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**CHANGES THROUGH TIME: VARIATIONS IN SPATIAL
PATTERNS OF LAND-COVER WITHIN THE STONY SWAMP
REGION OF THE OTTAWA GREENBELT**

by

Andrey Spiwak, B.E.S.

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfillment of
the requirements for the degree of
Master of Arts
Department of Geography

Carleton University

Ottawa, Ontario

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submitted by
Andrey Spiwak, B E S
in partial fulfillment of the requirements for
the degree of Master of Arts

Thesis Supervisor

Chair, Department of Geography

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October 1996

ABSTRACT

Spatial changes in land-cover in the Stony Swamp region of the Ottawa Greenbelt were identified and mapped between 1964 and 1994. Mapping the cumulative spatial changes of land-cover that comprises a landscape provides a good measure of regional ecological change because of the broad regional interrelationships that exist between them. By identifying changes in land-cover it is possible to assess the effects of these changes upon wildlife and vegetative species.

Two trends were identified: an increase in vegetated land-cover inside Stony Swamp Conservation Area due to re-forestation, and its decrease outside the conservation area due to urbanisation. Between 1964 and 1977 agriculture decreased in area within the study site, while pine plantations and non-forest dry increased. Since 1987, urbanisation has been the greatest modifier of the landscape outside the conservation area. These changes in land-cover have reduced areas for wildlife outside the conservation area, while increasing pressure on the remaining ecosystems inside the conservation area. Continued urbanisation will no doubt result in Stony Swamp Conservation Area becoming an isolated forest, affecting wildlife and plant species found there.

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TABLE OF CONTENTS

ABSTRACT	iii
ACKNOWLEDGMENTS	iv
TABLE OF CONTENTS	v
LIST OF TABLES	x
LIST OF FIGURES	xi
 1 INTRODUCTION	 1
1.1 LAND-COVER CHANGE AT THE RURAL-URBAN FRINGE	2
1.2 A HOLISTIC VIEW OF A HETEROGENEOUS LANDSCAPE	4
1.3 ECOSYSTEM PLANNING AND THE OTTAWA GREENBELT	6
1.4 THESIS OBJECTIVES	10
1.5 THESIS STRUCTURE	12
 2 BACKGROUND AND LITERATURE REVIEW	 13
2.1 CHARACTERISTICS OF PERI-URBAN ENVIRONMENTS	13

2 1 1 Urban Growth and the Rural-Urban Fringe	14
2 1 2 Methods of Management Along the Rural-Urban Fringe	15
2 1 3 History of the Greenbelt Concept	19
2 2 HISTORY OF THE OTTAWA GREENBELT	20
2 3 LITERATURE REVIEW	27
2 3 1 Concepts In Landscape Ecology	27
2 3 2 Change Detection Using Remote Sensing	35
3 STUDY AREA AND DATA	41
3 1 OTTAWA GREENBELT	41
3 2 STONY SWAMP REGION OF GREENBELT	43
3 3 DATA SOURCES	48
3 3 1 Classification Scheme	49
3 3 2 Minimum Mapping Unit	53
3 3 3 Air Photograph Specifications	55

3.3.4 Satellite Data	56
3.3.5 Maps	59
4 METHODOLOGY	60
4.1 AIR PHOTO ANALYSIS	60
4.1.1 Air Photo Interpretation	61
4.1.2 Image Polygon Transfer	66
4.2 GIS ANALYSIS	68
4.2.1 Inputting Into The GIS	68
4.2.2 Polygon Analysis	71
4.3 ACCURACY ASSESSMENT	76
4.3.1 Types of Error	78
4.3.2 Data Processing Errors	79
4.3.3 Classification Accuracy	82
4.3.4 Field Work	84

5 RESULTS AND DISCUSSION	86
5.1 DIGITIZING TEST AND ACCURACY ASSESSMENT	86
5.2 GIS ANALYSIS	91
5.2.1 Land-Cover In 1964	92
5.2.2 Land-Cover In 1977	95
5.2.3 Land-Cover In 1987	98
5.2.4 Land-Cover In 1994	100
5.2.5 Patch Analysis	120
5.3 DISCUSSION	123
5.3.1 Land-Cover Patch Analysis	129
6 SUMMARY AND CONCLUSIONS	137
6.1 SUMMARY	137
6.2 CONCLUSIONS	139
6.3 LIMITATIONS	143

6 3 1 General	143
6 3 2 Technical	144
6 4 FURTHER RESEARCH	145
REFERENCES	147

LIST OF TABLES

TABLE 2 1	GREENBILL AREA	24
TABLE 3 1	LAND-COVER CLASSIFICATION SCHEME	51
TABLE 3 2	AIR PHOTO SPECIFICATIONS	56
TABLE 3 3	LANDSAT THEMATIC MAPPER SENSORS	57
TABLE 3 4	LIST OF MAP SOURCES	59
TABLE 4 1	LAND-COVER INTERPRETATION KEY	62
T	EXAMPLE OF COUNT OUTPUT FILE	72
TABLE 5 1	DIGITIZING ACCURACY TEST	87
TABLE 5 2	ERROR MATRIX	89
TABLE 5 3	PRODUCER'S AND USER'S ACCURACIES	90
TABLE 5 4	TOTALS OF LAND-COVER TYPES INSIDE STONY SWAMP CONSERVATION AREA	92
TABLE 5 5	TOTALS OF LAND-COVER TYPES OUTSIDE STONY SWAMP CONSERVATION AREA	94
TABLE 5 6	TOTAL AREA OCCUPIED BY LAND-COVER CLASSES IN STUDY AREA	105
TABLE 5 7	AREA GAINS BETWEEN CLASSES FROM 1964 TO 1977 IN TOTAL STUDY AREA	107
TABLE 5 8	AREA GAINS BETWEEN CLASSES FROM 1977 TO 1987 IN TOTAL STUDY AREA	109
TABLE 5 9	AREA GAINS BETWEEN CLASSES FROM 1987 TO 1994 IN TOTAL STUDY AREA	112
TABLE 5 10	TRANSPORTATION ROUTES	114
TABLE 5 11	CONVERSIONS OF AGRICULTURAL LAND (1964-1994)	115
TABLE 5 12	CHARACTERISTICS OF SELECTED LAND-COVER PATCHES BETWEEN 1964 AND 1994	122

LIST OF FIGURES

FIGURE 1.1	THE OTTAWA GREENBELT AND LOCATION OF STUDY AREA.....	7
FIGURE 3.1	STUDY AREA	44
FIGURE 4.1	EXAMPLE OF LAND-COVER IDENTIFICATION METHOD FROM AIR PHOTOGRAPHS	66
FIGURE 4.2	ACCUMULATION OF ERROR.....	77
FIGURE 4.3	BOUNDARY LINES USED IN THE DIGITIZING TEST.....	81
FIGURE 5.1	STONY SWAMP AND SURROUNDING AREA LAND-COVER IN 1964.....	93
FIGURE 5.2	STONY SWAMP AND SURROUNDING AREA LAND-COVER IN 1977.....	96
FIGURE 5.3	STONY SWAMP AND SURROUNDING AREA LAND-COVER IN 1987.....	99
FIGURE 5.4	STONY SWAMP AND SURROUNDING AREA LAND-COVER IN 1994.....	101
FIGURE 5.5	LAND-COVER CHANGE INSIDE STONY SWAMP CONSERVATION AREA.....	103
FIGURE 5.6	LAND-COVER CHANGE OUTSIDE STONY SWAMP CONSERVATION AREA	104
FIGURE 5.7	AREAS OF LAND-COVER CHANGE BETWEEN 1964 AND 1977.....	108
FIGURE 5.8	AREAS OF LAND-COVER CHANGE BETWEEN 1977 AND 1987.....	111
FIGURE 5.9	AREAS OF LAND-COVER CHANGE BETWEEN 1987 AND 1994.....	113
FIGURE 5.10	CONVERSION FROM AGRICULTURE TO URBAN BETWEEN 1964 AND 1994.....	117
FIGURE 5.11	CONVERSION FROM AGRICULTURE TO NON-FOREST DRY BETWEEN 1964 AND 1994	118
FIGURE 5.12	CONVERSION FROM NON-FOREST DRY TO URBAN BETWEEN 1964 AND 1994	119

**FIGURE 5.13 CONVERSION FROM AGRICULTURE TO PINE PLANTATIONS
BETWEEN 1964 AND 1994**

121

CHAPTER I

INTRODUCTION

The purpose of this thesis is to map and interpret the cumulative spatial changes in land-cover¹ over a recent thirty year period both inside and outside the Stony Swamp Conservation Area, a protected area located on the urban fringe within the Ottawa Greenbelt. This setting has led to different landscape patterns on opposite sides of the Greenbelt boundary. An examination of the study area is achieved through many steps: the classification of land-cover patches from air photographs of the study site; inputting the classified areas into a Geographic Information System (GIS) for areal analysis over time, and interpreting the cumulative spatial changes and their broad effects on the landscape through the conceptual framework of landscape ecology.

Landscapes are not static, as landscape elements interact with one another over time. The size, shape and juxtaposition of various land-cover types, both natural and non-natural, along with the presence or absence of barriers between them, are critical factors in determining how individual areas function and interact with each other (National Capital Commission, 1991a, 13). Changes in the spatial attributes of these areas are

¹ The term land-cover relates to the types of features present on the surface of the earth, such as buildings, lakes and trees. Land-use relates to the human activity associated with a specific piece of land, like single-family housing (Lillesand and Kiefer, 1987, 137). This thesis mainly discusses land-cover so the terms land-use and land-cover are combined as one term, land-cover.

known to have a strong influence on functions in the landscape as pattern affects process (Couturier, 1995, 135) Mapping the spatial changes of land-cover patches that comprise a landscape allows us to investigate and analyse cumulative effects, which enhances our ability to assess potential consequences of human activity on the environment. These changes may be individually minor in their extent and impact but, when accumulated over time and broad spatial scales, may result in significant environmental effects

From an analysis of land-cover patches and the interrelationships that exist between them information on the structure, quality, and abundance of vegetation within a landscape can be determined. It is useful to know this because ecologists, for example, can use the spatial information to determine what effects both environmental and human changes can have on the distribution of wildlife and vegetative species within the overall landscape. Efforts can be made to minimise human disturbance in future management decisions by identifying these changes and their effect on the ecosystem

1.1 Land-Cover Change at the Rural-Urban Fringe

The study site for this thesis is located in the rural-urban fringe of the Ottawa-Carleton metropolitan area. This rural-urban fringe area is a zone of transition between the city and country, where changes occur as rural land-cover is modified for different urban uses

at many locations, an ongoing process that takes place at varying rates along the fringe. Humans modify landscapes due to changes in management practices and the social, political, and economic forces controlling the land, altering the ecological character of the land permanently (Dunn et al . 1991, 173) Varying rates of rural-to-urban conversion are the product of the different pressures for development that are found at different locations along the rural-urban fringe. Having so many different factors at play, the boundary of the rural-urban fringe in most cities is dynamic and in constant change (Bryant et al , 1992, 158) With strong planning controls, a very regular city edge could occur, without controls, a more sprawling and irregular city edge is created (Martin et al , 1988, 73) Accurate methods of control exist, such as zoning enforcement and forms of taxation, that have achieved mixed results. One way of controlling urban development is the green belt, a method that has been used in Great Britain and subsequently adopted in Ottawa

The primary effect of much of this change occurring along the rural-urban fringe is the fragmentation, modification, and conversion of forest and wetland areas into isolated islands among a predominantly agricultural and urban environment (National Capital Commission, 1991a, 13) These patches are usually remnants of previous landscapes, and as a result wildlife species located within them are disturbed and must adapt to the changes in their environment. Gradually species that cannot adapt are driven out by more opportunistic species that can take advantage of the modified environment, a process that alters the species composition of the landscape permanently (Smith, 1986, 442)

1.2 A Holistic View of a Heterogeneous Landscape

Previous theories that have related the effects of human disruptions on wildlife ecosystems analysed the isolated areas as independent components of the landscape, without identifying the links and relationships to other elements of the landscape (Turner and Gardner, 1991, 4). The field of landscape ecology, however, takes a different perspective, one that has been growing in recognition and acceptance. "Landscape ecology is a study of the spatial distribution of natural areas in a human-dominated ecosystem, the flow of plants, wildlife, nutrients, and water among these natural areas, and the temporal changes in the ecology of the landscape" (National Capital Commission, 1991a, 13). The recognition of landscape units is a fundamental task in landscape ecology and identifying patterns can lead to an understanding of process on the landscape, such as flows of energy and movements of animal and plant species (Forman and Godron, 1986, 24).

From these origins the principles of ecological planning have evolved, rooted in an understanding of the landscape patterns that are derived from life systems that can be identified and mapped in the planning process (National Capital Commission, 1991a, 2). Examples of biological patterns include the patterns of streams and tributaries and the patterns of woodlands, wetlands, and wildlife migration (National Capital Commission, 1991a, 2). This integration of ecological planning within the broader field of regional planning, emphasizing the impact of anthropogenic forces on the landscape, is seen as

having many benefits, including the creation of more balanced decision-making tools that attempt to bridge the gap between natural, agricultural, human, and urban systems (Naveh and Lieberman, 1994, 21)

An ecosystem planning approach, derived from the landscape ecology perspective of the environment, was proposed as a component of a Greenbelt policy review initiated in 1991 by the National Capital Commission (N.C.C.) to determine the future role of the Greenbelt in the capital region. One of the reasons for the review was the continually changing regional context, specifically the growth of Kanata, Orleans and Barrhaven as satellite cities on the outer edge of the Greenbelt, which made it necessary to consider the Greenbelt in terms of an evolving region (National Capital Commission, 1995, 5)

The ecosystem planning approach applies the concepts and theories of landscape ecology by integrating ecosystems in a way that provides a basis for protecting the landscape and maintaining ecological health, while accommodating urban pressures in a more "natural" way (National Capital Commission, 1991a, 1). The approach recognizes 1) relative value and significance, where the importance of an area is only one part of the ecosystem plan, 2) diversity, where all types of environments are preserved to maintain a complex network of biologically rich natural systems; 3) sustainability, where the biological and physical functions affecting an area are protected, and 4) restoration, in which degraded and destroyed areas are encouraged to regenerate through long-term management practices (National Capital Commission, 1991a, 2). Analysis of landscape patterns, managing greenspace, restoring the urban landscape, and monitoring changing land-

cover are all components of this approach, and are based on an understanding of landscape patterns that can be identified and mapped

1.3 Ecosystem Planning and the Ottawa Greenbelt

For the 1991 Greenbelt review the report "The Future Greenbelt Ecological Analysis" (National Capital Commission, 1991a) was prepared for the N.C.C.'s Long Range Planning Division with the ecosystem planning approach as its basis. This ecological analysis not only examined natural areas in the Greenbelt separately as distinct elements of a heterogeneous landscape, but also analysed their relationships with the other environments that collectively comprise the Greenbelt. One of the ecosystems studied in the review was the Stony Swamp Conservation Area, which along with the land immediately adjacent to it comprise the study area of this thesis.

The Stony Swamp Conservation Area is located in the western end of the Greenbelt within the municipality of Nepean, and is bordered by the urban concentrations of Bells Corners, Nepean, and Kanata (Figure 1.1). A provincially significant wetland and home to many different species of vegetation, the Stony Swamp Conservation Area is recognised as being a significant natural and recreational area in the capital region (National Capital Commission, 1991a, 31). Being the largest contiguous forested area in

Figure 1.1 The Ottawa Greenbelt and Location of Study Area

Source: National Capital Commission (1995). Greenbelt Master Plan 1995-2015 Summary Draft.

the Greenbelt, it provides habitat for species which do not occur elsewhere in the Greenbelt, such as the Red-shouldered Hawk (National Capital Commission, 1991a, 32)

The landscape of Stony Swamp has been undergoing an unusual type of change for land in a peri-urban location. Previous studies, such as Ulliman (1992) and Weaver et al (1980), have examined natural areas under pressure from urban encroachment in rural-urban fringe areas in attempts to determine the change in land-cover over time, they determined that land-cover conversion usually takes place in a sequence of changes from natural to agriculture to abandoned farmland to urban land-cover. While land outside the conservation area is under pressure from urbanisation, land-cover within the conservation area, however, has been reverting from a fractured, managed, largely agricultural landscape with many small forest and wetland patches, to a more or less "natural" heterogeneous landscape mosaic of fragmented patches and corridors. Not a closed system, the Stony Swamp Conservation Area has links outside its borders where land-cover changes no doubt have an effect on the health of many ecosystems in the conservation area. The landscape outside the conservation area has changed dramatically over time, as urban development has gradually spread to the borders of the conservation area. With the impact that these changes outside the conservation area can have and because ecosystems within Stony Swamp extend beyond the conservation and even study area borders, land-cover located outside will be included as part of the thesis. Thus the study area comprises the Stony Swamp Conservation Area together with areas outside the Greenbelt but still adjacent to the conservation area borders.

The influence of this ongoing land-cover change outside the conservation area has already been recognised. "The Future Greenbelt-Ecological Analysis" states that "the Stony Swamp Conservation Area is considered to be of moderate health due to its fragmented condition, and because it is surrounded by ongoing urban development" (National Capital Commission, 1991a, 33)

To understand the changing functions and interactions amongst all elements and to establish long-term management practices to maintain a diversity of ecosystems while under increasing human pressure, many recommendations were made in the 1991 Greenbelt review regarding the Stony Swamp Conservation Area and its future survival as a component of the Greenbelt. One such recommendation made to the N C C was for the mapping of the forest interior of Stony Swamp Conservation Area using GIS. The GIS would be used to document the extent of internal openings in the forest, and to aid in predicting the effects of future proposed development near Stony Swamp Conservation Area (National Capital Commission, 1991a, 75)

GIS allows for the development, display, and analysis of spatially explicit data. Remote sensing provides spatial information at various scales and dates that can be incorporated into a GIS. Quantitative methods in landscape ecology have begun to increase with significant advances in computer capabilities, and with the increased availability of GIS and remote sensing technologies. Together GIS and remote sensing have contributed to

the process of landscape change analysis, and methods incorporating their use are discussed in greater detail later in the thesis

1.4 Thesis Objectives

The adoption of broader spatial scales can reveal cumulative effects not apparent at individual land-cover sites within the landscape. The linkage of remote sensing and GIS technologies with landscape ecology theory can provide a basis for assessing broad scale land-cover changes (Dunn et al., 1991, Odum and Turner, 1990, Mladenoff and Host, 1994). By expanding on the recommendation in the Greenbelt review, the relationships over time between Stony Swamp Conservation Area and its surrounding region will be better understood. The objectives of this thesis are to

- 1) use remotely sensed data to create a digital database of the different land-cover patches found within the Stony Swamp study area, both inside and outside the conservation area, between 1964 and 1994
- 2) map the historical spatial changes in land-cover throughout the study area using GIS between 1964 and 1994
- 3) identify the more general spatial relationships between the different land-cover patches in the study area over time inside and outside the Stony Swamp Conservation Area

- 4) provide an interpretation of the relationships identified in 3 from a broad spatial scale using concepts in landscape ecology and patch analysis techniques
- 5) provide "baseline data" for a general overall assessment of the condition of the present landscape for future management and planning practices

The intent of this thesis is to identify general broad scale variations in the spatial patterns of land-cover patches over time and the probable causes of these changes. This will be done by studying the different land-cover patches using landscape ecology theories and techniques. From this thesis further research can be done to determine how these land-cover changes affect different species, and the potential consequences of human activity in the environment. Discovering the nature of the cumulative changes could lead ecologists and planners to a better understanding for managing the resources of the conservation area, and can also help minimise the effect of the growing human presence in maintaining the health of an important ecological area. By meeting the objectives of this thesis the intention is not to analyse the data in great detail and hypothesize how these land-cover changes have affected individual wildlife and vegetation species in sections of the study area. The methods suited to documenting change in land-cover at the landscape level are not suited to measuring other attributes at lower levels of ecological organisation and within specific patches.

1.5 Thesis Structure

This thesis is presented in six chapters. Chapter 2 discusses background within the fields of landscape ecology and the use of remote sensing for land-cover change analysis. A description of the study area, along with the various forms of data and the land-cover classification scheme used for the thesis are described in Chapter 3. Chapter 4 discusses the methods used in the field and laboratory to classify the air photographs and map the cumulative land-cover changes that have occurred, as well as the accuracy assessment used to assess the classification of these land-cover patches. The results of the data analysis and a discussion of their impact on the study area are presented in Chapter 5. The final chapter, Chapter 6, discusses the implications and limitations of the thesis, and also recommends future avenues for further research.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

2.1 Characteristics of Peri-Urban Environments

Two components come together to make the study site for this research an unusual area: the location of Stony Swamp Conservation Area in the Ottawa Greenbelt, a managed area of forest, wetlands and agriculture; and the conservation area being surrounded by the settlements of Kanata, Nepean, and Bells Corners (located within Nepean), whose presence have created a rural-urban fringe environment of ongoing land-cover change. For this reason the rural-urban fringe, methods of regulating explosive urban growth at the fringe, and the greenbelt concept will be discussed in this chapter. Material on the rural-urban fringe is drawn extensively from Bryant et al (1992), who provide a thorough review. Also included in the chapter is a background to the Ottawa Greenbelt, which has played a major role in shaping the pattern of urban development along the rural-urban fringe of the city of Ottawa-Carleton.

2.1.1 Urban Growth and the Rural-Urban Fringe

A major component in the expansion of Western cities has been their peripheral growth at the expense of the countryside. City form evolves as its population expands into the surrounding rural areas, as a result, new areas are required to accommodate the services needed

Most cities have a spatial form conditioned by seven form-generating factors: population growth, competition for land, property rights, developers activities, planning controls, technological developments such as the automobile, and the physical environment (Bryant et al., 1992, 194). The weakening friction of distance brought about by changes in the form-generating factors has made many rural landscapes in both metropolitan and adjacent non-metropolitan areas accessible for development (LaGro, 1994, 144). The manner in which these forces bring about change within the city has a direct effect on the rural landscape in the surrounding countryside. Urban growth combined with accessibility of land leads to the creation of the rural-urban fringe.

The rural-urban fringe of any large Western city can be described as a zone of transition, one that contains both the built-up urban and suburban areas of the central city, and the rural land-cover of the country existing side by side. The rural-urban fringe contains an: 1) Inner fringe, where land is undergoing the greatest pressure for change from rural-to-urban uses and is in the advanced stages of transition from rural-to-urban uses, 2) Outer fringe, where rural land-cover dominates the landscape but where urban elements in the landscape can be found, such

as highway interchanges and residential estate lots. The processes working at the rural-urban fringe do not create very well-defined borders on the landscape because pressures for development, such as population growth and increased mobility and access, vary from place to place as a result of many factors, including the distribution of developable land and barriers to accessibility. As a result, the inner and outer boundaries of the rural-urban fringe in most cities are dynamic and in constant change (Martin and Howarth, 1989, 56). The study area for this research has the characteristics of an inner fringe, while the existence of the Stony Swamp Conservation Area has prevented development from occurring inside a large portion of the study area.

2.1.2 Methods of Management Along the Rural-Urban Fringe

According to conventional planning wisdom constant change at the rural-urban fringe requires planning and management to ensure that development happens in an orderly manner. A variety of management methods are employed in attempts to ensure that controlled development occurs.

Planning is generally concerned with both the function and the use of land, with function viewed as having a higher standing than use (Bryant et al., 1992, 164). Functions are broadly assigned to zones of land, e.g. residential, agriculture, and the use of land can be seen as subsidiary to the function assigned, such as subdivisions and cash crop growing. The use of

the land must be compatible with function, and identifying the level of compatibility between use and function is an important process, something that planning authorities must consider in the context of development on the rural-urban fringe

At the rural-urban fringe, areas under pressure for development can be seen as potentially having many different functions. Williams (1969) lists six basic functions of undeveloped and open land under pressure that can be found on the rural-urban fringe of any urban centre: 1) open space for managed resource production, (forestry, agriculture, etc.), 2) open space for the preservation of natural and human resources-functions involving values, especially in the natural environment; 3) open space for health, welfare and well-being, consisting of protection functions (maintenance of groundwater, etc.), play functions (parks), and design functions (shaping of urban morphology), 4) open space for public safety, including protection functions against natural and man-made hazards, 5) open space for corridors of utilities and transportation; and 6) open space for urban expansion (Williams, 1969, 18)

Clearly, a particular parcel of land can fulfill more than one function and this possibility of many roles is what underlines the difficulty of land planning and land allocation at the rural-urban fringe. In addition to having several functions, parcels of land can be seen as having many different uses. Problems that can arise are based on actual and potential conflicts of values attached to the various elements found in the landscape. With strong planning controls, a very regular city edge could occur, without controls, a more sprawling and irregular city edge is likely to be created. If a city is expanding haphazardly in many

directions, chances of retaining large contiguous blocks of open space are slim. If the expansion process is a channeled one, the possibilities of a contained expansion creating a regular edge to the city and retaining large blocks of land are much greater (Martin et al., 1988, 73). Attempts have been made, those by Martin et al. (1988) and Quarmby and Cushnie (1989), to use remote sensing technology to monitor the rapid change that can occur on the rural-urban fringe. A review of this literature will occur later.

A number of land management methods have been used in attempts to channel the expansion process and prevent haphazard expansion on the city edge. Nevertheless, it is difficult to establish a single perspective for any area of substantial size because of the intermixture of uses and functions for the parcels of land that are found there. Managing development can be defined as "an attempt to achieve efficiency, with efficiency meaning some improvement in land-cover patterns resulting from the application of various methods of land management" (Bryant et al., 1992, 195).

Methods for managing land in and around urban centres can be categorised as negative-regulatory, persuasive-regulatory or positive-regulatory. The negative-regulatory method views land mainly as a commodity allocated by supply and demand, associated with a lack of coordination with any guiding principles or goals, and with being firmly entrenched within a value system in which private property rights remained practically secured (Bryant et al., 1992, 202).

The persuasive-regulatory method rests mainly on cooperation and the voluntary association of adjoining municipalities, partly supported by local and federal funds with an emphasis on local and individual rights (Bryant et al , 1992, 224)

The positive regulatory method is based on the idea that development rights are 'created and allocated to the land by society' and that 'development potential, on any land and in any community, results largely from the actions of society', a concept that became popular in England after World War II (Elson, 1986, 23) The recognition of the rights of both the individual and society is applied through a broader-scale more centrally directed regulation system with policies for particular issues, such as the 1947 Town and Country Planning Act in the UK The key assumptions in the positive regulatory method are that somehow both individual and collective rights can be accommodated, that a better and more efficient use of land is possible, and that government direction at the highest level will result in a more efficient use of the land (Bryant et al , 1992, 197)

In most cities, land management methods are combinations of either the negative, persuasive, or positive regulatory approaches, using a variety of tools in an attempt to ensure the 'efficient' use of land on the rural-urban fringe One tool that has been employed within the positive-regulatory method of land management is the green belt, a concept that originated in Great Britain and has been adopted in Ottawa as a means of managing urban expansion

2.1.3 History of the Greenbelt Concept

The concept of the green belt first originated in England, with its first modern implementation occurring in 1938 with the passing of the Green Belt Act. The act enabled the purchase of 35,000 ha of land around London to prevent urban sprawl from engulfing whole towns and villages in the countryside (Herington, 1990, 11)

In 1944 Sir Patrick Abercrombie presented his concept of a green belt with the introduction of the Greater London Plan. Abercrombie proposed a family of three greenbelts surrounding London that would form parts of a park system, symbolizing Abercrombie's belief that there should be a clear separation of town and country to provide for beauty, health and convenience (Elson, 1985, 8)

In 1955, the newly released 'Circular 42' laid out the firm rules and proposals for green belts in Great Britain: 1) to check the further growth of a large built-up area, 2) to prevent the neighboring towns from merging into one another, and 3) to preserve the special character of a town. The various roles and conditions of the green belt included being several miles wide to ensure an appreciable rural zone around the built-up area; within green belts there would be severe restrictions on development, approval would not be given except in special circumstances for the construction of new buildings or for the change of use of existing buildings for purposes other than agriculture, sport, cemeteries, institutions standing in extensive grounds, or other uses appropriate to rural

areas, within towns and villages in a green belt limited infilling and rounding off would be allowed, but such settlements would not be allowed to expand further, within defined urban areas, every effort should be made to prevent further building for industrial and commercial purposes since if this was allowed, further demand for the release of housing would occur, green belts were to be part of urban policies that would disperse the growing population and protect areas outside the city (Elson, 1985, 14)

By the end of the 1950s, the green belt concept had become firmly entrenched in England and had become an important tool for managing urban growth and protecting rural land. Although extensive criticisms regarding the role of the green belt in regional planning strategies in England do exist (Gregory, 1970, Herington, 1990, Munton, 1986), the green belt has managed to contain urban areas and prevent extensive sprawl into the rural countryside of Great Britain. It did not take long for the potential of the green belt concept to be recognised and exported to other countries, including Australia and Canada.

2.2 History of the Ottawa Greenbelt

Studies prior to the Second World War, such as the Holt Plan in 1915, the Cauchon Report in 1922, and early work by Jacques Gréber all attempted to create a plan for the national capital (National Capital Commission, 1991c, 18)

The outline for the transformation of the city of Ottawa into a capital worthy of Canada did not begin in earnest until the Gréber Plan of 1950 (National Capital Commission, 1991c, 24). Put forth by Jacques Gréber at the request of then Prime Minister Mackenzie King, the plan was to transform the capital into a reflection and symbol of the country itself (National Capital Commission, 1991c, 24). After World War II, Ottawa experienced unprecedented urban growth, and a mechanism was needed to manage this growth in order to prevent scattered and uncontrolled urban sprawl and ribbon development. At the same time, there was a desire to preserve natural areas close to Ottawa to offset the growing urbanisation that was occurring (National Capital Commission, 1991c, 10). The method decided upon by Gréber to accomplish this was the implementation of a large belt of protected land around the city to conserve and manage the undisturbed land, a green belt that would be managed through the cooperation of the local municipalities and the federal government.

"The Plan for the National Capital" (National Capital Commission, 1991c, 24) stated that "the capital should be a national undertaking of which each Canadian can be proud and through which national desires and aspirations can be exposed through material accomplishment" (National Capital Commission, 1991c, 24). Consistent with planning thought at the time, the five recommendations outlined in the plan are what have served to alter the shape of the national capital. The fifth of Gréber's recommendations was the Greenbelt (National Capital Commission, 1991c, 25). By creating a Greenbelt around the capital, Gréber hoped to do three things: 1) confine urban development to the areas

which could be provided with the needed facilities at a reasonable cost, 2) provide future parks and public open space for future government expansion, and 3) to provide and protect areas of natural beauty in close proximity to the urban population of the capital (National Capital Commission, n.d., 10)

The Canadian government approved all of Greber's plan and attempted to convince local land-owners and the administrations of the then largely rural townships of Nepean and Gloucester to help with one of Gréber's main recommendations, the creation of a Greenbelt. Many refused and so the federal government, seeing no other alternative, decided to expropriate all those parts of the planned Greenbelt not already in public ownership (National Capital Commission, n.d., 10). In 1958, the federal government adopted the National Capital Act. As a result the National Capital Planning Committee, later the National Capital Commission (N.C.C.), was granted increased funding and powers to carry out the Greber plan for the capital. At that time the specific purposes of the Greenbelt, expanded on from the original design as outlined by Gréber, were: 1) to prevent further haphazard urban sprawl around the Capital, including ribbon development along approach highways that was characteristic of other cities, and so to protect adjacent farming areas from being swallowed up by uncontrolled development, 2) to meet long term National Capital planning needs by ensuring that when the central area was built up an adequate reserve of sites for future building for government and public institutional purposes was retained, 3) to place a practical and economic limit on the growth of the capital by confining intensive building developments to an area which

could be provided with municipal services at a reasonable cost, 4) to satisfy recreational demands of the population for both present and future use, and 5) to organise satellite cities to absorb the overspill of Ottawa (National Capital Commission, 1991c, 15). By 1974, these satellite cities were outlined as the Western Urban Community, including Kanata, Eastern Urban Community, including Orleans, and the South Urban Community, including south Nepean and south Gloucester (National Capital Commission, n d , 10)

The N C C was given sweeping powers to fulfill these objectives. They were empowered to acquire and dispose of properties, construct and maintain parks, parkways, bridges and other structures, cooperate with local municipalities, public and private agencies in joint projects, administer, preserve and maintain historic places, and carry out planning related to proper development on public lands in the region (National Capital Commission, 1991c, 32). Between 1958 and 1966 the Greenbelt was assembled at a cost of \$33 million dollars (National Capital Commission, 1995, 2) (Figure 1.1).

By the early 1980s the overall Greenbelt area, including land owned by the N C C. and land owned by other federal agencies, such as Energy, Mines and Resources, Agriculture Canada, Department of National Defense, and Transport Canada, totaled close to 20,350 ha (Table 2.1)

At present the Greenbelt totals almost 20,000 ha (National Capital Commission, 1995, 7). Of the total area, 14,950 ha are owned and directly managed by the N C C, with

Table 2.1 Greenbelt Area

<u>N.C.C. Managed</u>	<u>Total Hectares</u>	<u>Government Dept.</u>	<u>Total Hectares</u>
Agriculture	4,900	Natural Resources	240
Natural areas	6,900	Agriculture Canada	1,680
Multipurpose	3,150	Dept of National	1,560
(transport routes, utilities, residential)		Defense	
		Transport Canada	1,920
Total N C C land	14,950	Total Government	5,400
Total Greenbelt Area		20,350	

Source Morrie, P (1991) The Future Greenbelt-Agricultural Analysis

the remaining area owned by various government departments like Natural Resources, Agriculture Canada, Transport Canada, and Department of National Defense

The National Capital Act was amended in 1986 and the N C C 's emphasis was shifted away from building the capital to programming its day-to-day activities (National Capital Commission, 1995, 2) This new direction added another function to the traditional Greenbelt goals as outlined by Gréber, placing the focus on the goal of ensuring that the

long-term relevance and health of the Greenbelt was preserved. Another goal was that the capital should be reflecting an accurate, cross-cultural image of the country, and should be presented as a national symbol for all Canadians (National Capital Commission, 1991c, 2). The National Capital Act was outlined by three main principles: 1) to serve as Canada's meeting place, bringing Canadians together through the democratic process. One way of doing this is through improving access to the capital, 2) to communicate Canada to Canadians, with the capital demonstrating those principles which are common to all Canadians, and 3) to safeguard and preserve those national treasures in the capital which are unique in their influence on all Canadians (National Capital Commission, 1991c, 2).

In 1991, a Greenbelt review was started to determine the future role of the Greenbelt in the capital region. Besides the new mandate for the N C C, there were other reasons that gave rise to the review: 1) the continually changing regional context, specifically the growth of Kanata, Orleans and Barrhaven as satellite cities on the outer edge of the Greenbelt, made it necessary to consider the Greenbelt in terms of an evolving region, 2) the N C C needed a decision making tool to help manage the Greenbelt's diverse landscape, 3) federal policies in the 1990s were changing in relation to the environment, and because of financial restraint new approaches were needed in order to manage public assets, and 4) the Greenbelt Master Plan represented the first major review of the area since the Greber plan in 1958 (National Capital Commission, 1995, 5). Some proposals brought forth included using the Greenbelt to reflect and enhance the commitment and

understanding of Canadians to environmental quality, to contribute to the quality of life in the capital, and to set an example of relevance to other cities across Canada (National Capital Commission, 1991b, 6). Many separate studies were done examining the different aspects of the Greenbelt, including agriculture and ecology (Greater detail regarding the Master Plan for the Greenbelt can be found in the "Greenbelt Master Plan 1995-2015 Summary" (National Capital Commission, 1995)).

The N C C recognises that any future plans for the Greenbelt should include 1) the future management of the Greenbelt's built and natural resources in light of changes in future Greenbelt orientation, management costs, and urbanisation outside the Greenbelt, 2) coordination of planning efforts, particularly for infrastructure throughout the Greenbelt, and in the use of lands adjacent to the Greenbelt boundary, and 3) the need for clear direction concerning the use of Greenbelt lands for local uses (National Capital Commission, 1991b, 7). With growing fiscal restraint within government at all levels, the degree to which these aspects will be considered will determine the future state of the Greenbelt.

The Stony Swamp Conservation Area is located in the Ottawa Greenbelt and without the Greenbelt's creation, a product of the positive-regulatory method of land management, the conservation area would most likely not have been formed. As a result, the existing unusual situation of a protected natural site surrounded by urban areas outside the Greenbelt would not exist. In this way, the Ottawa Greenbelt is directly responsible for

the creation of the conservation area and has had an influence on the land-cover changes that have occurred there since

2.3 Literature Review

Within this section the fields of landscape ecology and remote sensing will be reviewed. Some theories of landscape ecology are reviewed in order to provide a background to the concepts found in ecosystem planning. Landscape ecology also provides a context in which the characteristics of land-cover patches identified on the air photographs can be described over time. This understanding can then be used to explain the effects of landscape change on wildlife and vegetative species. Literature on remote sensing applications in urban and rural-fringe areas using air photographs will be discussed because methods incorporated into this study have been influenced by similar applications found within the literature.

2.3.1 Concepts In Landscape Ecology

Landscape ecology emphasizes large areas and the ecological effects of the spatial patterning of ecosystems and human disturbance (Zonneveld and Forman, 1990, 4).

Specifically, it considers 1) the development and dynamics of spatial heterogeneity; 2)

interactions and exchanges across heterogeneous landscapes, 3) the influence of spatial heterogeneity on biotic and abiotic processes, and 4) the management of spatial heterogeneity. It is this consideration of spatial patterns which distinguishes landscape ecology from traditional ecology, which frequently assumes that systems are spatially homogeneous (Turner and Gardner, 1991, 4). The heterogeneity of a given site, or ecotope, is studied from both the horizontal and vertical perspectives at different spatial and temporal scales giving a holistic view of the relationship between all patches (Zonneveld and Forman, 1990, 7). An ecotope is the smallest contained land-unit and characterised by homogeneity of at least one land attribute, such as vegetation, with non-excessive variations in other attributes (Naveh and Lieberman, 1994, 5). Many ecotopes of different varieties make a landscape, thus creating the main object of study.

Landscape ecology is rooted in three concepts (Naveh and Lieberman, 1994, 74): 1) General Systems Theory, which is the holistic theory of the hierarchical order of nature as open systems, from this originates landscape ecology's basic assumption, that it considers a landscape as a holistic entity, 2) Biocybernetics, which is the theory of how the many systems existing in the landscape regulate themselves, enabling their self-stabilization and self-organisation through positive and negative feedback, and 3) Ecosystemology, or more specifically the Total Human Ecosystem (THE), which is the idea that "humans and the environment form one single whole in nature that can be, should be, and will be studied in totality, and is the highest possible level of ecosystem existence" (Naveh and Lieberman, 1994, 74). The human population is a modifier of

nature and at the same time a receiver of inputs from nature, thereby affecting, and being affected by the many modifications. Collectively, this leads to a new relationship between humans in nature as a new level of complexity is reached where humans are no longer seen as being dominant over all of nature, but existing at the same level in the ecosystem. Landscape ecology is seen to play an important role in the evolution of this new understanding by supplying scientific, technological, and educational information as regulative feedbacks for the structural and functional integration of nature.

The term landscape ecology and its growth as a scientific discipline can be attributed to one person: C. Troll (Turner and Gardner, 1991, 4). Troll was a German geographer who in 1939 developed the basic concepts that would in time become landscape ecology. Troll saw landscape ecology as the result of a collaboration between the geographer and the ecologist, combining the horizontal approach of the geographer in examining the spatial interplay of natural phenomena with the vertical approach of the ecologist in studying the functional interplay in a given site (Naveh and Lieberman, 1994, 5). Firmly established in Europe, landscape ecology is seen as the basis for landscape planning, management, conservation development, and as the basis for the creation of more balanced and far-sighted policies and decision-making tools to be used by planners, foresters, engineers and politicians (Naveh and Lieberman, 1994, 22). From Europe, the concepts of landscape ecology have moved to North America where others like Forman and Godron (1986), Naveh (1989), Merriam (1990), and Gardner (1991) have contributed to the growing field and have helped establish theories and methodologies.

Within landscape ecology can be found several different subfields: landscape morphology, the study of the land structure and its components; classification of the land for evaluation, relationships between the land attributes, and chorological studies, which monitor the variation in spatial patterns of the ecological mosaic over time (Zonneveld and Forman, 1990, 12). It is the last subfield that is directly related to this study. Chorological studies describe spatial patterns, which can be expressed through maps that can provide a better understanding of landscape functions and land-cover or for management, planning and conservation (Zonneveld and Forman, 1990, 15). Examples of chorological studies include those by Dunn et al. (1991) who monitored temporal changes in landscape pattern in Wisconsin, Sklar and Costanza (1991) who developed spatial models for quantitative analysis, and Mackenzie (1994) for forest ecosystem studies.

Monitoring landscape heterogeneity can provide a good measure of regional ecological changes. Humans modify landscapes, altering the ecological character of the land permanently. Their impact depends on the degree of ecosystem modification, and the spatial extent and pattern of landscape modification. This can best be examined from a broad scale landscape perspective (Sample, 1994, 179). At this scale changes in the spatial characteristics of patches are considered significant indicators of the viability of these areas, and hence their function (Couturier, 1995, 35). Landscape pattern refers to the number, size, and relationships of landscape elements such as patches of land-cover, which are important contributors to the interpretation of ecological processes within the

landscape (Dunn et al , 1991, 175) Inventorying and mapping land-cover change are crucial to understanding why landscapes appear as they do, and are also important for understanding how they came to exist (Quattrochi and Pelletier, 1991, 58). The spatial interaction among landscape elements ties the landscape together as a system, with feedbacks and mutual dependencies among the various elements of the landscape (Rastetter, 1991, 370) By establishing how the landscape has been modified, it is possible to determine the effects that this modification can have on wildlife species Correlating spatial changes in land-cover over time with changes in wildlife species can provide a clearer understanding of the processes occurring on the landscape This understanding can then be applied to the landscape through ecosystem planning.

Through the analysis of land-cover patches, theories explaining the different types of natural landscapes the result of human intervention and manipulation have been developed Forman and Godron (1986) provide a detailed explanation of the five different landscape types that can evolve through their Landscape Modification Gradient (Forman and Godron, 1986, 286)

The first type is the Natural landscape Natural is defined as an area where human effects, if present, are not ecologically significant as a whole (Forman and Godron, 1986, 596) This is a landscape without significant human impact that is highly connected with a low density of natural patches and corridors, having indistinct boundaries between elements The few corridors that are found in this landscape are almost always stream

corridors. Patch size is large, the number of patches is low, and the variability in patch size is high in this homogeneous landscape. The second landscape is the Managed landscape, which consists of pastureland, rangeland, or forest (harvested for wood products) that dominates the landscape. Small clusters of homes are evident while line corridors are in abundance, reducing the connectivity of the landscape. Patchiness increases in this landscape, while average patch size and variability in size decrease. The third type of landscape is the Cultivated landscape. Instead of simply small cultivated patches entire cultivated landscapes are visible, bordered and cut by many straight lines. This geometrization of the landscape occurs through the construction of roads and irrigation ditches. Connectivity in these areas is low and patch density increases while variability in patch size decreases, as entire landscapes are modified for agricultural production.

The Suburban landscape is the fourth type of landscape. This a heterogeneous landscape, a patchy mix of residential, agriculture, managed forests and remnants of natural areas. Line corridors and networks increase in number, while stream corridors decrease in this landscape. Connectivity between natural patches is minimal, while overall patchiness continues to increase. In the face of increasing urban pressure, cultivated fields and remnant patches are quickly modified for other uses. The fifth type of landscape is the Urban landscape of the city. Urban landscapes contain extensive street networks and corridors, creating small block-patches of equal size in a built-up

urban matrix. Natural patches are scarce, with those remaining usually being golf courses, cemeteries or urban woodlots (Forman and Godron, 1986, 286)

Distinctive patterns tend to characterise each landscape type. The numbers of natural patches and their regularity in shape increase, while their size and variability decrease as the landscape progresses from natural to urban. These patch changes affect biomass production and nutrient storage per unit area, as well as species composition and diversity. Changes in patch characteristics strongly correlate with changes in species diversity, as species that can flourish in the new landscape displace species accustomed to the previous landscape (Forman and Godron, 1986, 105). Along with patches, line corridors and networks increase while stream corridors decrease with greater human presence, creating a landscape whose changes are the product of both human influence and natural processes (Forman and Godron, 1986, 310). Through analysis of the natural land-cover patches in a landscape, information about the spatial arrangement of the landscape and what the change in spatial patterns means to the species that inhabit the landscape can be collected.

To analyse these landscape changes, quantitative methods in landscape ecology have increased to take advantage of the significant advances in computer capabilities, and with the increased availability of GIS and remote sensing technologies. Works by Quattrochi and Pelletier (1991), Musick and Grover (1991), Dunn et al., (1991), and Coulson et al. (1991) have shown that quantitative methods using remote sensing and GIS can be

incorporated into models for analysis in landscape ecology. Moreover, remote sensing can be used as an important data source for the development and refinement of models, and can also be used to validate models that predict alteration in structure and function of the landscape over time (Quattrochi and Pelletier, 1991, 51). Remotely sensed data can be collected at many scales and times, thereby offering the opportunity for analyses of various phenomena synoptically, from local to global scales through time. These attributes make remote sensing appealing for applications in landscape ecology (Gardner and Turner, 1991, 51). In the near future, remote sensing is seen as the tool that will bridge the gap between ecological research and the planning and management of landscapes (Quattrochi and Pelletier, 1991, 52).

Inherent in any remote sensing analysis is the landscape perspective, the holistic view of the Earth that is the basis for landscape ecology. Indeed, any comprehensive physiographic or integrated approach to the survey of separate land elements is, in fact, making use of landscape ecology even if the user has never heard of the actual term (Zonneveld (1972) in Naveh and Lieberman, 1994, 5). There are many remote sensing studies within the literature that have analysed land-cover change in both rural and urban settings using a variety of techniques and methods. A representative selection of these studies will be reviewed in the following section.

2.3.2 Change Detection Using Remote Sensing

Remotely sensed imagery in the form of air photographs is the main source of information in this thesis. The photographs are used to identify changes in land-cover on the ground, a particular application of remotely sensed data that have been used in a variety of previous studies. As well, mixed results have been reported by Martin and Howarth (1989) and Gong and Howarth (1992) in using satellite data to identify land-cover change in urban-fringe environments.

Remote sensing is the science of deriving information about the Earth's land and water areas from images acquired at a distance (Campbell, 1987, 2). Until the launch of the first commercial remote sensing satellite, the Landsat Multispectral Scanner (MSS) in 1972, the most widely used form of remote sensing data was aerial photography (Dunn et al., 1991, 179). One application of remotely sensed data is detecting changes in land-cover on the Earth. Detecting changes using remotely sensed data is the process of identifying the conversion of land parcels from one cover type to another over time, through either visual or automatic computer-based interpretation methods. One must realise that the assessment of changes is limited to those dates on which the images were captured, which might not include events between image capture that might be pivotal in the process of land-cover change in the area (Dunn et al., 1991, 179). A variety of data sources and techniques have been used to detect change in urban areas, digital methods using satellite data are one of these.

The basic premise in using satellite data for change detection is that changes in land-cover must result in changes in radiance values, and those changes in radiance values must be large with respect to radiance changes caused by other factors (Singh, 1989, 989) There are many different methods that can be used to identify areas of change on satellite imagery Howarth and Boasson (1983) have detailed three different colour enhancement methods a simple band overlay, a band ratio, and a vegetation index, with the band overlay producing the best results Some other methods of identifying change include Principal Component Analysis (PCA), post-classification comparison, image differencing, and direct multirate classification (Singh, 1989, 999) The success of each change method depends on the satellite data used and the objectives of the study Examples of studies of change in urban-fringe environments using different forms of satellite data include Jensen and Toll (1982), Martin and Howarth (1989), Quarimby and Cushnie (1989) and Howarth and Gong (1992) These works have studied the usefulness of incorporating satellite imagery into urban change monitoring

One drawback of using satellite data for change studies is the limited library of available data If land-cover data before 1972 are required, one must instead turn to aerial photographs for remotely sensed data Similarly, air photographs can be used for a detailed analysis of land-cover change since they can be acquired at large scales and high resolutions at which detailed land-covers can be accurately identified Identification of features on air photographs involves the consideration and knowledge of photo elements in the physiographic appearance and physical characteristics of the features These are

shape, size, pattern, tone (or hue), texture, shadows, resolution and association (Janssen and van der Wel, 1994, 419) Typically, air photographs are interpreted visually using these features in a spatial sense This permits higher accuracy polygon-based mapping than can generally be achieved using digital data, which is represented as a raster of discrete points More accurate classifications (90% or higher) of temporal landscape changes have been achieved using air photographs rather than digital methods (Dunn et al , 1991, 179) As well, the capability of acquiring stereo pairs of air photographs makes the identification of land-cover types even more effective Using a dot grid or planimeter, total changes in area by class can then be calculated from the classified photographs Some shortcomings of using air photographs to monitor land-cover change over large areas identified by Hoffer (1994) include the cost of repeated air photo collection to build a substantial database, and the time-consuming process of classifying air photographs visually (Hoffer, 1994, 29).

Previous studies have used air photographs to identify large scale land-cover change in both rural and urban environments of small size over long time periods A detailed assessment of the procedural steps needed to perform a change detection study using historical air photographs is outlined by Ulliman (1992) Operational aspects to be considered, such as ground surveys, materials needed, methods of photo-interpretation, editing, and polygon transfer are described by Ulliman for the reader and were useful as a reference These methods were incorporated into the thesis and are given in Section 4.1.

Work has been done on identifying vegetation change in ecosystems from air photographs in rural and wilderness areas, an application that is similar to this study. Blanchard (1977), Weaver et al (1980), Civco et al (1986) and Lyon and Greene (1992) all studied changes in wetland environments for resource planning and future vegetation monitoring. These studies documented changes in the historical areal extent of wetlands in great detail, and attempted to relate the wetland changes to human ecosystem alterations. For example, Blanchard (1977) linked wetland changes in Oklahoma to nearby dam and canal construction by measuring the stressed condition of the vegetation. Lyon and Greene (1992) incorporated lake water levels into their study to measure the historical changes of coastal wetlands in Lake Erie the result of dam construction. Using air photographs allowed for a historical measure of the change taking place on the landscape, giving an indication of the disturbance to the surrounding ecosystem.

Studies in urban areas have also been successful in documenting historical changes in land-cover using air photographs. Batie and Niedzwiedz (1984) used aerial photography to assess the progress of urban development into coastal wetlands in Virginia. They determined that the historical information that can be collected from air photographs is useful for wetland management and for regulating development. Subsequent programs can then be designed to focus efforts on areas where they would be most needed and effective (Batie and Niedzwiedz, 1984, 212).

Thibault and Zipperer (1994) also studied the historical change in urban wetlands in upstate New York. They documented the change from wetlands to an agricultural landscape to an urban landscape between 1926 and 1988, and highlighted the importance of multiple-sampling years for detecting temporal changes during shifts in the land-cover (Thibault and Zipperer, 1994, 245). It was determined that understanding the spatial patterns of wetlands over time is essential to developing effective long-term wetland management strategies that will enhance wetland functions within an urbanizing landscape (Thibault and Zipperer, 1994, 250). Other studies, such as Marceau (1996), have incorporated zoning maps into the analysis in order to help identify the changes between air photographs taken on different dates. This method not only identifies land-cover change occurring at the moment of image capture but land-cover changes occurring between the dates of image acquisition as well.

Researchers in the fields of landscape ecology and remote sensing have developed methods and theories that have contributed to a better understanding of the processes that are occurring on the ground, both natural and anthropogenic. Landscape ecology has provided theory to better understand the holistic relationships between elements on the ground, a broad perspective in which the entire landscape is seen as one functioning unit with humans being part of the ecosystem, not above it. This perspective can then be applied in a variety of fields, such as ecosystem planning and management. On the other hand, remote sensing has provided the tools and the methods to effectively use these tools to accurately collect information in many different environments. The qualitative

information of landscape ecology complements the quantitative methods of remote sensing. Together remote sensing and landscape ecology could be used to study and identify the conflict and competition over land in rural and urban environments, and to model the results of these constant changes. An awareness of the close links by specialists in both remote sensing and landscape ecology would be advantageous for they would have a similar background which would encourage communication between the two fields. Working together, this combination would lead to more effectively shared skills and knowledge that would foster a better understanding of our changing planet.

CHAPTER 3

STUDY AREA AND DATA

The location and characteristics of the Ottawa Greenbelt are described in this chapter, providing an indication as to the variety of conditions that are found in the specific study area. Characteristics of the specific study site are then discussed, followed by the classification scheme and a description of the data used to perform the spatial analysis.

3.1 Ottawa Greenbelt

The Stony Swamp study area is located in the Regional Municipality of Ottawa Carleton (R M O C), which includes the City of Ottawa. Since 1945 the population of the region has been growing steadily, particularly between the years 1951 and 1971 when the regional population increased by one-third. From 1906-1991, the amount of urban land in the region increased by more than 1,300%, with the greatest increase occurring after 1945 (Regional Municipality of Ottawa Carleton, 2, 1993). By 1991, the population totaled approximately 700,000 people, with the City of Ottawa experiencing a slow absolute decline in population over the years, while suburban areas like Kanata have seen their populations grow.

The Greenbelt forms a continuous semi-circular belt around Ottawa, from Nepean and Kanata in the west to Gloucester in the east. The Greenbelt is 45 kilometers in length and an average of about 4 kilometers in width, with its inner margin an average of about 9.6 kilometers from Parliament Hill (National Capital Commission, 1991c, 52).

The Greenbelt is a diverse landscape and serves a wide variety of uses. From a physical standpoint, the ground surface of the Greenbelt area is a level to gently undulating plain of a relatively thin layer of marine and moraine deposits interrupted by bedrock uplands (Agriculture Canada, 1979, 9). This mixture is the result of the Pre-Cambrian rock of the Canadian Shield meeting the alluvial plains formed by the receding Champlain Sea. Materials include clay, silt, sand, sand ridges, and glacial till on limestone and dolomite bedrock plains (Greenbelt Workshop Group, 1992, 13). To the north the Greenbelt is bordered by the Ottawa River, while the Rideau river divides the Greenbelt into two sections from east to west.

The Greenbelt is ecologically diverse (Brunton, 1988, 10) and has a rich variety of plant and animal life, the result of the region being located in a transitional zone between the coniferous-dominated boreal forest to the north, and the broadleaf-dominated deciduous forest to the south. According to "The Management Plan for the Greenbelt" (National Capital Commission, 1982) of the almost 14,950 ha owned by the N C C in the early 1980s, close to 4,900 ha were leased to 85 individual farmers for agriculture, while approximately 6,900 ha were made up of wetlands, open lands, ravines, waterways, and

woodlands. Some of the many tree species found in the Greenbelt include jack, white and red pine, sugar maple, soft maple, birch, beech, poplar, and white cedar (National Capital Commission, 1991a, 35). Also scattered throughout the Greenbelt can be found marshes, bogs, and swamps of predominantly soft maple or poplar trees (National Capital Commission, 1991a, 33). The two largest wetland areas found in the Greenbelt are the Mer Bleue and Stony Swamp. Overall, the wetland communities of the Greenbelt provide examples of the five classes of wetlands identified by the Canadian Wetland Classification System for all of Canada: bog, fen, marsh, swamp and shallow water.

The Greenbelt provides some visually attractive areas and spaces for many recreational activities, such as municipal playing fields and hiking in summer and cross-country skiing in winter, which are found within many of these same natural areas. As well, 3,150 ha are used for many different purposes, including transportation routes and N.C.C. residential units (National Capital Commission, 1982, 11).

3.2 Stony Swamp Region of Greenbelt

The defined study site for this thesis, roughly 6 miles by 4 miles, is partly located inside the western end of the Greenbelt, and includes the Stony Swamp Conservation Area and the residential enclave of Bells Corners (Figure 3.1). The borders of the Greenbelt and

Figure 3.1 Study Area

Stony Swamp Conservation Area are largely the same, except around Bells Corners.

Sections of the study area found outside the Greenbelt boundaries include portions of the south-eastern corner of Kanata, as well as portions of the city of Nepean. Centered in the study area is the Stony Swamp Conservation Area, which is a highly heterogeneous landscape with a diverse mixture of upland and lowland environments that contain native or non-native vegetation that is either pristine or in a state of recovery (National Capital Commission, 1991a, 32)

Originally logged and then used predominantly for agriculture the land was designated a conservation area in the 1970s (Agriculture Canada, 1979, 8), a decision which has prevented further deforestation. The conservation area is made up of almost 2,000 ha of forested environment that includes natural forest covers of sugar maple, poplar and white cedar, as well as extensive plantations of jack, red, and white pine (National Capital Commission, 1991a, 31). As well, there are open patches of grass and small shrubs (National Capital Commission, 1991a, 31)

Wetlands, including wet forests and marshes, also make up a large part of the conservation area due to relatively poor drainage. The head-waters of Stillwater Creek, Watts Creek, Carp River, and Graham Creek all rise in the conservation area and drain north to the Ottawa River, while Monahan Creek drains south to the Jock River (National Capital Commission, 1991a, 31). The underlying bedrock comprises gently undulating limestone and dolomite bedrock plains, with a thin surficial layer of clay and

silt deposits allowing for one of the greatest diversities of plant species in the Greenbelt (Brunton, 1988, 151)

The Stony Swamp Conservation Area contains the largest contiguous forest in the Greenbelt, providing a home for many animal species that do not occur anywhere else in the Greenbelt and are dependent on the health of the conservation area for their survival (National Capital Commission, 1991a, 32) Some of the many forest-dependent wildlife species include the Least Bittern, Red-shouldered Hawk, Pine Warbler, and White-Tail Deer (Brunton, 1988, 152) Along with the Mer Bleue, Stony Swamp is recognised by the Ministry of Natural Resources as a provincially significant wetland and an Area of Natural and Scientific Interest (ANSI) within the Greenbelt (National Capital Commission, 1991a, 35)

Urban land-cover can also be found in close proximity to Stony Swamp Conservation Area along its north-east border where, although enclosed by the Greenbelt, the settlement of Bells Corners is located The conservation area is fragmented, with six medium to high volume roads, four high-tension hydro lines, and an abandoned railway line cutting through its forested and wetland portions (National Capital Commission, 1991a, 33) For example, Highway 417 cuts off the northern portion and prevents a natural link between Stony Swamp and another natural area in the Greenbelt, Shirley's Bay (National Capital Commission, 1991a, 33) As well, the recently completed Highway 416 passes through the eastern end of the conservation area close to sensitive

wetland ecosystems. On the western edge of Stony Swamp Conservation Area can be found the expanding suburbs of Kanata, which are exerting pressure as a result of Kanata's continuing growth as a satellite of Ottawa. To the south is the city of Nepean where are found residential areas, a quarry and lumber yard in close proximity to the conservation area. These urban features can affect wildlife through fragmentation of the forested environment, as well as affecting the water quality and quantity of the base flow to the streams in the area through their energy and resource demands (National Capital Commission, 1991a, 34). Studying the cumulative spatial changes created by these urban forces can provide an indication of the condition of the conservation area.

The N C C itself has recognised the conservation area's precarious position, and has stated that "The swamp's location between the capital's core and Kanata presents the challenge of integrating a major natural complex into the fabric of a growing urban area, while maintaining links to natural ecosystems beyond Greenbelt borders" (National Capital Commission, 1995, 27). By incorporating the principles of ecosystem planning, future management and planning practices can attempt to minimise the damage of integration, something that an identification and understanding of past spatial changes on the landscape can help with.

Within the rather short time frame of 30 years, Stony Swamp Conservation Area has seen forest re-generation on land that was previously used for agriculture. Although protected by the N C C from disturbance, the conservation area borders sites of intense

urban development that have put increasing pressures on the area in recent times, and could affect the quality of the environment in the future. Outside the conservation area human actions have heavily influenced the landscape, resulting in a heterogeneous landscape of remnant patches and urban developments of varying size and shape. These changing spatial patterns can influence a variety of ecological phenomena, such as animal movement and vegetative species (Odum and Turner, 1990, 140), and as a result the ability to quantify spatial changes in landscape structure through time is crucial to an understanding of the dynamics of the Stony Swamp area of the Greenbelt.

3.3 Data Sources

Two forms of remotely sensed data were obtained for this study, aerial photographs and satellite images, along with ancillary data in the form of maps of the study site. The classification scheme that was used to identify land-cover will be explained in the following section, along with characteristics of both forms of remotely sensed data and the ancillary data.

3.3.1 Classification Scheme

A classification scheme is required in order to be able to identify the different land-cover types on the ground. As well, identifying changes in landscape pattern requires a classification scheme that can be applied uniformly over all the air photographs. All classes of interest must be carefully selected and defined to successfully classify remotely sensed data into land-cover information (Jensen, 1996, 200). Several land-cover classification schemes have already been developed, such as the USGS Land-Use/Land-Cover Classification System and the U.S. Fish and Wildlife Service classification hierarchy, and can be used as a basis for creating one's own classification scheme (Dunn et al., 1991, 181).

The classification scheme for this thesis was created by combining two classification schemes already in use by the R M O C for land-cover identification within their GIS database. The map "1991 Urban Land Use", published in 1993 at a scale of 1:35,000 by the R M O C, uses Industrial, Commercial, Residential, Institutional, Agriculture, and Under Construction classes, among others, to identify urban land-cover. The map "Natural Vegetation In Ottawa-Carleton", published in 1995 at a scale of 1:120,000 by the R M O C, uses Non-Forest Wet, Non-Forest Dry, Dry Forest, Open Water, Wet Forest, and Pine Plantation classes to identify natural land-cover in the region. These natural patches can be identified as largely undeveloped areas that are distinguishable from other types of areas (urban, agriculture) by their higher species diversity, which

results in a characteristic vegetative appearance of different types. These patches may be remnant, modified, or created by human activity.

These twelve classes from the two maps were combined to create one classification scheme that could be used for this study (Table 3.1). By adopting existing land-cover classes from the region the database created for this study would be available and familiar to those who would find it useful to review for future planning and resource management projects, such as the NCC and RMO.

The non-forest wet class includes bogs, fens and marshes. Bogs are generally covered by sphagnum moss, but may have trees or shrubs. Bogs are usually acidic, low in nutrients, with the water table at or near the surface (Snell, 1989, 2). A fen consists mainly of sedges, grasses, and reeds with sparse shrub or tree cover. Fen soils are organic and have a high water table at or above the surface, providing more nutrients than bogs. Marshes consist of non-woody plants like rushes, reeds, grasses, sedges, with a border of trees and shrubs. Marshes are periodically inundated by standing or slow moving waters that cause surface levels to fluctuate seasonally, and their soils can be either mineral or organic (Snell, 1989, 2).

The wet forest class includes swamps, which are wooded wetlands consisting of coniferous or deciduous species, tall shrubs, herbs and mosses. Waters are nutrient rich, while soils are usually mineral or well decomposed organic (Snell, 1989, 2).

Table 3.1 Land-Cover Classification Scheme

<u>Land-Cover</u>	<u>Characteristics</u>
Open Water	visible open areas of water inside and outside the conservation area, provide an important aquatic habitat and provide surface storage runoff, streams and rivers were not included
Non-Forest Wet	includes marshes, areas of shallow water, bogs and fens as defined in the Canadian Wetland Classification system (Snell, 1989, 4)
Non-Forest Dry	abandoned farmer fields, scrubland, power corridors, generally, open dry areas that are not entirely forested, yet soil is not bare and exposed (R M O C, 1995b)
Dry Forest	natural mixed-forest cover dominated by deciduous species, such as sugar maple, soft maple, poplar occurring mainly in upland areas (National Capital Commission, 1991a)
Pine Plantation	plantations are dominated by jack pine, with small areas of white and red pine (National Capital Commission, 1991a)
Wet Forest	includes all the swamp areas in the R M O C , which usually have a cover of deciduous and coniferous trees (R M O C , 1995b)
Bare Soil	bare soil as the result of agricultural activities, relatively easy to identify on the ground because of the geometric shape of the patches and their spectral reflectance

continued..

Table 3.1 (continued)

Agriculture	all crop and grazing areas, an identification of individual crops was not seen as being vital to the study
Residential	important for identifying land undergoing rapid urbanisation in close proximity to the study area
Under Construction	transitional class, indicates a growing human presence on the landscape, includes building foundations, cleared and exposed soil, and partially installed roads (Martin et al , 1988, 75)
Commercial	typically with little or no surface vegetation and concrete surfaces, shopping malls and strip malls are examples
Industrial	typically with little or no surface vegetation and concrete surfaces, warehouses, auto yards are examples
Institutional	includes government complexes and educational facilities
Extractive Industries	includes quarries and gravel pits

Added to the twelve classes of the regional classification scheme were two other classes that could be identified using air photographs. Extractive Industries, and Bare Soil. The bare soil class was developed for agricultural settings because it is different from bare soil found in land under construction, having a distinct and separate meaning in the

identification of areas of change. Bare soil as the result of agricultural activity is different from bare soil as the result of construction activity because bare soil under agricultural management simply identifies agricultural areas, while bare soil in development projects highlights areas undergoing change as a result of urbanisation (Martin et al., 1988, 74)

3.3.2 Minimum Mapping Unit

Interpretation of the aerial photographs was based on the delineation of relatively homogeneous areas of the various land-cover types down to a 1 ha minimum size. The 1 ha size is equal to 10,000m² or a 100 meter by 100 meter square area. Measured at 2.5 millimeters on the photographs this minimum unit was determined through field checking by evaluating the size of land-cover patches that could be accurately classified, and the resolution of the photographs with the largest scale (1:40,000). From the air photographs 1 ha was determined to be the minimum land-cover patch size that could be accurately identified and mapped. At 1 ha boundaries between land-cover types are distinguishable on the air photographs, resulting in a more accurate identification of the boundaries on the ground during subsequent field checking. As well, preliminary surveys of the study site determined that many of the patches were relatively small in size, and that a small minimum mapping unit would be needed to include them all. With a minimum mapping unit of 1 ha small land-cover patches, such as non-forest dry, open

bodies of water, or dry forest could be accurately mapped through the different time periods. A minimum unit smaller than 1 ha would decrease the accuracy of the land-cover patches being identified from the air photographs. If the mapping unit was any larger, such as 10 ha, a number of these small patches would not be included in the analysis because they would be below the 10 ha mapping unit at certain time periods in the study.

The patches of the conservation area together form a continuous forested area, excluding patches because of their size would not provide an accurate description of the landscape. Including land-cover patches with a variety of sizes, from the largest homogeneous unit down to small 1 ha patches, provides greater detail regarding the individual land-cover patches and the landscape as a whole. Although patches less than 100 metres in area are most likely important ecosystems to many species, a minimum size had to be selected which was practical and could be effectively mapped using the research methods. Establishing the minimum mapping unit had to coincide with this level of information required. It should be noted that the total area of land-cover classes, particularly natural ones, may be underestimated as the minimum mapping unit represents a source of error since very small patches cannot be detected. However, it is not desirable to include exceedingly small patches, because they essentially represent "clumps of trees" rather than natural areas.

3.3.3 Air Photograph Specifications

A total of four stereo-pairs covering the conservation area and adjacent areas were chosen, and were obtained from the National Airphoto Library. The characteristics of the photographs are shown in Table 3.2. The air photographs are black and white and are of high quality, displaying a good contrast between features on the ground.

Table 3.2 Air Photo Specifications

<u>Date</u>	<u>Scale</u>	<u>Format</u>
1964-June	1:40,000	B/W
1977-June	1:50,000	B/W
1987-June	1:50,000	B/W
1994-May	1:50,000	B/W

Many photographs and flight lines at various scales were studied in order to find the appropriate air photographs that contained the entire study area. The structure and function of a landscape can be perceived differently at different scales, and deciding on an appropriate scale is important for a study (Quattrochi and Pelletier, 1991, 67). Three air photo sets at 1:50,000 and one at 1:40,000 were selected so that all of the Stony

Swamp Conservation Area, as well as most of the study area in close proximity outside the boundary, could be studied on a single stereo pair of each date. Larger scales of 1:10,000-1:20,000 would not have provided the overall synoptic view of the spatial patterns and interrelationships in the region that the smaller scale photographs offer. This overall view lets the user see the landscape in its complete form, which is important in aiding an understanding of the ongoing changes in the conservation area as well as the changes that have occurred on its periphery. Also, larger scales would have involved the use of more than one stereo pair for each date.

The thirty year time period of the air photographs was selected so that changes in land-cover conditions within the Stony Swamp region could be studied from its state before its inclusion in the Greenbelt to the present day. The air photographs document the area in different stages of change from 1964 to 1994, something that would be impossible to do with existing satellite data archives. Using the air photographs, the process of natural re-generation within the study site can be observed from the early days to the present.

3.3.4 Satellite Data

It was originally intended that satellite imagery be the primary data source because they provide additional spectral information that black and white air photographs do not provide. Two Thematic Mapper (TM) satellite images were provided by the Canada

Centre for Remote Sensing (C C R S) in Ottawa, and were acquired TM images contain seven spectral bandwidths from which information about the landscape, such as the location of different vegetation types, can be derived (Table 3.3)

Table 3.3 Landsat Thematic Mapper Sensors

<u>Band</u>	<u>Spectral Sensitivity</u>
Band 1	0.45-0.52 μm (blue-green)
Band 2	0.52-0.60 μm (green)
Band 3	0.63-0.69 μm (red)
Band 4	0.76-0.90 μm (near infrared)
Band 5	1.55-1.75 μm (mid infrared)
Band 6	10.4-12.5 μm (far infrared)
Band 7	2.08-2.35 μm (mid infrared)

Source: Campbell, J. B. (1987) Introduction To Remote Sensing Guilford Press, USA, 551 pgs

Different combinations of these bands, such as bands three, four and five, provide information for discriminating between wetland types and good differentiation between other vegetated land-cover such as forest, agriculture and abandoned land (Thomas,

1988, 22) Of the seven available bandwidths listed in Table 3.3, only six bands were processed with each image. The far infrared band, Band 6, is not included with the images, and therefore not available for use.

In order to hold constant as many environmental variables as possible on each date, attempts were made to acquire near-anniversary images. Also, to highlight much of the change that has occurred in the Stony Swamp region of the Greenbelt, images of at least five years apart were sought. Unfortunately, meeting both these aims proved to be impossible as it was discovered that the majority of the older TM data stored at C C R S could not be retrieved from the computer compatible tapes and therefore could not be used. One recent TM image, taken on July 19, 1994, was available for use in Exabyte tape format. After repeated attempts to retrieve any images taken before 1994, the only image that could be recovered was one that was acquired on September 25, 1992.

With the difficulty in obtaining the satellite data and the subsequent problems encountered in the attempts to classify the images, ultimately only the 1994 image was used as ancillary data for the air photo interpretation. Thus, the air photo analysis became the primary focus of the study.

3.3.5 Maps

Other ancillary data were acquired to aid the interpretation of the aerial photographs and satellite data. Numerous maps of the Stony Swamp region of the Greenbelt were collected, from both the NCC and RMOC, that identify various types of vegetation as well as other land-cover conditions during the time span of the air photographs and the satellite images. These maps, listed in Table 3.4, also aided in the creation of the classification scheme that was used for land-cover identification on the air photographs.

Table 3.4 List of Map Sources

The Planning Challenge of the Ottawa Area: Farmland Abandonment and Urban Encroachment 1:94,000 (Energy Mines and Resources, 1969)
National Capital Greenbelt-Landuse 1:200,000 (National Capital Commission, 1974)
Ontario Base Map Series 1:10,000 (Ministry of Natural Resources, 1988)
1991 Urban Land Use 1:35,000 (Regional Municipality of Ottawa Carleton, 1993)
Classified Wetlands 1:100,000 (Regional Municipality of Ottawa Carleton, 1995)
Natural Vegetation In Ottawa-Carleton 1:120,000 (Regional Municipality of Ottawa Carleton, 1995)

With the classification scheme created and the various forms of data collected, the next step was the classification of land-cover on the air photographs. Also, this land-cover information had to be entered into a GIS for subsequent analysis of cumulative change. The steps used in this process are outlined in Chapter 4.

CHAPTER 4

METHODOLOGY

Land-cover change in the study area was analysed in several discrete steps, from the outlining of land-cover polygons on the air photograph sets, to their subsequent input and manipulation in the GIS, and the interpretation of the results of the analysis. These steps are detailed in this chapter.

4.1 Air Photo Analysis

The first step in identifying land-cover from the air photographs was to prepare them for observation. Transparent overlay sheets of approximately 23 centimeters x 23 centimeters, upon which the land-cover polygons were to be drawn, were cut and taped to fit over each set of air photographs. Study area boundaries were identified and outlined on the aerial photographs and on reference maps beforehand, so that they could be easily identified on all the sets of air photographs before interpretation. The boundaries of the Stony Swamp Conservation Area were not officially delimited until the 1982 Management Plan for the Greenbelt (National Capital Commission, 1982, 48), and then were expanded in 1991 upon the acquisition of land near Kanata and Bells Corners.

As a result the 1982 boundary was used for the years 1964, 1977, and 1987 to maintain a consistent boundary. The boundary was altered for the 1994 photographs to reflect the most recent boundary changes in 1991. Preliminary field trips to the area were done before the air photo analysis, in order to increase knowledge and familiarity of the study site.

4.1.1 Air Photo Interpretation

The stereo photographs were interpreted using a pocket stereoscope. The stereoscope proved to be satisfactory for the identification of land-cover in the air photographs at the defined minimum mapping unit. As already suggested in Chapter 2 identification of features in air photographs involves the consideration of elements in the physiographic appearance of these features. These are shape, size, pattern, tone (or hue), texture, shadows, resolution and association (Janssen and van der Wel, 1994, 419). Objects are then identified by a combination of both geometric and thematic properties. Some of these basic characteristics were used in identifying the features found in the photographs of the study area. An interpretation key was devised for classification using the above-mentioned characteristics and the land-cover maps acquired of the study area (Table 4.1). Each land-cover patch was identified visually and a decision was made regarding its class. For forest and non-forest patches, a subjective decision was made based on the

Table 4.1 Land-Cover Interpretation Key

<u>Land-Cover</u>	<u>Interpretation Characteristics</u>
Open Water	very dark tone on image with smooth texture that is in distinct contrast with surrounding vegetation, polygons irregular with clear edges
Dry Forest	light gray in tone compared to other vegetation in area with no openings in tree cover, rounded tree crowns appear rough and coarse in texture, tree height visible in stereo (see Figure 4 1)
Pine Plantation	dark tone and somewhat rough texture with a distinct round pattern on the image, areas where plantations begun in 1964 identifiable on 1994 photos, tree crown texture appears smoother than dry forest with no openings (see Figure 4 1)
Agriculture	large areas comprising generally rectangular fields, very light gray tone and smooth texture distinguishes areas from surrounding land-cover, vegetative boundaries between adjacent fields, occasional patch of trees, height difference between forested sections, association of farm-buildings and farm tracts, and orderly appearance
Wet Forest	mix of pine and cedar trees creates medium-gray tone, rough, mottled texture with indistinct boundaries and few openings, crowns appear narrow, patches not very large making identification difficult (see Figure 4 1)
Non-Forest Dry	medium texture, light gray tones of grasses with indistinct boundaries, scruffy, no forested cover, only a few individual trees which are visible in stereo (see Figure 4 1)

continued

Table 4.1 (continued)

Non-Forest Wet	mottled texture with mixed light and very light gray tones, polygons are of various shapes and sizes with visible edges, stereoscopic coverage of air photographs provides height contrasts with surrounding forests (see Figure 4.1)
Extractive Industry	very light tone on image with relatively smooth texture, irregular polygon shape; excavations visible in stereo
Commercial	smooth texture of concrete and bright tones, buildings located close together, situated mainly along main roads with minimal or no vegetation noticeable, associated with other urban features such as highway interchanges and parking lots
Industrial	smooth texture and bright tones similar to commercial areas, patterns of larger buildings with more space between them, with occasional vegetated patches and small parking lots surrounding some buildings, borders between compounds identifiable
Residential	large areas with a heterogeneous mix of small buildings that create a variety of tones and textures with a distinct pattern that reflects the road networks
Under Construction	bright, almost white tone with a smooth texture that is flat, usually located on the edges of existing residential developments
Bare Soil	smooth texture, distinct light tones and rectangular shapes on photographs, associated with agricultural areas
Institutional	buildings with bright tones and small parking lots isolated from urban, commercial and industrial areas, maps of study area were used to aid in the identification of this class

amount of tree cover visible in the patch. The stereo format of the photographs made it easier to identify differences in vertical vegetation structure so that non-forested patches were easily distinguishable from forested patches. If the majority of the polygon was forested then it would be classed as forest. If most of the polygon was open with no visible trees, then it was classed as non-forest. Maps of the study area also aided in identifying forested and non-forested patches of land.

Areas of wet and dry forest were identified based on their tonal variation, textures, and the visual appearance of the forest from the photographs. Species like cedars prefer wetter environments while deciduous trees like maples prefer dry environments, this difference in vegetation could be identified from the stereo air photographs, and helped in distinguishing between the land-cover types. Ancillary maps produced by the R M O C and N C C also aided in determining forest type. Nonetheless, this was the most difficult part of the classification process.

Interpretation was performed on the most recent (1994) set of air photographs first because there were a large number of reference maps available for the area at that time. These maps provided road network information, and also contained landmarks that aided in identifying urban and natural features. Also used as a source of ancillary information was the 1994 TM satellite image, which was acquired during the same summer month as the air photographs. Therefore, land-cover types that were difficult to distinguish solely from the air photographs could be identified on the TM image by their unique spectral

characteristics and corresponding locations on the air photographs. Once comfortable with identifying land-cover of all types on the most recent set of air photographs, that knowledge and understanding of the study area was then translated to the air photo sets for the other years.

All transportation routes, which include roads and railway corridors, were delineated first in order to provide reference points for identifying the subsequent land-cover polygons. Polygons were then carefully delineated on the transparent overlay sheets, and then labeled according to their class (Figure 4.1). The polygon delineation was completed using a 0.5 millimeter Micron black pen which minimised the amount of line error.

All the land-cover polygons delineated on the air photographs were drawn starting from the bottom-right corner of the photograph, moving to the top and then back to the bottom, moving across the photo from right to left. This method was used for consistency, and the same steps were then applied to the remaining air photographs. The four sets of air photographs were analysed in this manner, resulting in four transparent overlay sheets containing polygons from the air photographs outlined and labeled according to their various land-cover classes. The classification of the 1994 air photographs was then field-checked, the methods used are given in section 4.3. Results of the accuracy assessment can be found in Chapter 5.

Figure 4.1 Example of Land-Cover Identification Method From Air Photographs

4.1.2 Image Polygon Transfer

Once the land-cover polygons were traced onto the transparent overlays, they were then transferred to a base map. The transparent overlays contained the delineated land-cover polygons from the air photographs, and were projected onto very large transparency sheets laid over maps of the study area. This projection was done using the PROCOM-2 optical transfer device, designed by Gregory Geoscience Ltd. in Ottawa, and part of the Remote Sensing Laboratory at Carleton University. The instrument projected the image

of the transparency onto a working surface that can accommodate large map sheets. The transparency was held between two glass plates that move together along horizontal and vertical axes, permitting movement throughout the entire image. The scale of the image can then be matched to the map using a Nikon zoom projection camera lens. Data registration is achieved by a series of adjustments of image scale and map rotation (Thomas, 1988, 43). In order to fit the projection scale of the PROCOM-2 device, the original polygon overlays were reduced by 50% using a standard photocopier with minimal distortion. This reduction in size allowed for an accurate projection and placement of the traced polygons onto the map sheet. Using this method the polygon overlays were matched with map sheets, meaning the overlays could then be accurately registered into a GIS database using the UTM co-ordinates of the maps.

The transparent overlays were projected onto copies of the 1:10,000 Ontario Base Map series for the study area, which were surveyed in 1987 (printed in 1988). The 1:10,000 series was chosen because the scale of the maps would provide a more accurate and time-efficient digitizing process later, and much of the land-cover delineated from the air photographs could already be found on the map sheets. Since at the 1:10,000 scale the study area could not fit on one individual map, four separate maps were taped together to create one large base map of the study area, upon which the overlays were projected.

The projected polygons of each individual overlay were transferred to the larger transparency sheets using a fine tip felt pen. A fine pen was needed, for projecting the

overlays through the PROCOM-2 lens onto the map sheet caused the polygon lines to increase in width. As a result, the middle of each projected line was traced onto the map sheet, and great pains were taken to trace the lines onto the map sheet accurately. This transfer process was aided by using the road intersections in the study site on the 1:10,000 map sheet as ground reference points. A process of local registration was used, whereby the projected transparent overlay was aligned with the reference points in one part of the image (map), and the various polygons adjacent to the points were transferred to the larger sheets. The projected image was then adjusted to match the next set of reference points, and the polygons adjacent to them were traced onto the larger sheets. In this fashion each individual overlay was transferred to the larger transparency sheets using the PROCOM-2, resulting in four large transparency sheets with land-cover polygons at a 1:10,000 scale.

4.2 GIS Analysis

4.2.1 Inputting Into The GIS

With the polygons transferred to the large transparency sheets, they were registered to the base map at a scale of 1:10,000. The next step was to digitize them into a GIS software package to create polygon coverages for 1964, 1977, 1987, and 1994 that could be analysed. The software chosen was Eppil7, a GIS package released by the

University of Minnesota and available in Carleton University's Geography Department

The system is raster-based and relatively easy to learn and use. Before digitizing could

begin, a Tic file was created which contained the UTM co-ordinates from the 1:10,000

base maps. This Tic file was used to register the large transparency sheets on the

digitizing tablet for every digitizing session. Once the bounds and co-ordinates were

established, each polygon was carefully digitized and then given its own point label

according to the class it belonged to. The transparency sheets were digitized in the same

manner as the polygons on the air photographs were delineated, bottom to top, right to

left. Some type of structured order in digitizing was important because the transparency

sheets were so large and detailed that it was not very difficult to lose one's place while

digitizing. The sheets were then digitized in chronological order, from 1964 through to

1994.

Once the final coverage of polygons was created, a transportation coverage for each year

was digitized separately. This was done to permit the overlaying of the transportation

routes onto the polygon coverages for the later creation of maps, and also aided in

determining the land area that transportation routes occupied inside and outside the

conservation area over time.

The final feature to be digitized were the Stony Swamp Conservation Area borders.

These boundary files were used later in analysing cumulative land-cover changes inside

and outside the conservation area, and for subsequent map production. As mentioned

earlier in this chapter, the boundaries of the conservation area have changed in the thirty year time span of this study. To maintain consistency the current delineated boundaries were selected for the 1994 polygon coverage, while the boundaries for the 1964, 1977, and 1987 files were based on the initial boundaries defined in 1982 by the N C C (National Capital Commission, 1982, 48)

Once the digitizing was completed the separate polygon, transportation, and boundary files were rasterised in Epp17. The rasterisation process converts the digitized file into an Epp1 display file, upon which analysis was performed. A cell size of 5 was chosen for rasterisation, based upon the possible minimum size of land-cover patches (1 ha) to be mapped within the study area. The rasterisation process changed the cell sizes on the files to m^2 , since UTM co-ordinates in meters were used to register the maps. Viewing the display file after rasterisation, it was apparent that each polygon coverage had to be cleaned and edited, for individual colours had bled out of their polygon boundaries into surrounding polygons. This was the result of the polygon lines not being fully closed, leaving a space through which the assigned colours passed. On the rasterised files any spaces between the digitized lines were repaired, any unlabeled polygons were found and properly labeled, and any polygons that were labeled twice were corrected. As well, areas between polygons that were not classed through the rasterisation process were given a default colour value of 255 by Epp17, and appeared as white specks throughout the image. These cells were reclassified to their assigned land-cover class.

Once the coverages were cleaned and edited, a legend file and a colour file were created for map production. The legend file contained all 14 classes that were identified on the air photographs. A colour file was created using a combination of values from 0 to 255 for red, green, and blue. The entire map-making procedure was completed in Dotshell, the map-making component of Epl7.

4.2.2 Polygon Analysis

Changes in land-cover inside and outside the borders of Stony Swamp Conservation Area were identified on the polygon files using the digitised boundary files. Epl7 has a Clip function that operates much like a cookie-cutter, which allowed analyses of polygons inside and outside of a fixed boundary. This was done by giving the polygons on the opposite sides of the boundary different point values. For this thesis, area inside the boundary was given a value of 1 while the area outside the boundary was given a value of 2. The boundary file was superimposed onto each polygon file using the Clip function, which created two new images for each of the four coverages, both inside and outside the boundary. After the Clip operation, the newly created output files were then counted using the Count command. Both inside and outside boundary counts of total area for each class were done, which were outputted to a file that was subsequently opened in a spreadsheet program. These newly created files listed the land-cover class, the number of cells occupied by each class, the percentage, the cumulative percentage,

and the total area occupied by each land-cover class in the part of the file that was clipped (Table 4.2). In the end, totals for the land-cover classes inside and outside the conservation area boundaries were calculated for all four polygon coverages using the Clip and Count functions. Overall land-cover change for each class without reference to the conservation area boundary was also calculated by simply adding the inside and outside totals together.

Table 4.2 Example of Count Output File

Count of C:\THESIS\CLIP\INCHNGE6.EPP

Land-Cover classes inside Stony Swamp Conservation Area boundaries in 1964

<u>Class</u>	<u>Count</u>	<u>Percent</u>	<u>Cumulative Percentage</u>	<u>Area (m²)</u>	<u>Legend</u>
1	245358	14.14	14.14	6133950.0	Dry Forest
2	5379	0.31	14.45	134475.0	Pine Plantation
3	1411	0.08	14.53	35275.0	Extractive
4	213260	12.29	26.82	5331500.0	Agriculture
5	43840	2.53	29.35	1096000.0	Non-Forest Wet
6	19928	1.15	30.50	498200.0	Wet Forest
7	246161	14.19	44.68	6154025.0	Non-Forest Dry
9	127	0.01	44.69	3175.0	Residential
10	628	0.04	44.73	15700.0	Under Construction
15	21461	1.24	45.97	536525.0	
255	937565	54.03	100.00	23439125.0	

1735118 cells are onsite

Using this method, totals for each class inside and outside the conservation area boundary were obtained. Offsite values (values outside the study area) such as the map background (value 255 in Table 4.2), and the value of the boundary files used to clip the polygon coverages were included in the count. As a result, the output counts in total area and percentage were not accurate for the fourteen land-cover classes and were re-calculated for the desired classes. Using Table 4.2 as an example, the cumulative percentage was calculated for only the fourteen required classes to determine the percentage and total area for each class.

The following steps were taken to calculate the correct class values: the percentage of each separate class was divided by the cumulative percentage total and then multiplied by 100, giving the totals for all the classes for the area excluding the offsite values. Referring to the example in Table 4.2, the percentage for dry forest, 14.14, was divided by 44.73, the cumulative percentage for the fourteen classes, then multiplied by 100 to determine the accurate percentage. Before class area totals were re-calculated, they were converted to hectares by dividing by 10,000. Subsequently, the corresponding area total for each class was then re-calculated, using the total area for only the fourteen classes multiplied by the percent of each class, and then divided by 100.

Using these two steps, percentage and total area for each class inside and outside the conservation area boundary for the four polygon coverages were calculated. The next step in the analysis determined how the different classes changed in area over time,

specifically from which other classes did they gain area from or lose area to over 30 years

This was done by running a two-way count on two coverage files at the same time in Epp17. A two-way count can be performed in two different ways: an individual file can be identified as the first file to be counted, or as the second. For example, the 1964 file can be chosen the first file, or it can be identified as the second file in the count with another coverage, such as the 1977 file, being made the first. When a later file, 1977 for example, is selected as being the first file counted, gains made by each class between that file and an earlier one can be calculated. If an earlier file, such as 1964, is chosen as being the first counted, losses by each class between 1964 and another file can be calculated. An arbitrary decision was made and the area gains, as opposed to losses, made by each land-cover between air photo sets were calculated to show how the land-cover patches within the entire landscape have been altered.

Using the two-way count, the class, count, percentage, and total area for each class were once again calculated. Percentages and total area were re-calculated once more to account for the inclusion of offsite values in the two-way count. From these results, tables were made showing the land-cover conversions between each class in hectares. These changes were mapped using the Reclass and Evaluate functions. First the classes on the different maps were grouped and given a unique identifier using Reclass, and were then compared using logical expressions with the Evaluate function. The following

expression, "IF OLD1 = 4 AND OLD2 = 7 THEN NEW1 =1 ELSE NEW1 =0 END" compared each individual raster cell on two separate files. If a cell that was class four on the first map, OLD1, became class seven by the second map, OLD2, then that cell was given a value of 1. If a cell on the first map remained unchanged on the second map then it was given a value of 0. Expressions such as this were used to determine the spatial extent of the conversions between classes in the study area, and produced three maps that show the spatial distribution of the changes from 1964-1977, 1977-1987, and 1987-1994.

Using these same functions other analyses were undertaken. Total land area occupied by the transportation network in the study area was calculated over the thirty year time period of this thesis using the Count function. Conversions of agricultural land to areas of urban, non-forest dry and pine plantations between 1964 and 1994 were also calculated, along with conversions of areas of non-forest dry to urban. Using the Reclass and Evaluate commands files were created showing where these changes between classes occurred, and a count of the files provided the total area for the specific classes involved in the changes. Using the Clip function changes between classes inside and outside the conservation area were also calculated.

The final analysis performed on the data set was a patch analysis. Most landscapes are heavily influenced by human use and the resulting landscape is a mosaic of different patches varying in size and shape which can influence a variety of ecological phenomena

(Odum and Turner, 1991, 139) Patch analysis is but one method, along with connectivity tests and fractal analysis, that can be used to determine the characteristics of a landscape. To perform the patch analysis each natural land-cover polygon was given a unique identifier using Epp17. Then a Count was performed on the reclassified files to calculate the number of polygons on each file. From the Count file, the average patch size and variability of the patches was then calculated for the natural land-cover patches inside and outside the conservation area over the thirty year time period.

4.3 Accuracy Assessment

Accuracy assessment or validation is an important step in the processing of remote sensing and GIS data. It aids in determining the value of the resulting data to a particular user (Janssen and van der Wel, 1994, 419). A responsible use of the stored data is only possible if the quality and accuracy of the data are known. Performing spatial data analysis operations with data of unknown accuracy or with incompatible error types will produce a product with low confidence limits and lead to restricted use in decision making (Lunetta et al., 1991, 667). Previous works by Hord (1976), Czaplewski (1992), Moody and Woodcock (1994) and Janssen and van der Wel (1994) have studied the possible errors that can be accumulated when integrating remotely sensed data and GIS. Lunetta et al. (1991) have compiled a thorough review of methods

for assessing many of these errors, and some of the following points have been adapted from their work

The process of integrating remote sensing and GIS data includes many procedures, such as image interpretation and digitizing (Figure 4.2)

Figure 4.2 Accumulation of Error

Source: Lunetta et al. (1991)

Error may be transferred from one data process to the next, unknown to the analyst until it manifests itself in the final product, error may accumulate throughout the process in an additive or multiplicative fashion, and individual process errors can be overshadowed by other errors of greater magnitude (Lunetta et al. 1991, 677)

4.3.1 Types of Error

Sets of air photographs were interpreted for the identification of land-cover change in this thesis, and the results were digitized into a GIS for analysis. Error that can be accumulated and transported through the various steps before or after either or both of these two procedures will be discussed in the following paragraphs.

Geometric errors caused by variations in altitude, attitude, velocity of the camera platform, Earth curvature, and relief displacement can be introduced to the image, even though conventional air photography has the advantage of nearly instantaneous film exposure using highly calibrated equipment (Lunetta et al. 1991, 678). Registration errors, such as errors in drawing and interpreting boundary lines, can occur as a result of the classification process and by misregistering polygon boundaries during the digitizing process using the GIS.

A GIS database is formed by different types of information with their own accuracies. If one layer of information is queried, the maximum error is that worst layer. If many layers of information are queried, accuracy may be worse or better than the worst layer. Being an assemblage of information from diverse sources, it is important for the user to know the data sources used so that he/she can make their own decisions about the accuracy and usefulness of the final product produced.

An accuracy assessment was performed twice on the data set and determined the accuracy of the final map products created using the air photographs and GIS, with a total of three separate measures which assessed the total error through the entire integration process. The line thickness of the projected lines when using the PROCOM-2 device was calculated to assess possible distortions in the polygon transfer, and the accuracy of the registration of the polygons within the GIS database was assessed. As well, a classification accuracy was performed which determined the correspondence between the class labels assigned to the 1994 air photo and the "true" class on the ground.

4.3.2 Data Processing Errors

One of the most difficult sources of error to quantify is human subjectivity during analysis and interpretation. The two primary procedures of this thesis included judging

to which class the land-cover belonged (classification), and the process of transferring the delineated polygons from the transparent overlay sheets into the GIS. Performing both these tasks involved many steps through which error could have been accumulated. To assess the possible error in these steps, a number of measures were used:

a) Calculating Projected Line Thickness

The thickness of the delineated lines being projected from the transparent overlays through the PROCOM-2 device onto the basemaps was calculated. Five measurements were taken of the line thickness, which were then subsequently averaged to one value and multiplied by 100 to calculate the percentage. The average width of the lines originally drawn on the air photograph overlays were approximately .05 millimeters thick. With projection of these lines through the PROCOM-2 onto the larger transparent sheets, the line width enlarged to .2 millimeters. At a 1:50,000 scale the pen width of 0.05 equals 2.5 metres on the ground, therefore the linear error might be as much as 2.5% of the 100 x 100 metre minimum mapping unit. Recognising this change in line thickness will allow for a clearer assessment of the final product. As a result of this increase in line thickness, the lines projected from the transparent overlay sheets onto the basemaps were drawn through the middle of the projected lines, in an attempt to reproduce the polygon boundaries as accurately as possible.

b) Assessing the Digitizing Process

The four sheets that contained the delineated polygons were digitized into a GIS. As a means of assessing the possible error in this digitizing process, a digitizing test was devised (Figure 4.3). Three lines of varying degrees of difficulty "simple, medium and complex" were drawn on a piece of paper and were subsequently digitised three times over a one day period.

Figure 4.3 Boundary Lines Used In The Digitizing Test

Any variation in the digitizing process was then measured, resulting in a final average that indicated the amount of possible error incurred through the digitizing of the polygon coverages. This value and the resulting positional inaccuracy could then be taken into account when interpreting the boundaries of the polygons on the final map products.

4.3.3 Classification Accuracy

Assessing the accuracy of the classified data is an important component of any research project using spatial data. To perform an accuracy assessment correctly, it is necessary to compare the classified data and the reference, or ground, data. The relationship between the two forms of data can then be summarized in an error matrix. An error matrix is a square array of numbers set out in rows and columns which express the number of sample units assigned to a particular category relative to the actual category as verified on the ground. The columns usually represent the reference data, while the rows indicate the classification generated from the remotely sensed data (Congalton 1991: 36). From the error matrix can be calculated the overall accuracy, which is computed by dividing the total correct found along the major diagonal by the total number of pixels in the matrix.

With the majority of the work for this thesis occurring during the winter months, the standard process for the accuracy assessment ended up being completed in reverse order

The overall producer's accuracy for all the sampled polygons is 89.8%, while the overall user's accuracy is 79%. Individual user's and producer's accuracies for each class in the error matrix are listed in Table 5.3, with pine plantation and commercial having the highest user's accuracy and non-forest dry having the highest producer's accuracy.

Another method of assessing the accuracy of the classification is the Kappa analysis. Kappa measures the difference between the observed agreement (91 correct out of 104 sampled) and the expected agreement by chance by incorporating the error accumulated in the columns and rows. The Kappa analysis provides a measure of agreement that is adjusted for chance agreement.

Table 5.3 Producer's and User's Accuracies

Class	User's	Producer's
Dry Forest	80%	88%
Pine Plantation	100%	92%
Non-Forest Wet	90.5%	95%
Wet Forest	75%	38%
Non-Forest Dry	93.1%	96.4%
Commercial	100%	67%

Instead of first selecting training sites for classification and then performing a ground survey to assess the accuracy of the classification, the air photographs were classified first and the resulting maps were used to identify possible test sites to visit for the accuracy assessment

To assess the accuracy in the classification of individual categories the producer's and user's accuracies were calculated (Congalton, 1991, 38). The producer's accuracy measures the probability of a reference area being correctly classified in the classification, and indicates how well the study area has been classified. The user's accuracy indicates the probability that an area classified on the map actually represents that category on the ground. These accuracy measures are important and should be reported, because it is never known how the classified product may be used (Jensen, 1996, 250).

Another measure of classification accuracy used was the Kappa coefficient. The Kappa analysis is a multivariate technique that resulted in the Khat statistic, a value of 1 indicates perfect effectiveness of the classification, but as the effect of chance agreement increases and the percentage correct decreases the Khat statistic decreases and may become a negative value (Campbell, 1987, 350). The Khat statistic was calculated by measuring the actual agreement minus the agreement expected by chance, this was done through the multiplication of the row and column marginal totals and incorporating them along with the major diagonal values. The overall accuracy only takes into account the major diagonal values, so the results between the Khat statistic and the overall accuracy

can be different because they measure different information. With the overall accuracy and the Khat statistic reflecting different information contained within the error matrix, they were both calculated "to glean as much information from the error matrix as possible" (Congalton, 1991, 41).

The sampling scheme used is an important part of any accuracy assessment. Selection of the proper scheme is essential in generating an error matrix that is representative of the entire classified image, and a balance between what is statistically sound and what is practically attainable must be found for the scheme (Congalton, 1991, 43). The sampling scheme used for this study was systematic, as opposed to a purely random sampling. Polygons that could not be easily identified from the air photographs and were noted as "questionable", such as dry forest, wet forest and non-forest wet polygons, were identified for field checking. Polygons that were relatively easily identified and were not highly variable over time, such as residential, were only sampled if encountered en route to the polygons specifically targeted for sampling.

4.3.4 Field Work

Assessing the accuracy of the 1994 air photo classification was done over a two-day period, with a representative set of 117 out of 220 possible polygons sampled throughout the study area. Six of the fourteen classes sampled (extractive, agriculture,

The resulting Khat statistic for the above error matrix is calculated to be .84 meaning that the classification achieved an accuracy that is 84% better than would be expected from a random assignment of pixels to categories.

5.2 GIS Analysis

Changes in the Greenbelt area between 1964 and 1994, and specifically in the Stony Swamp region, have had many effects on the landscape and the variety of organisms that inhabit it. Inside the conservation area borders, the shift from a landscape of many open patches because of logging and extensive clearing for agriculture to a conservation area has resulted in changes in the spatial patterns of land-cover classes. At the same time, the landscape outside the conservation area has undergone a gradual progression to an urbanized landscape that has also affected land-cover. Through analysis in the GIS, a detailed picture of cumulative change was developed for the study area. In this section patterns of land-cover in each year are described in chronological order along with a patch analysis, while in section 5.3 a discussion of the changes and their role in altering the processes of the study area will be evaluated.

CHAPTER 5

RESULTS AND DISCUSSION

This chapter detailing the results of the research and their discussion is divided into several sections. In the first section, the results of the accuracy assessment of the digitising process and the air photo classification are provided. The second section contains the results of the quantitative analysis using the GIS on the different land-cover patches in the study area over time, including the patch analysis. The third section discusses the results qualitatively in a landscape ecology context as they are examined to explain the relationships between land-cover patches in the area, changes in their characteristics, and the effect on the landscape that serves as a home for many different wildlife species.

5.1 Digitizing Test and Accuracy Assessment

Separate tests were performed on the dataset to assess the accuracy of the final maps and the data used to create them. In assessing the accuracy of the digitising process, a digitizing error was calculated (Table 5.1). Given that equal proportions of each line

Table 5.1 Digitising Accuracy Test

Assessing Digitising Accuracy					Units in millimetres				
Simple	Test 1	Test 2	Test 3	Average	Medium	Test 1	Test 2	Test 3	Average
1	0	0	0		1	0.03	0.08	0.10	
2	0	0	0		2	0.01	0.06	0.09	
3	0	0	0		3	0.01	0.08	0.10	
4	0	0	0		4	0.00	0.00	0.00	
5	0	0	0		5	0.10	0.01	0.01	
6	0	0	0		6	0.08	0.01	0.00	
7	0	0	0		7	0.10	0.04	0.01	
8	0	0	0		8	0.08	0.08	0.01	
9	0	0	0		9	0.10	0.10	0.09	
10	0	0	0		10	0.10	0.09	0.09	
Average	0	0	0	0	Average	0.06	0.05	0.05	0.05

Complex	Test 1	Test 2	Test 3	Average
1	0.00	0.10	0.10	
2	0.03	0.07	0.09	
3	0.03	0.00	0.10	
4	0.00	0.08	0.10	
5	0.05	0.02	0.09	
6	0.00	0.00	0.09	
7	0.00	0.00	0.05	
8	0.10	0.02	0.01	
9	0.10	0.01	0.01	
10	0.10	0.02	0.02	
Average	0.04	0.03	0.07	0.05

Average Calculated

Digitising Error For 3 Lines $0+0.05+0.05/3 = 0.034$ Error x 100 = 3.4

Total Average Error = 3.4%

type complexity were present, this suggests that the average accuracy of the placement of the polygon boundaries through digitising is 96.6%. As well, a maximum linear error of 7.5% was calculated for the polygons by adding the 2.5% linear error of the projected line thickness and the calculated 5% line width on the photos together. This means the minimum accuracy in relation to the polygon minimum mapping unit was 92.5%, equaling a difference of 7.5 metres on either side of the boundary of the 100 x 100 metre, or 1 ha, minimum mapping unit. From this the maximum allowable linear error was also calculated by squaring the minimum accuracy (92.5) and dividing the resulting number by 10,000. The maximum allowable linear error was calculated to be 14%, giving a quantitative measure of the reliability of the digitising process. From Table 5.1 it is clear that most error was accumulated in digitising the medium and complex lines. These two types of lines are more intricate than the simple line, and it was more difficult to repeatedly digitise them accurately.

An accuracy assessment was also performed on the manual classification of land-cover patches from the air photographs. With the exclusion of the six land-cover classes outlined in section 4.3.4 (extractive, agriculture, residential, industrial, open water and institutional), the accuracy of the 104 polygons sampled in the ground survey are represented in the error matrix below (Table 5.2).

Table 5.2 Error Matrix

Reference Data										
Classified Data	Dry For	Pine Pl	Non-For	Wet	Wet For	Non-For	Dry	Comm	Indust	Row Totals
Dry Forest	28		1		1	2				32
Pine Plantation	1	12								13
Non-Forest Wet	1		19							20
Wet Forest	4		1		3					8
Non-Forest Dry	1					27				28
Commercial								2	1	3
Industrial										
										91
Column Totals	35	12	21		4	29		2	1	104

The overall classification accuracy is 87.5%, as 91 sites were correctly classified out of 104 sites sampled. The wet forest and dry forest classes were the most difficult to identify from the air photographs, with wet forest being misclassified as dry forest in 11% of sampled sites. This is the result of not being able to determine if the soil beneath the forest is wet or not simply from the air photographs. Difficulties in distinguishing between tree species from black and white air photographs has been documented by Ulliman (1992). Using colour infrared photographs for an improved discrimination between forest types to improve accuracies has been reported in previous work by Blanchard (1977) and Civco et al. (1986). As well, undertaking ground surveys before classification to increase interpreter knowledge of the study area could improve final accuracies if resources permit it.

The overall producer's accuracy for all the sampled polygons is 89.8%, while the overall user's accuracy is 79%. Individual user's and producer's accuracies for each class in the error matrix are listed in Table 5.3, with pine plantation and commercial having the highest user's accuracy and non-forest dry having the highest producer's accuracy.

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The resulting Khat statistic for the above error matrix is calculated to be .84, meaning that the classification achieved an accuracy that is 84% better than would be expected from a random assignment of pixels to categories.

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Changes in the Greenbelt area between 1964 and 1994, and specifically in the Stony Swamp region, have had many effects on the landscape and the variety of organisms that inhabit it. Inside the conservation area borders, the shift from a landscape of many open patches because of logging and extensive clearing for agriculture to a conservation area has resulted in changes in the spatial patterns of land-cover classes. At the same time, the landscape outside the conservation area has undergone a gradual progression to an urbanized landscape that has also affected land-cover. Through analysis in the GIS, a detailed picture of cumulative change was developed for the study area. In this section patterns of land-cover in each year are described in chronological order along with a patch analysis, while in section 5.3 a discussion of the changes and their role in altering the processes of the study area will be evaluated.

5.2.1 Land-Cover In 1964

The spatial patterns of the land-cover patches in 1964 can be seen in Figure 5.1. The total area occupied by the fourteen individual land-cover classes in hectares is provided in Table 5.4.

Table 5.4 Totals of Land-Cover Types Inside Stony Swamp Conservation Area

Class	1964		1977		1987		1994	
	Percent	Area (ha)	Percent	Area (ha)	Percent	Area (ha)	Percent	Area (ha)
Dry Forest	41.6	609.8	34.1	655.1	34.7	665.7	46.4	721.9
Pine Plantation	0.7	13.2	16.8	206.9	17.0	327.0	18.3	362.9
Non-Forest Wet	5.7	108.6	8.6	165.0	10.2	196.9	10.3	205.2
Wet Forest	2.6	49.3	3.0	57.8	2.8	53.9	2.6	52.4
Non-Forest Dry	31.4	604.9	29.3	562.3	25.1	482.6	25.7	486.3
Open Water			1.2	23.6	3.7	31.6	2.0	39.1
Extractive	0.2	3.8	0.1	2.1	0.2	3.5	0.1	2.6
Agriculture	27.5	527.4	11.8	226.3	5.8	116.9	1.7	54.2
Commercial								
Residential	0.0	0.4	0.3	5.2	0.6	11.1	0.5	10.7
Bare Soil					1.0	19.8		
Under Construction	0.1	1.7	0.1	2.1	0.2	4.8	2.1	41.3
Industrial			0.0	0.8				
Institutional			0.6	11.9	0.5	10.4	0.5	9.3

The borders of the conservation area did not exist in 1964, which accounts for the relatively high proportion of land occupied by residential and agriculture in this portion of the study area. Dry forest and non-forest dry occupied the greatest area with totals of 609.8 ha and 604.9 ha respectively. The number of patches is high and the patches are of various sizes and shapes. Polygons of non-forest wet and dry forest, along with two

**Figure 5.1 STONY SWAMP AND SURROUNDING
AREA LAND-COVER IN 1964**

\ Transportation Routes
 • Stony Swamp Conservation
 • Area Boundary

Scale: 0 1 2 mi

Dry Forest
 Pine Plantation
 Extractive
 Agriculture
 Non-Forest Wet
 Wet Forest
 Non-Forest Dry
 Commercial
 Residential
 Under Construction
 Industrial
 Open Water
 Bare Soil
 Institutional

Areas of dry forest and non-forest dry were located mainly west and south of the conservation area, while the majority of wet forest was found on land west of the conservation area.

Agriculture west and south of the conservation area occupied roughly 40% of the land reflecting its importance in the area at that time. Residential sites, mainly located in the still growing community of Bells Corners north of the conservation area, comprised only about 10% of the landscape in 1964. The extractive industries located south of the conservation area were not very close to its borders at this time. Land-cover patches such as dry forest, non-forest wet, wet forest and non-forest dry outside the conservation area, located in the western and southern portions of the study area, have some links to ecosystems inside the conservation area. This provided connectivity between patches and corridors, something that is required for species movement between patches (Forman and Godron, 1986: 119). Dry forest patches in the southeast corner are small and appear to be isolated from each other by sections of agriculture, resulting in low connectivity between these patches and inhibiting wildlife movement.

5.2.2 Land-Cover In 1977

In Figure 5.2 the spatial patterns of the landscape by 1977 can be seen. Dry forest, wet forest, non-forest wet, pine plantations, and patches of open water made gains in area

conservation area from previously non-forest dry sections. Land under construction grew 86% over the time period, increasing in area by 35.2 ha mainly west of the conservation area. Agriculture decreased 99% in total area, losing 381.8 ha along the western end of the study area where land under construction was increasing. Overall, patches of dry forest, wet forest, pine plantation, non-forest dry, and non-forest wet land-cover outside the conservation area all continued to decrease in number and size as large tracts of residential areas and land under construction began to dominate the landscape.

5.2.4 Land-Cover In 1994

By 1994 the interior of the conservation area was mainly comprised of dry forest, wet forest, non-forest wet, non-forest dry, pine plantation, and open water classes (Figure 5.4). A notable exception was that the land under construction class increased by 760% from 4.8 ha to 41.3 ha. This is the result of the construction of Highway 416 occurring within the eastern end of the conservation area. In 1994 small patches of agriculture could still be found in the northwest corner of the conservation area as agriculture decreased by 51% to 54.2 ha. The number of patches, their variability in size, and the variety of land-cover classes all remained high in the conservation area while the majority of the patches remained small in size. By 1994 many open areas visible in 1964 had been forested, creating the contiguous forested area that is Stony Swamp Conservation Area.

while non-forest dry decreased to 562.3 ha for a drop of 7%. Most notable increase is the 1,467% increase in area occupied by pine plantations inside the conservation area

By 1977 pine plantations had increased from 13.2 ha in 1964 to 206.9 ha. The majority of these plantations were begun on land that had been non-forest dry at various locations inside the conservation area in 1964. Agriculture appeared to be slowly pushed out of the conservation area and had decreased 57% by 1977, being isolated to small patches along the eastern and northwest corners of the conservation area. The number of patches remains high inside the conservation area at this time, with the patches being of many sizes and shapes. Pine plantations closed many of the openings between patches in the conservation area, providing more forest cover and improving conditions for movement between patches.

Outside the conservation area dry forest, wet forest, open water, non-forest dry, non-forest wet and pine plantations increased slightly in area. Non-forest dry had the largest gain with a 40% increase of 161.3 ha, mainly concentrated in the southern section of the study area. Extractive and residential land-cover increased by 89% and 33%, 53.5 ha and 57.5 ha respectively. This increase in residential area corresponds with an increase in the size of Bells Corners. On the other hand agriculture decreased in its share of the area by 48% to 384.6 ha, with losses occurring mainly in the vicinity of Bells Corners and south of the conservation area. Land outside the conservation area was still dominated in 1977 by larger homogeneous patches of land-cover than those inside the

conservation area. Smaller land-cover patches of dry forest, non-forest dry, wet forest, non-forest wet, and pine plantations in this section of the study area are still isolated from each other and have low connectivity.

5.2.3 Land-Cover In 1987

The spatial patterns in 1987 can be seen in Figure 5.3. Inside the conservation area, dry forest continued to occupy the largest total area of all the classes, almost 35% of the conservation area. Non-forest dry decreased by 14%, mainly near the centre of the conservation area, while wet forest patches also dropped in area by 7%. Agriculture also decreased 51% between 1977 and 1987 by losing 115.3 ha. By 1987 all that remained of agriculture in the conservation area were four small sections located in the eastern and northwestern corners. A mosaic of different land-covers of various sizes and shapes still characterised the landscape inside the conservation area. Together these patches comprised an increasingly connected heterogeneous landscape of trees, wetlands and open areas. Outside the conservation area, the dry forest, wet forest, non-forest wet, and pine plantation classes decreased in total area between 1977 and 1987. A 5% gain was made by non-forest dry between 1977 and 1987, increasing in area by 26 ha in the western portion of the study site, while open water bodies increased 62% in area by 2.4 ha. Some classes appeared to gain area at the direct expense of other classes, such as residential land-cover, which increased by 136% and gained 315.2 ha mainly south of the

**Figure 5.3 STONY SWAMP AND SURROUNDING
AREA LAND-COVER IN 1987**

\ Transportation Routes
 ■ Stony Swamp Conservation
 ■ Area Boundary

Scale: 0 1 2 mi

Dry Forest
 Pine Plantation
 Extractive
 Agriculture
 Non-Forest Wet
 Wet Forest
 Non-Forest Dry
 Commercial
 Residential
 Under Construction
 Industrial
 Open Water
 Bare Soil
 Institutional

conservation area from previously non-forest dry sections. Land under construction grew 86% over the time period, increasing in area by 35.2 ha mainly west of the conservation area. Agriculture decreased 99% in total area, losing 381.8 ha along the western end of the study area where land under construction was increasing. Overall, patches of dry forest, wet forest, pine plantation, non-forest dry, and non-forest wet land-cover outside the conservation area all continued to decrease in number and size as large tracts of residential areas and land under construction began to dominate the landscape.

5.2.4 Land-Cover In 1994

By 1994 the interior of the conservation area was mainly comprised of dry forest, wet forest, non-forest wet, non-forest dry, pine plantation, and open water classes (Figure 5.4). A notable exception was that the land under construction class increased by 760% from 4.8 ha to 41.3 ha. This is the result of the construction of Highway 416 occurring within the eastern end of the conservation area. In 1994 small patches of agriculture could still be found in the northwest corner of the conservation area as agriculture decreased by 51% to 54.2 ha. The number of patches, their variability in size, and the variety of land-cover classes all remained high in the conservation area while the majority of the patches remained small in size. By 1994 many open areas visible in 1964 had been forested, creating the contiguous forested area that is Stony Swamp Conservation Area.

**Figure 5.4 STONY SWAMP AND SURROUNDING
AREA LAND-COVER IN 1994**

\ Transportation Routes
 • Stony Swamp Conservation
 •• Area Boundary

Scale: 0 1 2 mi

Dry Forest
 Pine Plantation
 Extractive
 Agriculture
 Non-Forest Wet
 Wet Forest
 Non-Forest Dry
 Commercial
 Residential
 Under Construction
 Industrial
 Open Water
 Bare Soil
 Institutional

Outside the conservation area the dry forest, pine plantation, wet forest, non-forest dry, and non-forest wet land-covers continued to decrease in total area, such as non-forest dry decreasing 32% to 396 ha in area mainly west of the conservation area. These land-cover classes are found mainly south and west of the conservation area mixed in with residential areas. Classes related to urban areas continued to increase, such as the extractive industries south of the conservation area increasing 23% or 39.6 ha in total area. As well, residential land-cover increased 35% in area and began to dominate the land west of the conservation area. Land under construction continued to increase in territory west of the conservation area, up 52% to 115.4 ha. Dry forest, wet forest, non-forest wet, and pine plantations outside the conservation area in 1994 remained very small in number and size, as they were modified to fit the urbanising landscape. Development continued up to the borders of the conservation area, specifically along the south-west borders near Kanata.

Land-cover categories identified in this thesis that changed substantially in percentage area between 1964 and 1994 (pine plantations, non-forest dry, non-forest wet, agriculture, under construction, residential, and extractive) both inside and outside the conservation area are graphed in Figures 5.5 and Figures 5.6 respectively. The most substantial change that occurred inside the conservation area of all the land-cover classes is the reduction of agriculture. The graphs illustrate two patterns of succession: large

Figure 5.5 Land-Cover Change Inside Stony Swamp Conservation Area

sections of agriculture outside the conservation area abandoned and gradually changing to a non-forest dry land-cover, which in turn were modified by development and turned into residential land-cover, and the abandonment of agriculture inside the conservation area, with these areas becoming pine plantations. It can be seen in Figure 5.5 that agriculture land-cover as a percentage of area inside the conservation area dropped sharply between 1964 to 1994, while pine plantations in the conservation area

Figure 5.6 Land-Cover Change Outside Stony Swamp Conservation Area

rose sharply as a percentage of total area from 1964 to 1987, and then evened off by 1994. Figure 5.5 also shows that the non-forest wet class made modest gains in percentage area of the conservation area, while the non-forest dry class decreased slightly over the thirty year time period. Finally, areas under construction began to increase between 1977 and 1994 inside the conservation area boundaries.

The dramatic decline in agriculture outside the conservation area is illustrated in Figure 5.6 along with the increase in other land-cover types, particularly the large increase in residential. Land under construction and extractive also increased in percentage area outside the conservation area. Non-forest dry patches increased in area outside the conservation area until 1987, when they began to decrease. Figure 5.5 and Figure 5.6 illustrate the different trends inside and outside the conservation area boundary: the regeneration of vegetative species due to the creation of the conservation area and its protection from further disturbance, and the growing presence of land-cover related to urban development outside the conservation area.

Total area for each land-cover class throughout the entire study site, regardless of their location with respect to the conservation area, are given in Table 5.6. The decline in agriculture throughout the study area, from 1260.2 ha to 57.8 ha, is the most obvious.

Table 5.6 Total Area Occupied By Land-Cover Classes In Study Area (ha)

	1964	1977	1987	1994
Dry Forest	957.7	1007.7	1003.2	960.9
Pine Plantation	17.7	221.7	329.8	370.9
Non-Forest Wet	144.7	201.6	208.7	214.2
Wet Forest	113.4	135.8	73.8	62.4
Non-Forest Dry	1000.5	1119.1	1065.5	882.3
Open Water		27.5	37.9	44.5
Extractive	63.8	116.0	173.1	211.8
Agriculture	1260.2	610.9	113.7	57.8
Commercial	24.3	23.4	35.1	31.6
Residential	174.4	236.8	558.0	748.6
Bare Soil			58.6	3.6
Under Construction	1.7	42.9	80.8	156.7
Industrial		3.9	9.9	16.3
Institutional		11.9	10.4	12.0

trend along with the increase in urban features like residential and land under construction. Land appears to have been removed from agriculture and put into other forms like natural land-cover, with the underlying forces causing this related to more non-farm, urban-related forces than to agricultural ones.

A two-way count in Epp17 was used to determine the exchanges in area between the different land-cover classes throughout the entire study area between 1964-1977, 1977-1987, and 1987-1994. Table 5.7 shows the gains in area between all the classes from 1964 to 1977. The spatial extent of these conversions is illustrated in Figure 5.7.

Between 1964 and 1977 agriculture lost the most area when compared to the other fourteen land-cover classes identified in the study area, losing a total of 676 ha with the majority, 418.8 ha, being converted to non-forest dry through the process of farmland abandonment. Areas under construction and residential land also acquired territory at the expense of agriculture, 40.3 ha and 82.9 ha respectively. Although it gained area from agriculture, non-forest dry lost a total of 412.7 ha, mainly to dry forest and pine plantations in the study area. The area where the largest conversions occurred can be seen on Figure 5.7 south and north of the conservation area, and along the conservation area's eastern borders.

Table 5.7 Area Gains Between Classes From 1964 To 1977 In Total Study Area (ha)

		Losses 1964								
		<u>Class</u>	<u>Dry Forest</u>	<u>Pine Plantation</u>	<u>Extractive</u>	<u>Agriculture</u>	<u>Non-Forest Wet</u>	<u>Wet Forest</u>	<u>Non-Forest Dry</u>	<u>Total Gains</u>
Gains 1977		Dry Forest	-	5.1	2.8	57.1	15.6	20.9	179.4	288.1
		Pine Plantation	16.3	-	1.0	92.0	1.1	1.9	100.1	212.7
		Extractive	20.7	-	-	4.3	2.2	-	48.7	72.9
		Agriculture	5.1	0.3	-	-	-	0.2	22.1	29.0
		Non-Forest Wet	76.3	0.1	0.4	6.7	-	5.3	17.4	106.2
		Wet Forest	23.2	-	-	4.1	9.1	-	16.0	52.4
		Non-Forest Dry	85.7	3.2	15.5	418.8	5.0	1.9	-	535.3
		Commercial	-	-	-	1.5	-	-	-	9.5
		Residential	1.1	-	-	51.3	-	-	19.0	82.9
		Under Construction	-	-	-	38.3	-	-	2.0	40.3
		Industrial	-	-	-	-	3.9	-	-	3.9
		Open Water	8.1	2.5	1.7	1.9	12.3	-	1.0	27.5
		Bare Soil	-	-	-	-	-	-	-	-
		Institutional	1.0	-	0.1	-	-	-	10.0	11.1
Total Losses			237.5	11.2	21.5	676.0	49.2	30.2	412.7	
		Losses 1964								
		<u>Class</u>	<u>Commercial</u>	<u>Residential</u>	<u>Under Construction</u>	<u>Industrial</u>	<u>Open Water</u>	<u>Bare Soil</u>	<u>Institutional</u>	
Gains 1977		Dry Forest	-	6.3	0.9	-	-	-	-	
		Pine Plantation	-	0.3	-	-	-	-	-	
		Extractive	-	-	-	-	-	-	-	
		Agriculture	-	1.3	-	-	-	-	-	
		Non-Forest Wet	-	-	-	-	-	-	-	
		Wet Forest	-	-	-	-	-	-	-	
		Non-Forest Dry	-	4.5	0.7	-	-	-	-	
		Commercial	-	7.9	-	-	-	-	-	
		Residential	11.5	-	-	-	-	-	-	
		Under Construction	-	-	-	-	-	-	-	
		Industrial	-	-	-	-	-	-	-	
		Open Water	-	-	-	-	-	-	-	
		Bare Soil	-	-	-	-	-	-	-	
		Institutional	-	-	-	-	-	-	-	
Total Losses			11.5	20.3	1.6	-	-	-	-	

**Figure 5.7 AREAS OF LAND-COVER CHANGE
BETWEEN 1964 AND 1977**

Between 1977 and 1987 minor exchanges in area occurred between all the land-cover classes (Table 5.8)

Table 5.8 Area Gains Between Classes From 1977 To 1987 In Total Study Area (ha)

		Losses 1977						
		Class	Dry Forest	Pine Plantation	Extractive	Agriculture	Non-Forest Wet	Wet Forest
							Non-Forest Dry	Total Gains
Gains 1987	Dry Forest	-	21.9	3.7	8.9	33.1	35.9	280.6
	Pine Plantation	52.6	-	-	3.3	10.2	1	164.1
	Extractive	40.4	-	-	-	12.2	15.9	71.6
	Agriculture	3.0	0.7	-	-	0.2	0.7	12.6
	Non-Forest Wet	53.8	8.1	0.7	0.2	-	14.3	95.8
	Wet Forest	22.9	-	-	-	0.7	2.3	25.9
	Non-Forest Dry	73.3	17.5	7.0	340.2	15.1	22.9	479.8
	Commercial	-	-	-	-	-	3.6	11.5
	Residential	30.1	2.8	-	57.7	-	197.1	326.8
	Under Construction	4.2	6.1	-	12.8	1.0	8.0	76.1
	Industrial	1.9	-	-	-	-	7.9	9.8
	Open Water	3.0	0.9	0.5	-	15.9	0.2	22.8
	Bare Soil	0.5	-	-	50.7	-	2.0	58.6
	Institutional	0.4	-	-	-	-	0.6	1.0
	Total Losses		284.1	58.0	11.9	510.2	88.4	527.1
		Losses 1977						
		Class	Commercial	Residential	Under Construction	Industrial	Open Water	Bare Soil
								Institutional
Gains 1987	Dry Forest	-	-	1.2	-	-	2.9	1.8
	Pine Plantation	-	-	-	-	-	0.4	-
	Extractive	-	-	-	3.1	-	-	-
	Agriculture	-	-	1.0	-	-	-	-
	Non-Forest Wet	-	-	-	0.8	6.8	-	-
	Wet Forest	-	-	-	-	-	-	-
	Non-Forest Dry	-	1.6	0.9	-	1.3	-	-
	Commercial	-	-	7.9	-	-	-	-
	Residential	1.8	-	37.3	-	-	-	-
	Under Construction	-	-	-	-	-	-	-
	Industrial	-	-	-	-	-	-	-
	Open Water	-	-	-	-	-	-	-
	Bare Soil	-	-	-	-	-	-	-
	Institutional	-	-	-	-	-	-	-
	Total Losses		1.8	10.7	39.2	3.9	31.4	1.8

Most notably agriculture again lost the most area, a total of 510.2 ha, following the period when most farmland was being abandoned, masked by a conversion to non-forest dry. Between 1977 and 1987 urbanisation increased in the study area as 211.4 ha of non-forest dry patches were converted to residential and to areas under construction. These large conversions can be seen in Figure 5.8, occurring mainly south of the conservation area and along the southwest corner of the study area.

Finally, conversions between 1987 and 1994 are given in Table 5.9, where the most dominant trend is the conversion of land to residential and under construction land-cover. These changes are illustrated in Figure 5.9 along the southwestern corner of the study area. Conversions of agriculture slowed, mainly because agricultural land-cover in the study area by this time had already been greatly reduced. It can be seen that conversions of large land patches of non-forest dry to residential or under construction between this period occurred largely outside or along the borders of the conservation area as urban pressures continued to move closer. From these maps it is evident that some sites have been undergoing conversion for most of the thirty year study period. In the extreme southwest corner land-cover has changed forms many times, along a gradient from agriculture to non-forest dry to urban development. This process illustrates the stages of land conversion from farmland to abandoned farmland to urban development.

**Figure 5.8 AREAS OF LAND-COVER CHANGE
BETWEEN 1977 AND 1987**

Stony Swamp Conservation
Area Boundary

No Change
Change

Scale: 0 1 2 mi

Table 5.9 Area Gains Between Classes From 1987 To 1994 In Total Study Area (ha)

		<u>Losses 1987</u>							
	<u>Class</u>	<u>Dry Forest</u>	<u>Pine Plantation</u>	<u>Extractive</u>	<u>Agriculture</u>	<u>Non-Forest Wet</u>	<u>Wet Forest</u>	<u>Non-Forest Dry</u>	<u>Total Gains</u>
<u>Gains 1994</u>	Dry Forest	-	53.3	4.4	5.2	31.3	4.5	135.6	241.8
	Pine Plantation	57.7	-			8.5	2.6	51.1	125.8
	Extractive	26.3		-		7.5		18.7	52.5
	Agriculture				-			0.7	0.7
	Non-Forest Wet	40.9	4.6			-	13.0	7.4	73.2
	Wet Forest	8.5	3.2			2.9	-	5.0	19.7
	Non-Forest Dry	71.1	17.9	4.1	46.8	9.8	0.7	-	223.6
	Commercial								2.4
	Residential	54.2					6.2	83.2	217.0
	Under	17.7	5.3	4.2	1.6		1.9	95.6	142.5
	Construction								
	Industrial	2.6						1.7	8.3
	Open Water	3.6	1.8		0.8	9.0	1.0	1.0	17.2
	Bare Soil							3.7	3.7
	Institutional	0.6						1.2	3.7
Total Losses		283.2	86.1	12.7	57.4	69.0	29.9	404.9	

		<u>Losses 1987</u>						
	<u>Class</u>	<u>Commercial</u>	<u>Residential</u>	<u>Under Construction</u>	<u>Industrial</u>	<u>Open Water</u>	<u>Bare Soil</u>	<u>Institutional</u>
Gains 1994	Dry Forest		3.0	0.7	0.1	2.1	0.8	0.8
	Pine Plantation		5.3	0.4		0.2		
	Extractive							
	Agriculture							
	Non-Forest Wet					7.3		
	Wet Forest			0.1				
	Non-Forest Dry		16.8	3.2	3.1	1.6	47.9	0.6
	Commercial	-	2.4					
	Residential	5.9	-	67.4			0.1	
	Under		1.0	-		0.9	10.3	1.0
	Construction							
	Industrial	2.9		1.1	-			
	Open Water					-		
	Bare Soil		0.1				-	
	Institutional			1.9				-
Total Losses		8.8	28.6	74.8	3.2	12.1	59.1	2.4

**Figure 5.9 AREAS OF LAND-COVER CHANGE
BETWEEN 1987 AND 1994**

Stony Swamp Conservation
Area Boundary

No Change
Change

Scale: 0 1 2 mi

A network of service corridors consisting mainly of roads exists in the study area and has been modified over the 30 year time period. These corridors fragment the study area, isolating patches from each other and making movement between patches difficult for land-based wildlife species. Changes in area occupied by the network both inside and outside the conservation area are found in Table 5.10.

Table 5.10 Transportation Routes

Inside Stony Swamp Conservation Area

<u>1964</u>		<u>1977</u>		<u>1987</u>		<u>1994</u>	
Percent	Area (ha)	Percent	Area (ha)	Percent	Area (ha)	Percent	Area (ha)
1.4	61.5	1.6	68.1	1.6	69.4	1.6	69.2

Outside Stony Swamp Conservation Area

<u>1964</u>		<u>1977</u>		<u>1987</u>		<u>1994</u>	
Percent	Area (ha)	Percent	Area (ha)	Percent	Area (ha)	Percent	Area (ha)
0.4	34.0	0.2	20.7	0.3	25.2	0.4	36.9

Results show that the corridor routes inside the conservation area had leveled off at about 69 ha total area by about 1987. This reflects N C C policy to minimize the intrusion of facilities and transportation routes in the Greenbelt as a whole (National Capital Commission, 1995, 21).

Outside the conservation area the increase in total area occupied by roads has been hardly noticeable, from 34 ha in 1964 to 36.9 ha in 1994. The section of Highway 416 located in the study area was under construction in 1994 but has since been completed,

so the total area occupied by roads outside the conservation area would increase in subsequent investigations

A most noticeable trend is the decrease in agricultural land-cover and the corresponding increase in other land-covers. Given the thesis objective of identifying and interpreting the general relationships between different land-covers in the study area, the loss of agricultural land was examined in more detail to determine what became of the large sections of agricultural land found in the study site in 1964 (Table 5.11)

**Table 5.11 Conversions of Agricultural Land
(1964-1994) (ha)**

<u>Total Study Area</u>	<u>Area</u>
Agriculture to Urban	478.6
Agriculture to Non-Forest Dry	442.4
Agriculture To Pine Plantation	143.4
Non-Forest Dry to Urban	111.3
 <u>Inside Conservation Area</u>	 <u>Area</u>
Agriculture to Urban	33.4
Agriculture to Non-Forest Dry	225.3
Agriculture To Pine Plantation	140.2
Non-Forest Dry to Urban	10.2
 <u>Outside Conservation Area</u>	 <u>Area</u>
Agriculture to Urban	445.2
Agriculture to Non-Forest Dry	217.1
Agriculture To Pine Plantation	3.2
Non-Forest Dry to Urban	101.1

GIS was used to compare patches of agriculture in 1964 that were converted to other classes by 1994 in the study area. Table 5.11 shows that approximately 478.6 ha of agricultural land in 1964 was converted by 1994 to such urban classes as residential, commercial, industrial, institutional, and areas undergoing transition such as under construction (Figure 5.10).

This trend is not very surprising given the urban fringe location of the study area, as most of this conversion occurred outside the conservation boundaries and Greenbelt area. Portions of agriculture in 1964 that were abandoned and gradually converted to non-forest dry by 1994 totaled 442.4 ha, split almost equally between locations inside and those outside the conservation area (Figure 5.11). Most portions of non-forest dry outside the conservation area are located in the southwest corner of the study area where urban developments later appeared.

Of note, areas that were already non-forest dry in 1964 and converted to urban uses by 1994 totaled only 111.3 ha. This suggests that this land was located in areas that are not prime for extensive urban development, such as within the conservation area borders, and were left as they were or later used for pine plantations (Figure 5.12).

**Figure 5.10 CONVERSION FROM AGRICULTURE
TO URBAN BETWEEN 1964 AND 1994**

Stony Swamp Conservation
Area Boundary

No Conversion
Conversion

Scale: 0 1 2 mi

**Figure 5.11 CONVERSION FROM AGRICULTURE TO
NON-FOREST DRY BETWEEN 1964 AND 1994**

Stony Swamp Conservation
Area Boundary

No Conversion
Conversion

Scale: 0 1 2 ml

Figure 5.12 CONVERSION FROM NON-FOREST DRY TO URBAN BETWEEN 1964 AND 1994

Stony Swamp Conservation
Area Boundary

No Conversion
Conversion

Scale: 0 1 2 mi

Another area where a large tract of agriculture became non-forest dry was along the eastern border of the conservation area, and a portion of this section became a pine plantation later on. A total of 143.4 ha of agricultural land was directly converted to pine plantations, with 98% of this land located within the conservation area borders (Figure 5.13).

5.2.5 Patch Analysis

One method used in landscape ecology to determine land-cover characteristics, a patch analysis, was performed on six selected classes (dry forest, pine plantation, non-forest dry, non-forest wet, wet forest, and open water) that provide environments for wildlife species. Changes in patch number, size, and the variability of their size were calculated to indicate how landscape pattern and structure have changed (Table 5.12).

Patch analyses have been undertaken in other studies, including Odum and Turner (1990) who used patch analysis to highlight landscape pattern in southern Georgia as an indicator of trends in cumulative land-cover change from 1935 to 1985. Turner et al. (1991) used patch analysis to describe changes in vegetative landscape pattern, and to also highlight process changes in flows of energy and organisms due to modification of

Figure 5.13 CONVERSION FROM AGRICULTURE TO PINE PLANTATIONS BETWEEN 1964 AND 1994

•• Stony Swamp Conservation
Area Boundary

□ No Conversion
■ Conversion

Scale: 0 1 2 mi

Table 5.12 Characteristics of Selected Land-Cover Patches Between 1964 and 1994 (ha)

	Inside			Outside	
	1964	1994		1964	1994
Number	93	131	Number	62	50
Average Size	14.9	14.3	Average Size	13.4	12.9
Variance	785.3	542.3	Variance	381.6	354.4

	Total Study Site	
	1964	1994
Number	155	181
Average Size	15.8	14.7
Variance	870.3	583

landscape structure. Patch analysis creates a description of patch characteristics that refer to spatial relationships that describe the structure of the landscape (Turner et al., 1991, 17). From this the structure, quality and abundance of vegetation within a landscape can be assessed along with its ability to provide habitat, emphasizing the relationship between ecological processes and spatial pattern (Hyman et al., 1991, 448). A time span of thirty years, between the 1964 and 1994 photographs, was selected for patch analysis in this thesis. Although a thirty year time span is very short in the natural world, more identifiable variation would occur in thirty years than would occur over fewer years.

In 1964, there were 93 various sized patches of different remnant land-cover types inside the conservation area having an average size of 14.9 ha. These included dry forest, wet

forest, non-forest wet, non-forest dry, pine plantation and open water. By 1994 the numbers of these patches had increased to 131, showing that the landscape of the conservation area became more heterogeneous, while the average patch size and variability in their size had dropped.

Outside the conservation area there were 62 patches of dry forest, wet forest, non-forest wet, non-forest dry, pine plantation and open water in 1964 of an average size of 13.4 ha. By 1994 the number of patches, mainly dry forest, wet forest, non-forest dry, and non-forest wet, had dropped to 50 with their size and variability decreasing as well, a documented characteristic of urbanisation increasing in rural areas as land-cover is modified into many small patches of similar size.

5.3 Discussion

Within landscape ecology the landscape is seen as one complete environment, with land-cover patches creating a horizontal pattern where any change in one area has an effect on processes in another. Describing the patterns of the landscape requires mapping, with the resulting maps being used as a basis for understanding the variations in spatial patterns (Zonneveld, 1990, 15). Maps created in this thesis using remote sensing and GIS provide a means of displaying the variations in spatial patterns in the Stony Swamp

region of the Greenbelt. These variations on the landscape can then be interpreted using different methods, including concepts and methods in landscape ecology.

Land-cover trends inside and outside the Stony Swamp Conservation Area have differed markedly between 1964 and 1994. In general, due to the decrease in human development and disturbance dry forest, wet forest, non-forest dry, non-forest wet, pine plantations and areas of open water within the conservation area increased while agriculture decreased between 1964 to 1994. Outside the conservation area borders a different process has taken place as land-cover such as dry forest, wet forests, non-forest wet and non-forest dry are threatened and being reduced through the process of urbanisation. More specifically in the study area certain land-cover change trends stand out clearly: the decline in agriculture and the corresponding growth in non-forest dry patches throughout the study area, regardless of the conservation area boundary; the growth of pine plantations inside the conservation area; the recovery of natural land-cover inside the conservation area; and the slow march of urban pressures to the conservation area borders.

The decline in agriculture in and around Stony Swamp Conservation Area is due partly to N.C.C. policy within the Greenbelt, which led to the gradual phasing out of marginal agriculture in this part of the Greenbelt. In 1961, roughly 10,900 ha of land were being farmed in what was to become the Greenbelt (Morrie, 1991, 5). It was considered then that about 4,000 ha of land in the Greenbelt were marginal or submarginal for agriculture.

and not suited for cropping or intensive livestock production. About 2,600 ha of this land were subsequently reforested, including a portion within the Stony Swamp Conservation Area borders (Morrie, 1991, 5). Total area occupied by agriculture in the study area (land inside and outside the conservation area) decreased 95%, from 1260.2 ha in 1964 to 57.8 ha in 1994, as land was taken out of agricultural production. Much of this abandoned farmland (442.4 ha) naturally converted to a non-forest dry land-cover through the process of farmland abandonment, and accounts for the growth of this land-cover from 1964 to 1977 inside and outside the conservation area.

At the same time, this decrease in the importance of agriculture was matched by urban expansion in this part of the R.M.O.C. By the early 1970s the Ottawa area was experiencing rapid growth, and this expansion was largely directed outside the Greenbelt to the satellite cities of Kanata, Orleans, and south Nepean. Most of the urban development in the study area occurred outside on the western border of the conservation area in sections zoned for development, specifically along the borders of Kanata and Nepean. By 1987 the majority of the former agricultural land in that location had been developed for urban uses, or was lying abandoned in anticipation of urban development. Other conversions occurred near the northeast corner of the conservation area, where large patches of agriculture were converted to accommodate the growth of Bells Corners, which by 1987 had advanced towards the conservation area borders.

Along the eastern edge of the study area large sections of former agricultural land were left abandoned between 1964 and 1977 as patches of non-forest dry, or were put to pine plantations. In 1961 the N.C.C. entered into a fifty-year management agreement with the Government of Ontario to reforest much of the Greenbelt (National Capital Commission, 1995, 1). The decrease in non-forest dry patches within the conservation area can be attributed to the growth of pine plantations. Many of the present pine plantations still contain the raised crop rows, indicative of farmer's fields, on which were planted the white, red and jack pine trees that comprise the plantations. Almost all the pine plantations visible in the study area after 1964 can be found within the conservation area, and this can be attributed to the long-term management practices put into effect in this part of the Greenbelt. As a result, much of the land that had been classed either non-forest dry or agriculture in 1964 had pine trees planted on it by 1977, with more areas of non-forest dry than agricultural land being converted to pine plantations. This simply shows that more non-forest dry patches than agriculture were found in the conservation area at that time. Harvesting may occur later in these pine plantations once an adequate stock has been reached using conservation techniques and horse skidding (National Capital Commission, 1991a, 75).

The 1982 Greenbelt Management Plan defined the borders of Stony Swamp Conservation Area, ensuring that there would be minimal human disturbance in the future. As a conservation area, the natural environment of Stony Swamp would be

preserved as a representative ecological area to maintain and develop suitable ecosystems and healthy wildlife populations (National Capital Commission, 1982, 33)

With the decline in agricultural activity in the study area natural land-cover began to regenerate and flourish, particularly within the Stony Swamp Conservation Area borders. Land-cover such as dry forest, non-forest wet, wet forest, and open water began to increase in area. The increase in these land-covers can be attributed to the resulting decline in agricultural activity and general human disturbance in this section of the Greenbelt. A reduction in agricultural activity meant that many areas were no longer worked and planted as extensively, resulting in less human disturbance. Dry forest, wet forest, non-forest wet, and open water land-cover responded in turn to the more favourable conditions and managed to re-establish themselves in the environment.

An example is the 66% increase in areas of open water in the study area between 1977 and 1994. An increase in open water over time can possibly be attributed to the reduction in agriculture, the poor drainage of the conservation area, and the time of year the air photographs were acquired. With agriculture being reduced in the study area water demand for irrigation purposes also reduced, increasing the amount of surface storage in the region. The reduction in agriculture also resulted in an increase in the number of beaver dams inside the conservation area, which retain water and prevent regular drainage. As well, the planting of trees and the preservation of forest cover in the study area provided a buffer of organic deposits that could also help increase the

water storage potential of the area. One final factor could be the time of air photo acquisition: taken in early summer, seasonal factors such as increased spring run-off could also be contributing to the visible increase in size of open water areas. Combinations of these factors could account for the increase in area of open water during the time period.

Outside the conservation area borders dry forest, non-forest wet, wet forest and non-forest dry land-cover began to grow back but by 1987 development pressures led to a decrease in their total area, a trend that has continued up to 1994. Patches of these land-covers have been reduced in number and size, creating a landscape of isolated vegetated patches. Although these land-cover classes have been under pressure from development throughout the study area, the region alongside the border of Nepean and Kanata has borne the brunt of it. As seen on Figure 5.3 and Figure 5.4 the extensive development in this area has pushed progressively closer to the conservation area border, particularly between 1987 and 1994. While performing the ground sampling in June 1996 for the accuracy assessment of the 1994 air photographs, it was noticed that many dry forest and wet forest patches in this area had already been modified since that time to varying degrees. One patch classified as wet forest had been cleared entirely and was under construction.

An example of increasing urban pressure has been the growth of the transitional under construction class: between 1987 and 1994 its total area outside the conservation area

increased by 39.4 ha. The under construction class inside the conservation area also grew during that time, with the majority of this increase the result of the construction of Highway 416 which cuts through the southeast corner of the conservation area. Other indicators of the growing urbanisation are the growth of extractive areas as the demand for sand and gravel for construction increase (Martin, 1975, 28). This entire urban development process has led to drained wetlands and cleared forest, leaving a fractured landscape of small dry forest, non-forest dry, non-forest wet and wet forest patches outside the conservation area.

5.3.1 Land-Cover Patch Analysis

Along with other existing methods, such as connectivity studies and fractal analysis to determine changes in patch edges, patch analysis can provide information on patterns and their effects on processes such as biomass production, nutrient storage, as well as species composition and diversity. Large patches support a higher diversity of native plant and animal species. Large patches are expected to contain a greater number and variety of small ecosystems which species may use for specific functions at different times (Couturier, 1995, 106). These patches support larger populations of species, thus reducing the risk of local extinction by disturbance, environmental changes, etc. Thus, these larger patches are more likely to maintain populations of organisms over the long term (Couturier, 1995, 107).

To get an indication of the configuration of landscape components the number, average size and variability of six land-cover patches (dry forest, wet forest, non-forest wet, non-forest dry, pine plantations, open water) were studied. Changes in patches as the landscape progresses from natural to urban, such as the decrease in their size and variance and increases in their number, have been documented in other studies by Odum and Turner (1990) and Turner et al (1991). The landscape gradient of human modification by Forman and Godron (1986) outlined in Chapter 2 is used as a means of comparing the patch changes in the study area with known landscape patterns, because distinctive patterns and relationships between patches tend to characterise each landscape type. Functions provided by natural environments are affected by the context (degree of landscape modification) in which they are situated (Couturier, 1995, 104). Analysis reveals that the Stony Swamp study area has some unique patch characteristics.

Overall, the land-cover patches in the entire study area in 1994 are smaller than they were in 1964 while at the same time increasing in number (Table 5.13), suggesting that the landscape became more heterogeneous as a whole. Outside the conservation area the land-cover patches actually reduced in number, with the average size and variance of the patches also decreasing as the patches contracted. To accommodate residential areas patches become more regular in shape and decrease in size variability, a trend that has been identified as common for natural land-cover in urbanising landscapes (Forman and Godron, 1986, 286). The shape of forest patches is very important as this affects the amount of edge, which is the outer band of a patch that is environmentally different from

the interior of the patch. Different species composition and abundance are found due to interactions at the edge, which is termed the edge effect (Forman and Godron, 1986, 108). An increase in patch edge and a reduction in interior will disrupt interior species, who exhibit an avoidance reaction to the edge (National Capital Commission, 1991a, 16). The reduction in patches outside is occurring because instead of reducing a large woodlot into many smaller sections for urban parkland, it appears that whole sections of dry forest or wet forest land-cover are simply being converted for development. This may be an indirect effect of the Greenbelt being located so close to the areas of urban development. With the preserved area of the Greenbelt in close proximity, some patches may be sacrificed for development. In areas not near a preserved greenspace such as the Greenbelt, it is possible that more dry forest and other land-cover patches would be retained as green spaces.

One characteristic of development in this region is its encroachment on the conservation area borders, leaving a minimal or no buffer between the conservation area and residential developments. Evidence of this can be seen in Figure 5.4 along the borders of Nepean and Kanata on the western end of the conservation area, and Bells Corners to the north. While Bells Corners has reached maximum size, the satellite communities of Nepean and Kanata continue to grow outside the Greenbelt. The edges of these communities are determined by political boundaries, not by ecosystems. The form of that development creates a distinct edge, demarcating on the ground the border between inside and outside the conservation area. This pronounced edge can be visually

attractive and can lead to greater species richness (Agee, 1986, 130) However, as indicated earlier, a distinct edge may also lead to the displacement and extinction of indigenous wildlife species, such as the Red-shouldered Hawk (National Capital Commission, 1991a, 32) The increased edge forces interior species to look deeper into the conservation area for undisturbed forest while edge species, such as the Brown-headed Cowbird, thrive in the new environment (National Capital Commission, 1991a, 33) An edge between forest and grassland may support more species than an edge between a young and mature forest, but an edge between a forest and subdivision may become an area with very little species richness (Smith, 1986, 442)

With urban development permitted to encroach to the border, the resulting loss in land-cover outside the conservation area could lead to a future scenario in which there might be very few natural land-cover patches left outside the conservation area (National Capital Commission, 1991a, 34) This would leave a landscape devoid of many native species that could not survive in the new environment changing the native composition of the habitat

An increase in urban development also generally meant an accompanying increase in the amount of traffic on roads in the region Major roads that cut through the study area, such as Highway 416, Richmond Road, Robertson Road, Moodie Drive, and Knoxdale Road, effectively cut off portions of the conservation area Moodie Drive runs north-south and divides the conservation area in half, and along with Richmond Road

fragments the sensitive wetland areas found in the southern portion of the conservation area. In some locations the roads appear to have affected natural drainage with subsequent loss of swamp and replacement by marsh with standing dead timber (National Capital Commission, 1991a, 33). This in turn affects other portions of the landscape as organisms are forced to find alternative wetlands.

Inside the conservation area, patchiness has increased as a result of the large sections of agriculture being broken into a mosaic of small non-forest dry or pine plantation patches. This suggests that expansion occurred through the establishment of new and smaller patches of land-cover. In 1964 the still remaining land-cover patches of dry forest, non-forest wet, wet forest and non-forest dry were scattered and intermixed with agricultural fields in a landscape of irregularly shaped patches that were not connected and did not provide cover. With the change in land management policy brought about by the National Capital Commission, a new forest was to be created in the Greenbelt. As a result many abandoned agricultural areas and non-forest dry patches in the conservation area were filled with pine plantations by 1977, maintaining the overall patchiness and heterogeneity of the landscape. This provided new potential corridors for wildlife movement and shelter, improving the landscape as a whole. The landscape of the conservation area still reflects this heterogeneity today in a unique combination of a restored forest landscape containing many different land-cover patches of small size. At the present time, Stony Swamp represents a protected area with a large number and variety of environments for wildlife and plant species.

Forman and Godron (1986) argue in their landscape modification gradient that in managed landscapes such as Stony Swamp Conservation Area the average size and variability of patches is high, while the number of patches is low. In suburban landscapes, such as outside the conservation area, the numbers of patches increases while average size and variability decrease. Land-cover patch analysis shows that the study area has its own unique spatial structure. Numbers of patches have increased since 1964 while average patch size and variability have decreased inside the conservation area. Even though the landscape is heterogeneous in pattern with many small patches, flows of energy, nutrients and organisms between patches is easier inside the conservation area than outside due to the greater patch connectivity in 1994. Outside the number of patches has decreased along with average size and variability in size of the patches, affecting the distribution of the elements that create an ecosystem.

These unique patch analysis results could be due to two factors. 1) previous land-cover patch analyses, such as the landscape modification gradient presented by Forman and Godron, only take into account land in the linear process of being converted from natural to cultivated to abandoned to urban landscapes, and do not consider a landscape that is regenerating and still evolving. As landscapes previously disturbed by human activity are managed back to a previous state patches of land-cover in the landscape will have different characteristics as a result of the earlier human modification, such as a high number of patches. The new landscape will not have the same pattern as it did before human disturbance, but it may well have the same flows of energy and organisms. This

mix of two different processes provides an in-between landscape with unique patch characteristics. The Stony Swamp landscape has many of the characteristics of a natural landscape, while having the heterogeneous appearance of a suburban landscape, and 2), the management practices of the Greenbelt. The decisions made in the early 1970s to reduce the amount of agriculture on marginal land and maintain a diversity of environments in the area (National Capital Commission, 1991c, 5), as well as the decision to create satellite cities outside the Greenbelt have all contributed to creating this highly heterogeneous and unusual landscape. These land management policies can be viewed as the catalyst for the change that followed in subsequent years in the study area.

Another point of concern is the growing human usage of Stony Swamp Conservation Area. With Stony Swamp Conservation Area part of a larger system of greenspaces found within and beyond the Greenbelt boundaries, it provides important habitat. But as natural areas surrounding the Greenbelt progressively diminish in size and number and as the satellite communities surrounding the Greenbelt continue to grow, more and more people have been and will continue to be attracted to the variety of flora and fauna located in protected areas like Stony Swamp. Attractions within the conservation area include many year-round walking trails through woods and wetlands for nature interpretation, and a wild bird care centre (National Capital Commission, 1995, 3). As well, being located inside a designated greenspace like the Greenbelt almost guarantees that Stony Swamp Conservation Area will receive increased human usage, in addition to

visitors from the communities of Kanata, Bells Corners and Nepean Increased human usage may put pressure on wildlife species unless human activity can be directed to non-sensitive parts of the conservation area (National Capital Commission, 1991a, 34)

These factors also contribute to the degradation of the environment through disturbance, but are not as physically visible as spatial changes in land-cover patches

Through varied landscape ecology concepts and methods a general understanding of the changes in the functions and interaction among all the elements of the study area has been achieved By analysing the spatial changes in the patches of different land-cover types it has been possible to determine the effect the creation of the Greenbelt and urbanisation outside the Greenbelt have had on the landscape Patch analysis provided a description of patch size, number and variability that refer to the spatial relationships that describe the structure of the landscape From this the structure, quality and abundance of vegetation within a landscape can be assessed along with its ability to provide a hospitable environment, emphasizing the relationship between ecological processes and spatial pattern (Hyman et al , 1991, 448) This understanding can then hopefully be incorporated into planning and wildlife management practices that can be developed to accommodate future spatial changes in the area Combining data, collected using remote sensing and analysed in a GIS, with a landscape ecology understanding of how landscapes and the patches that make up these landscapes relate to each other provides a powerful analysis tool, the sum being worth more than its parts

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 Summary

In this thesis remote sensing was used to identify natural and non-natural land-cover patches in the Stony Swamp study area between 1964 and 1994 to create a database of land-cover in the area. GIS was used to map the spatial changes in the patterns of the land-cover identified in the study area. Landscape ecology emphasizes the importance of spatial pattern in controlling ecological processes (Turner, 1991, 11). Changes in the patches that make the patterns represent changes in the established ecosystem of the landscape. Alteration of land-cover affects patch characteristics such as size, number, and variability in size which disrupt the flow of energy, nutrients and organisms across the landscape. One method in landscape ecology, patch analysis, was used to assess the degree of this alteration on the different land-covers inside and outside of the Stony Swamp Conservation Area. As a result, general relationships were identified and interpreted for the landscape over time. Baseline data regarding the general overall condition of the landscape have been provided that can be incorporated into future management decisions.

The study area has undergone many changes as logging of the forest and then extensive clearing for agricultural uses led to the creation of a fragmented landscape leaving little of the original forest intact by 1964. The Stony Swamp Conservation Area itself was established in the study area in the early 1970s as a component of the Greenbelt. By 1977 portions of land that previously had been cleared for logging or agriculture were converted to pine plantations inside the conservation area, a practice that continued through to 1987. By 1994 Stony Swamp Conservation Area had grown into a heterogeneous natural landscape that, however, shows some evidence of its past fractured form. The conservation area's current importance in the Greenbelt is evident in it being home to many different species of wildlife found nowhere else in the Greenbelt (National Capital Commission, 1991a, 32).

Outside the conservation area the recovery and growth of natural land-cover was short-lived, as the pressures of urban development began to affect this portion of the Greenbelt after 1977. Urban expansion beyond Ottawa to the satellite cities of Kanata and Barrhaven led to many agriculture and non-forest dry patches being abandoned in anticipation of urbanisation. By 1987 patches such as dry forests were being cleared to accommodate growing urban development. The trend of urbanisation outside the conservation area continued and by 1994 much of the Stony Swamp Conservation Area was surrounded by urban development. Urban development in the study area has brought the pressures of an increased human population to the conservation area through increased disturbance and modification.

These patch disturbances have an effect on species as they may undergo major population size changes, extinctions, and immigrations, leaving a species-poor mimic of the original ecosystem (Forman and Godron, 1986, 91). Patch analysis has determined that patches outside the conservation area are decreasing in number and size, restricting the flow of organisms, nutrients and energy. Inside the conservation area there are many patches of small size, but they are linked together in a landscape pattern that provides continuous vegetated cover for different species; however, they are under pressure from outside the conservation area. As a result, interior bird species such as the Red-shouldered Hawk will have to move farther into the forest interior of Stony Swamp Conservation Area or leave altogether to escape disturbance. As this occurs edge species such as Grackles arrive and colonize the sites abandoned by the indigenous species. This entire process has radically changed the overall species dynamics of the landscape (National Capital Commission, 1991a, 33).

6.2 Conclusions

This thesis has shown that even as dry forest, wet forest, non-forest dry, non-forest wet, pine plantation and open water land-cover increased inside the Stony Swamp Conservation Area by 1994, these same land-covers located outside the conservation area were under increased pressure from urban development. The Stony Swamp area of the Ottawa Greenbelt is an area of dynamic change, and this thesis reflects the ongoing

process. Accordingly the patterns of land-cover on the landscape have been altered to reflect these changes. This alteration of the landscape has disturbed flows of energy and nutrients across the land, affecting species that inhabit the region. As suitable land-cover is reduced outside the conservation area, species are forced to relocate and the importance of Stony Swamp Conservation Area potentially increases.

Looking at the study area from a landscape perspective illustrates the many relationships between the different elements found there. With this interaction it can be seen that changes in land-cover induced by human disturbance can have far-reaching effects on landscape pattern and the environment as a whole. As described in Chapter 2 of this thesis Forman and Godron (1986, 286) identify five primary landscape types: Natural, Managed, Cultivated, Suburban, and Urban. Each of these landscape types has unique patch characteristics, such as shape, size, origin, and number. A natural landscape provides optimum conditions for species as patches are connected and of a good size. As human disturbance on the landscape increased so did the modification of these patches, subsequently affecting the ability of the environment to provide shelter, biomass, energy and nutrient storage. As well, flows of organisms between patches is diminished as patches become more isolated from each other, reducing the quality of the ecosystem for species. Patch isolation may not affect birds and insects to the same extent as land-based animals, particularly interior species like white-tailed deer, which are effectively cut-off from other patches due to these road networks and urban developments (National Capital Commission, 1991a, 34)

From the patch analysis it can also be seen that a regenerating landscape like Stony Swamp Conservation Area seems to have its own unique patch characteristics, the result of land-cover conversions from agricultural and abandoned landscapes back to a more undisturbed landscape. By documenting these cumulative changes in the spatial patterns of land-cover patches, it is possible to provide a foundation for more complex investigations concerning the nature of landscape change and the potential interaction among the multiple factors that contribute to these changes.

With a single large patch containing more species than several smaller patches (Forman and Godron, 1986, 117), the importance of Stony Swamp Conservation Area as part of a network of forested sections in this portion of the Greenbelt providing a home to a variety of species must be maintained. As large sections of natural land-cover outside the Greenbelt continue to be reduced, the Stony Swamp Conservation Area represents the only remaining large forested ecosystem in the Greenbelt (National Capital Commission, 1991a, 32). Efforts must be made to reduce and minimise disturbance along the conservation area's edges by increasing the size of buffer areas, and by preventing urban development from continuing to the conservation area boundaries. As well, attempts should be made to maintain Stony Swamp Conservation Area's present form by preventing the future construction of road corridors through the conservation area. This will minimise the effects of fragmentation which could effectively cut off species from other ecosystems, as happened in the case of Shirley's Bay being severed from the conservation area by Highway 417. Species are even separated from

ecosystems inside the borders of Stony Swamp Conservation Area itself (National Capital Commission, 1991a, 34) With increased urbanisation and given that Stony Swamp Conservation Area is the only home in the Greenbelt to many different and rare wildlife species like the Red-headed Woodpecker human usage will increase, their disturbance should be minimised by limiting public trail access to these sensitive locations in the conservation area

Incorporating concepts in landscape ecology has provided a general understanding of how the variations in spatial patterns in the study area have been formed As indicated patch analysis can provide information on the changes in the spatial patterns of land-cover patches in a landscape over time Patch analysis, used by itself or in conjunction with other methods like connectivity tests and fractal analysis, is a technique in landscape ecology that provides information on the changing structure of the landscape due to spatial variations in patterns (Dunn et al . 1991, 192) Through a landscape ecology conceptual framework the patterns of land-cover patches captured using remote sensing can be qualitatively assessed The overall perspective of remote sensing provides a holistic view of the landscape, but landscape ecology provides the theories and concepts to better understand the relationships between patches of land-cover on the ground

6.3 Limitations

6.3.1 General

The major limitation of this study is the scale being used to analyse landscape change. Because landscapes are spatially heterogeneous environments the structure, function and change of landscapes are themselves scale dependent (Turner and Gardner, 1991, 6). As a result, the measurement of spatial patterns and heterogeneity are scale dependent. For example a dynamic landscape may exhibit a stable mosaic at one spatial scale, but not at another. Methods suited to documenting change in a natural area at the landscape level may not be suited for measuring other attributes of natural areas at lower levels of ecological organisation. While remote sensing provides a comprehensive overall landscape perspective, the level of study undertaken limits this thesis in its ability to effectively describe pattern change and its effects at a finer scale. As processes and constraints change across scales, the varied characteristics of a landscape can be perceived differently at different scales. While this study is a broad scale analysis of landscape change, a different scale of observation would change the perception of intersections among elements.

6.3.2 Technical

One limitation is the overall replicability of the methodology, that is, the ability to yield the same results when the methods are repeated. In effect the subjective nature of air photograph interpretation and GIS (no matter how rigorously natural area categories are defined, no matter how systematically boundaries of polygons are drawn, and despite great care in digitising) invokes inconsistency. The subjective process of visual identification, together with the interpretation key, was used to distinguish between land-cover patches such as dry forest and non-forest dry, and also to delineate the boundaries between the land-cover patches. The probability of producing identical numerical results when the methods are repeated are remote. However, given the broad temporal and spatial scale of this research, small differences between the GIS-calculated results and the true situation of land-cover on the ground are not likely to misrepresent the overall conclusions.

The majority of the research for this thesis was done during one of the snowiest winters in years, thereby delaying the ground checking of land-cover types for air photograph classification until the spring and summer months. Ground work and selection of test sites should be done before classification, preferably in the summer, to avoid bias during the accuracy assessment and creation of the error matrix. The satellite data originally intended for the study could not be obtained, the satellite data acquired produced questionable results. As a result, air photographs became the sole source of remotely

sensed data resulting in a long process of manual classification of the photographs. Digital data in the form of satellite imagery would have greatly reduced the time needed for the classification process. The steps used in transferring the delineated polygons were laborious and the computer time needed to prepare the final land-cover maps was also extensive. Any other projects of similar size would have to consider the amount of time needed to prepare the data for analysis.

6.4 Further Research

If modification and development in this part of the Greenbelt continues, dry forest, wet forest, non-forest wet, and non-forest dry land-cover will progressively disappear outside the conservation area, and Stony Swamp Conservation Area will become a forested island surrounded by urban development. This thesis provided an indication of the possibilities for identifying landscape ecological change between land-cover patches using landscape ecology concepts. Subsequent studies in the Stony Swamp region of the Ottawa Greenbelt employing other quantitative landscape ecology methods, such as connectivity tests, fractal and corridor analysis, would be needed to further quantify the specific effects of the ongoing land-cover change identified in this research. Together with patch analysis, these techniques would provide a more vivid and complete assessment of changes in land-cover patches and pattern on individual animal and plant species. Landscape ecological research, integrating both structure and function of the

landscape, can provide a sound conceptual base for assessing large-scale changes and in developing strategies for land management. This thesis is but one step in providing a more complete understanding of different ecosystems in the context of the continuously changing environment of the Ottawa Greenbelt.

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