	4860609 agricultural resource 8	3 agriculture
203	2373483 business park	1 human influenced
204	1244184 urban area 8	1 human influenced
205	955968 natural environment	16 other
206	531630 waterfront open	16 other
207	221364 experimental farm	3 agriculture
209	144149 central area	1 human influenced
210	419847 future development area	1 human influenced
211	1510219 limestone resource area	14 mining
212	1076859 greenbelt areas	10 open/non-built
213	206447 greenbelt employment	1 human influenced

214	80371 general institutional	1 human influenced
215	272590 primary employment	1 human influenced
216	248911 town centre	1 human influenced
217	88765 kanata north	1 human influenced
218	3030053 village	1 human influenced
219	1375213 sand and gravel	14 mining
220	1925034 general resource area	10 open/non-built
	5	
221	125617 carp airport	1 human influenced
222	660369 Macdonald cartier airport	1 human influenced
240	1008688 other mer bleue	9 wetland
300	1521828 other unknown	16 other