**THE ASSESSMENT OF
BIOGEOGRAPHICAL CHANGE
IN THE WESTERN GREENBELT OF OTTAWA
USING GEOMATICS**

by

Michael O'Neal Campbell.

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in partial fulfillment of
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Abstract.

This thesis examines the landscape change in the western Greenbelt of the City of Ottawa, Ontario, focusing on forest stand change and the land-use patterns that have influenced this change. The theoretical framework is based on the ideas of Burgi and Russell (2001) and Scoones (1999) linking biogeographical change and historical analysis by examining anthropogenic impacts. Research was conducted in the Western Greenbelt, using satellite images, aerial photographs, field data, interviews and secondary literature, focusing on phytogeographical change and urbanisation during the period 1934 to 2000. The tools of geomatics integrate these components. It is argued that the dynamics of landscape change in the surrounding areas must be examined from an historical viewpoint employing multiple research tools. Geomatics based analysis of remotely sensed images, in conjunction with intensive field studies offers a strong method for accurate documentation of landscape change.

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Introduction.

The Objectives of the Thesis.

The general goal of this thesis is to demonstrate the utility of geomatics as a tool for the greater understanding of landscape change, using the western Greenbelt of Ottawa as a case study. This involves the analysis of the relevant literature, the development of an effective analytical methodology and achievement of significant results. Within this general goal, there are several specific objectives.

- From a theoretical standpoint, the objective is to contribute to the current debates and approaches concerning the use of geomatics to analyse the relations and dynamics between phytogeographical change and land-use change. In particular, there is the possibility of developing a model broad enough to define and analyse the dynamics of multidirectional landscape change. This model may have generic significance, relevant especially to the assessment of environmental history, sustainable development and conservation management.
- From a methodological perspective, the objective is to demonstrate the possibilities and advantages of geomatics within integrated research (IR). Integrated research includes field observations, consultation and analysis of remotely sensed landscape images, and contacts with relevant stakeholders. Decisions concerning the relative merits of methodological approaches are among the most important in research work. In work involving an IR approach, the problems are amplified. Not only must each

tool be appraised and employed, but also a linkage must be established between the different tools for conceptual coherence.

- The third objective is to provide important information, which may narrow some of the current gaps in the knowledge on phytogeographical change under human impacts. This information must be sufficiently generic and practically oriented to be useful to stakeholders involved in rural decision making.
- The fourth objective is to answer the question: to what extent may such research analyse the changing landscape of the peri-urban Greenbelt of the National Capital Region of Ottawa? The selection of this study area is justified because it is relatively neglected in the literature, but a key area for the testing of viability of conservation in Canada. Important issues concern: the explanation of environmental history in the area, and the possibilities for the quantification of complex change; the assessment of environmental change in relation to urban, agricultural and conservation history and; the assessment of the sustainability of the conservation area, especially in regard to landscape configuration change; and the status of conservation management, by comparing the lands inside and external to the conservation area.

Particular sub-questions to be answered within this fourth objective are:

- What type of phytogeographical change has occurred in the area?
- Has the rapid urbanisation resulted in deforestation?

- Has the establishment of the conservation area contributed to the reforestation or has it merely halted deforestation.
- Can geomatics analysis of time series images, supported by inputs from field and literature-based sources, increase understanding of land-use dynamics and landscape change in this area?
- Can this geomatics analysis provide a stronger integrating role for landscape ecology and history as envisaged in the theoretical framework?

This research is particularly important for the study area of the Western Greenbelt of the City of Ottawa. The historical context of the area reveals complex dynamics. As noted by Ross (1927) the townships of Leeds and Grenville, including Nepean were first surveyed in 1793, and lots in Nepean township began to be developed by the early 1800's. However, even by 1827, most of the area was still covered by dense forest interspersed with cedar swamps and beaver meadows (Ottawa was then known as "Bytown").

The Ottawa Improvement Commission (renamed as the National Capital Commission) was established in 1899, and produced the first comprehensive plan for the National Capital Region in 1915. This recognised the need for more parks. By 1950, the General Report on the Plan for the National Capital recommended the creation of a Greenbelt (to control urban sprawl) and the enlargement of Gatineau Park. In 1958 the Canadian Parliament passed the National Capital Region (NCR) Act, which states that the NCC was established to support the development, conservation and improvement of the NCR in order that the nature and character of the seat of government may be in accordance

with its national significance. An important role was to safeguard and preserve natural and cultural heritage for future generations; this includes the protection of biodiversity and valued ecosystem components (NCC 2000). An assessment of the effectiveness of this role is vital for its continuance.

The Organisation of the Thesis.

Chapter One provides a broad background to the research by examining the issues of environmental history, sustainable development, conservation and IR in the global and Canadian contexts. The discussion of the global context is important because the issues examined (environmental history, sustainable development, conservation and the utility of geomatics) are linked to the Canadian context in the development of knowledges and methodologies. It is pointed out that the international applications of geomatics to environmental studies, the trend towards greater environmental awareness and the recognition of sustainable development as a developmental objective are reflected in recent developments in environmental research in Canada. The Canadian context is then examined in detail. The environmental history focuses on the recent history of deforestation and attempts to arrest this trend in Eastern Ontario. These environmental issues are posited as factors for the increased awareness of sustainable development in Canada. Specific concepts related to conservation policy actions, and the role of geomatics applications in the assessment are then examined. Environmental change in the narrower case study of the City of Ottawa is then described. The chapter concludes that perceptions of environmental issues are subjective, hence the need for more

quantification in environmental research. This provides the justification for the description of the methodology of geomatics based research in chapter two.

Chapter Two describes the theoretical framework of the research. This is based on the role of geomatics as a linking framework for IR, within the broad integration of landscape ecology and history postulated at a rudimentary level by Burgi and Russell (2001). It is noted that, despite the existence of good studies on the Canadian environment utilising geomatics, there are few such applications to the study of the Greenbelt of the City of Ottawa. This, in addition to the global merit of geomatics research as described in Chapter One, provides the justification for the methodology of the current research, which comprises the use of GIS packages, field surveys and literature analysis.

Chapter Three presents computer-based analysis images representative of eight dates (1934-partial coverage: 1955, 1964, 1970, 1977, 1987, 1994, 1999) were registered, and classified bitmaps created through digitising. The results were presented in four formats. Tables showed the general trends of change across the study period. Line graphs displayed this information to give a more visible general overview of the change. Matrices presented the results of the cross-tabulation of the theme maps, and thus documented multidirectional change. Overlaid images showed the results of the cross tabulation of the theme maps in image form and gave a spatial dimension to the results of the matrices. The contribution of this analysis to the objectives listed in this introduction is then examined. The main contribution to environmental history was the quantification of multidirectional change, which integrated human feature change (urbanisation) with

human impacts (vegetation change). The spatial display of the changes in the landscape configuration, in relation to wildlife corridors allowed an assessment of the sustainability of the conservation area as a habitat. These applications are argued to be relevant to decision making on forest change, cultivated areas and urbanisation. Errors in the analysis are discussed. The chapter concludes that within the case study, the analysis has provided new knowledge and justified the use of geomatics based research in landscape assessment.

Chapter Four summarises the contents of Chapter Three and suggests ways in which this type of research may be extrapolated to similar contexts. Such studies must be broadly based on IR, with geomatics utilised as the linking tool. Multidirectional change must be quantified for more critical assessment. In such assessments of conservation areas, there must be a consideration of the areas within and proximate to the conservation area. Also noted is the need for analyses not included in the current research. Short term environmental change must be assessed, in addition to the type of long term changes described and analysed in the earlier chapters. This type of assessment would be particularly valuable for regular environmental monitoring complements the long term assessments valuable for strategic planning and management.

Chapter 1. Environmental Issues: the Global and Canadian Background.

1.1. Introduction.

Biogeographical change is currently a topic that is receiving wide coverage in the global media. Biogeographers and ecologists have conducted major studies of landscape change, but now the wider academic, policy and practitioner communities are becoming increasingly involved. The reason for this development is the increased awareness of the complex human role in biogeographical change. Issues include deforestation, global warming, urban growth, conservation and sustainable development. Environmental topics (frequently termed green issues) may be seen as opposed or complementary to social issues (sometimes termed brown issues).

There tends to be a contrast between the dominant topics as seen as relevant to the north (the industrialised nations of North America, Europe and Asia) and the South (the so-called developing countries of South America, Africa and Asia). Issues of greatest interest in the north include fossil fuel emissions, eco-tourism, forest protection and environmental pollution, and the global, socioenvironmental significance of the mass consumerist culture. In contrast, issues of concern to the south include deforestation, desertification, soil erosion, population growth and urban expansion, and the associated socioenvironmental impacts of famine, social upheavals and national stability. Nevertheless, as noted above, historical socioenvironmental relations remain an internationally important issue. Environmental history, sustainable development and conservation are key topics within this issue (Scoones, 1999; Burgi and Russell, 2001).

1.2. The Global Issues of Environmental History, Sustainable Development, Conservation and Research Methods.

1.2.1. Environmental History and Ecological Disequilibrium.

Deforestation and forest stand change are cited as important areas to which hybrid research methods may be applied. The assessment of the existing knowledge of global forest stand change is frequently cited. Also noted are the perceptions of the neoclassical equilibrium ecological paradigm and the "new" disequilibrium model. The application of the new ideas regarding chaotic, unpredicted changes in forest stands is described in several case studies. The form of forest border change is frequently debated. For example, Millington, Styles and Critchley (1992) argue that the actual effects of farming, firewood cutting, timber extraction and construction on the forested environments are disputed. Examples from varying contexts are used to support and refute established narratives of environmental change. Therefore, context becomes a significant issue. There is recognition that the environmental impacts of socioenvironmental relations depend on the "specific historical and geographic conditions, which obtain in a given situation" (Cline-Cole, 1995, 172).

Within the broad and debatable issue of forest/grassland border change, two generally polarised paradigms have emerged. There are paradigms that promote non-linear disequilibrium models (this paradigm may also be termed the "new ecology" (see Zimmerer, 1994, 108), and the older paradigms based on the classical position of linear, mechanistic change exemplified by the classical school of ecology. The former cluster,

the "non-equilibrium hypothesis" emphasises: "chaotic fluctuations" in socio-environmental contexts (Solbrig, 1993, 21).. It acknowledges the existence of non-linear, multi-directional and non-equilibrium possibilities for processes of transformation. There is also a stronger focus on the history of ecosystem change and the fact that environments "do not necessarily return to their previous state when the source of the disturbance is removed" (*ibid.*). Other environmental factors such as soils and climate may have unpredicted effects on the ecology and these "unpredictable abiotic events" are seen as part of "healthy ecosystem behaviour" Sullivan (1996, 5). Studies that describe this paradigm include those of Solbrig (1991), Stott (1991; 1994), Pickett *et al.* (1992), Scholes and Walker (1993) and Khasa and Dancik (1997). The opposed, classical school of thought is based on climatic climaxes, mechanistic succession and human-nature separation, ecosystem theory, and an inherent assumption in the power of generalisation and scientific universalism (relevant references in this vein are Burrows, 1990; Pimm, 1991; Beeby, 1993; Allaby, 1994; Edwards, 1994; Begon *et al.* 1996; Pickett *et al.* 1992).

Scoones (1999) argues that the emergence of the new ecology has had some implications for the linking of social and natural science methods in the investigation and documentation of environmental change. There have been limitations on the impact on socioenvironmental analysis, which is perhaps "simply a consequence of the lag times of cross-disciplinary communication: different languages, frames of reference and methodological approaches are evident across the disciplinary divides" (*ibid.* 489). Nevertheless, the three main relevant impacts that the new ecology has had on such thinking are:

- The increased attention to environmental history, with offshoots towards paleoecology and evolutionary ecology (Williams 1994; O'Connor 1997). This has allowed appraisals of forest change that document patch dynamic change as a normal feature of landscape dynamics.
- The promotion of variability in both space and time, which has allowed the description of environmental dynamics to move "beyond the simple assumptions of equilibrial regulation to a wider appreciation of complex dynamics, uncertainty, and surprise" (Scoones, 1999, 483; Weins, 1976; Pickett and White, 1985; Holling 1986, 1994).
- There is also the greater attention to scale, structure, agency, allowing the documentation of "nonlinear interactions" (Scoones, 1999: 483) and their contribution to the creation of patterns at small and large scales (Allen and Starr, 1982; Turner 1989).

The development of environmental history is particularly relevant as a linking methodology for socioenvironmental analysis. It fills a gap, after a period in which, as Worster (1984; 1) argues "there is little history in the study of nature...and there is little nature in the study of history". One interesting factor for the development of methodologies for environmental studies was the work on landscape analysis pioneered by the French human geographers, based on the "pays" concept, as described by Vidal de

la Blache (1922). Also relevant was the contribution of Sauer and others in the Berkely school of geography (as noted by Price and Lewis, 1993; Rowntree, 1996), and other scientists who examined the interface and linkages of landscape and history (see Glacken, 1967, and Schama 1995).

Some of these studies might be termed multidisciplinary or IR, incorporating data and research methods from the documentation of economic, political, social change, as well as environmental dynamics (studies cited by Scoones in this vein include Worster, 1979, 1985; Cronon, 1983 and 1990; Merchant, 1989; Silver 1990; White 1990a and Hurley 1995). Another interesting development is the use of integrated methodologies for such studies (described by Batterbury, *et al.*, 1997 and Rocheleau, 1995 as hybrid methodologies).

Scoones (1999, 491) provides an instructive list of areas of research and the workers who have contributed. These are categorised as follows: *agricultural change* (Tiffen, *et al.* 1994; Amanor, 1994; Stone, 1996; Batterbury, 1997; Nyerges, 1997; Brookfield and Padoch, 1994; Zimmerer, 1996); *drylands and desertification* (Little, 1994; Dahlberg, 1994; Mortimore, 1998); *forest dynamics* (Peluso, 1994; Moore and Vaughan, 1994; Padoch and Peluso, 1996; Fairhead and Leach, 1996; Rocheleau *et al.*, 1997; Cline-Cole, 1998; Dove 1992, 1993; Sivaramakrishnan, 1999); *soils management* (Scoones, 1997; Sillitoe, 1996; Wilson, 1995); *livestock and rangelands* (Warren, 1995; Sullivan, 1996; Homewood and Rodgers, 1991; Roe *et al.*, 1998); *mountain systems* (Ives, 1987; Forsyth, 1998; Price and Thompson, 1997); *national parks and wildlife issues* (Adams, 1997;

Brockington and Homewood, 1996); and *water management* (Mehta, 1998; Mosse, 1997). The strength of these studies from the perspective of the development of new research orientations is the focus on landscape change through human action, at varying scales and levels of diversity and complexity.

1.2.2. Sustainable Development.

The examination of socioenvironmental relations over time leads to questions concerning the environmental sustainability of human actions. Long term interactions between people and their environments, as noted above are now seen as the principal determinants of biogeographical change, as the biosphere may be modified, enriched or degraded, at varying temporal and spatial scales (Iyer-Raniga, 2000). The issue of environmentally sustainable development is thus a key issue in global environmental change and management. In the context of conservation, this concept describes socio-economic change that includes strong awareness of the natural ecosystems within which human societies are contextualised, promoting varying protection and management of natural systems. Disputes however occur as to what exactly sustainable development means (Pearce *et al.*, 1989, 1990, Pearce and Turner, 1990; Serageldin, 1993; Ingham, 1993; Soussan, 1993; Redclift, 1987). The term "sustainable development" was put forward in the World Conservation Strategy (I.U.C.N., 1980; Adams, 1990) and was popularised by the World Commission on Environment and Development (the Brundtland Commission of 1987) which expressed it as development that "meets the needs of present generations without compromising the needs of future generations"(Serageldin, 1993; Soussan, 1993; Iyer-Raniga, 2000).

From the perspective of biodiversity preservation and protection, which constitutes the basis for conservation, many biogeographers, environmental biologists and ecologists have contributed to the development of a theoretical base for sustainable development. Despite arguments that ecological theory is rather unclear on the relevance of sustainable development to biodiversity management (Tisdell, 1990), the main focus is on the maintenance of biological diversity and productivity, and the resilience of ecosystems to external influences (Conway, 1983, 1985a, 1985b; World Conservation Strategy I.U.C.N., 1980; Leopold, 1933, 1966, World Commission on Environment and Development, 1987; Riddell, 1981; Simmons, 1974, 1979; Harlan, 1977; Serageldin, 1993). There is also a focus on the impact of development policies on ecosystems and the integration of ecological considerations into development policies (Rees 1993). When ecologists work with economists and policy scientists, green and brown issues may be linked. The results of some of these interactions are: the devising of regulatory management, protected area establishment, environmental action plans, environmental impact assessments on proposed projects, and the development of sustainable agricultural practices (Rees, 1993).

The political and deep ecologists of the North, frequently termed environmental or green activists, have also contributed to the conception and practice of sustainable development, their actions being relevant to the establishment of protected areas and influencing the formulation of environmental legislation. The more extreme activists, often the most visible, are often termed radical or dark greens. They argue for a limits to growth

approach, stressing a human partnership with nature, and the limits the finite carrying capacity of the Earth place on economic, technological and population growth (Dobson, 1990; Irvine and Ponton, 1988). One important Green argument is the promotion of zero growth. This refers to the reduction, or even cessation of economic growth, because it is perceived the main factor for environmental degradation (Dobson, 1990; Jacobs, 1991). It is believed that the Earth's resources are finite, and this places limits on the exponential rate of increase of industrial growth (as argued by Irvine and Ponton, 1988). Human beings are perceived as being dependent on the ecological status of their environments, and this is a major determinant of their well being, more so than economic and material well being (O'Riordan, 1981; Ophuls, 1977; Bunyard and Morgan-Grenville, 1987). Contrary to the modernist technocentric cultural mindset that produces technological and scientifically universalist solutions to socio-economic and environmental problems (O'Riordan, 1989; Bowlby and Lowe, 1992), the radical Greens argue that changes in human values and morality are vital for the reduction of extreme consumption patterns (Irvine and Ponton, 1988).

1.2.3. Conservation.

The conceptions of sustainable development described above support conservation as a practical policy measure. There are several definitions of conservation. Two are cited here: (1) The "planned management of a natural resource or the total environment of a particular ecosystem to prevent exploitation, pollution, destruction or neglect and to ensure the future use of the resource" (Encyclopaedia Britannica-Micropaedia, 1998, 3, 533); (2) "The concerns and strategies surrounding the protection of natural resources

from overuse or degradation" (Encyclopaedia Americana 1998, 17, 618). Beattie (1995) gives three related reasons for conserving biodiversity: function or acknowledgment of the role of biodiversity in the ecosystem; beauty, and profit. This reveals the complex nature of conservation mindsets which have dominated the perception of conservation. These include those of: scientists focused on the role of experts in environmental protection; policy makers, deriving their legitimacy from scientific positions, emphasised in protection schemes; and some social scientists who argue for local participation in conservation schemes as the most likely positive approach (see Beinart cited in Anderson and Grove, 1987; 15-17).

The establishment and merit of protected areas is internationally significant, but many efforts at conservation are insufficient and hence unsuccessful, despite the work of organisations such as the World Conservation Union, and subunits such as the Species Survival Commission (Rabb and Sullivan, 1995). Curio (1995) argues that many failures are due to the limited funding for such projects, the result of the low scientific and political priority that such projects obtain in policy, donor and science circles. Burbridge and Wallace (1995), Subak (2000) and Zumeta (2001) point out that for biodiversity conservation to succeed, there must be an integration of the daily social activities of various actors (individuals, communities, NGOs, business groups and governments) with the aims and methods of conservation policy and management. Inventories must also be conducted of the fauna (Ludwig, 1995) and flora of conservation areas (McNeely 1995; Prance 1995), and of those species which are especially vulnerable or fragile (Cole, 1995; Lajeunesse *et al.*, 1995; Nilsson and Grelsson, 1995; Akcakaya, 2000; Trakolis *et al.*,

2000). The competing land-uses of the areas proximate to conserved areas must also be analysed (as argued by Burroughs and Clark, 1995, in a study of Yellowstone and Georges Bank National Parks) and the human activities in such proximate areas must be evaluated as part of the larger socioenvironmental system (Salwasser *et al.*, 1995; Quon *et al.*, 2001).

The development of information bases and associated methodologies for the effective monitoring and evaluation of such areas is insufficiently analysed. Optimal strategies for landscape assessment are debatable, because the analysis of land-use is necessarily an interdisciplinary endeavour, being an assessment of diverse human activities in relation to complex spatial and temporal variations in the landscape (Thompson *et al.*, 1989; O'Riordan, 2000; Haberl *et al.*, 2001). An important issue concerns the integration of the interpretative and analytical methods of the social sciences with the arguably more rigorous methods of the natural sciences. Harberl *et al.*, (2001) describe the importance of comparative studies and the specification of human impacts, where interfacial studies of landscape ecology and social history are envisaged. Within the narrower field of protected area management, new difficulties arise, concerned primarily with short term and small scale assessments of impacts, and flexibility of methods. The goal is an adequate information base for regular, possibly daily, management decisions.

1.2.4. The Role of Geomatics in Integrated Environmental Research.

For the effective assessment of environmental relations, and subsequent competent conservation policy, there must be reliable information bases and analytical methods.

The accurate documentation of the environmental change has become a very important issue in the 1990s (Fairhead and Leach, 1995; Leach and Mearns, 1996; Leach *et al.*, 1997; Tiffen Mortimore and Gichuki, 1994; Campbell, 1998; Campbell and Palmer-Jones, 1999; Sullivan, 1999; Klemas, 2001; Wing and Johnson, 2001). Frequently, there are inaccurate assessments of socioenvironmental relations, based on less reliable data and inadequate syntheses. These have created dominant paradigms and mindsets that have influenced information bases and contributed to inappropriate policy actions. The principal contributions of geomatics are the more accurate documentation and quantification of temporal and spatial variations of land-use change and relations between contextual variables, such as topography and land-use. Geomatics is defined by Geomatica as

" a field of activities which, using a systematic approach, integrates all the means used to acquire and manage spatial data required as part of scientific, administrative, legal and technical operations involved in the process of the production and management of spatial information."

The examination of the landscape variation changes in visible representations of plant structures (crown height, position, perimeter canopy dynamics and open spots etc., assessed by the parameters of tone, shape, texture, size and pattern of the features) over time reveal phytogeographical change. Also, the size and shape of urban features also give evidence of the rate and character of urbanisation (Roscoe, 1960, Rubben 1960, White 1971, and Salami, 1999).

Aerial photographs generally have a finer resolution than satellite images and this allows more detailed feature identification (Ihse, 1994; Innes, 1998). SPOT and especially Landsat TM images have a lower spatial resolution. This creates difficulties for the measurement of the parameters of tone, texture, shape, pattern and size difficult without supporting information, such as field data or aerial photographs (Hunter, 1990; Turner, 1990; 1997, Innes and Koch, 1998). Nevertheless, problems may emerge even with high-resolution aerial photographs, especially where the coverage is of areas of high species and stand density (Merritt, Cunningham and Lueder, 1959; Ward *et al.* 1971; Whittaker, 1977). This may reveal image interpretation as “an art of probability, based on the assessment and judgement of evidence” (Rubben, 1960,109).

Many of the applications of such time series based research have been based on the African continent. This is generally because the ecological changes on that continent are perceived to be severe, hence requiring a strong research effort for the documentation of processes and promotion of solutions (see Gore, 1992, for an examination of the African environmental crisis). One major area of research is the dynamics of forest/savanna boundary change. Past attempts to document such landscape variation, based on field measurements and existing literature with an insufficient spatial and historical base, have created disputed narratives of socioenvironmental relations and environmental change.

Several recent studies works have employed IR (aerial photographs and/or satellite imagery, ground surveys, social research and historical data) in the forest/savanna mosaics of Africa. The results frequently challenge the currently popular narrative of

linear deforestation under the influence of human mismanagement. The evidence rather points to a scenario of multi-directional change. Environmental, economic and socio-cultural dynamics create multiple effects on the environment, from degradation to enrichment. In one famous study, conducted in the forest margin zone of Guinea, Fairhead and Leach (1995, 1023) used aerial photographs, the testimony of local respondents, colonial records and oral history, and thus derived a "a vegetation history that sharply contradicts the deforestation analysis..." and including "incontrovertible evidence" of increased or stable forest areas between 1952 and 1994 (*ibid.*). This contrasted with the established narrative of linear deforestation. In a similar study, of the Machakos Reserve of Kenya, Tiffen, Mortimore and Gichuki (1994) found that land degradation, called the "Machakos problem" (*ibid.* 3) which was believed to be caused by the five fold population growth and agricultural intensification, was less pronounced than expected. Photographic evidence from 1937 and 1991, showed that in many areas badlands had been replaced by farmlands, "erosion scars" (*ibid.*) were reduced, tree numbers increased and grazed fields mostly unchanged.

Other studies have supported the existing narrative of deforestation. For example, in the Guinea savanna of the Upper West region of Ghana, Nsiah Gyabaah (1992) used similar research tools to Fairhead and Leach (Land Satellite Multi-Spectral Scanner (MSS) images from 1972 and 1989, local ground surveys, and semistructured interviews). He found deforestation as the main form of change. This was similar to a study by Lieberman (1979) on the coastal savanna of Ghana. Lieberman used aerial photographs, quadrats, social surveys and archival data, and found deforestation (Lieberman, 1979; Ntiama-

Baidu, 1994). In a broader study, using similar research tools, and covering eight countries (Ghana, Congo, Cote de Ivoire, Ethiopia, Mali, Senegal, South Africa and Zaire), Millington, Styles and Critchley (1992) found that deforestation was evident in several areas, with cases of drier savanna woodland showing signs of being replaced by farm/shrub/grass mosaics, and with dynamic forest boundaries.

There has also been an increase in the application of geomatics to such research. This is largely due to the current availability of such technology and the higher awareness of the greater scientific precision and possibilities for quantification, statistical analysis and synthesis of multiple sourced data (Lavorel, Gardner and O'Neil, 1993; Hopainen and Wang 1998; Innes and Koch 1998, Campbell and Palmer-Jones, 1999; Salami, 1999). However, despite the high analytical possibilities of geomatics, the problems inherent in the images as described above exist. These include imprecise rectification and registration, insufficient synchronisation of times series images and field studies, and consequently misleading results (see Townshend *et al.*, 1992).

Using geomatics, Iverson *et al.* (1994) describe the use of the calibration center concept., the two data sets were Landsat Thematic Mapper with a comparatively high-resolution (30 m) and advanced very high-resolution radiometer (AVHRR) with a coarser resolution of 1.1 kilometers. In this study the objective was to classify small areas within larger areas of study into forest and non-forest zones. Other studies described in this work also document primary productivity (Tucker *et al.*, 1985; Goward *et al.*, 1985; 1987; Townshend and Justice 1986), rangeland condition (Sadowski and Westover, 1986) and

tropical deforestation (Nelson and Holben, 1986; Malingreau *et al.*, 1989; Graham *et al.*, 1990). However, a perceived weakness of such studies is the coarse level of generalisation (forest and non- forest) which makes it difficult to document more detailed change such as forest fragmentation. One method suggested to overcome this problem was the integration of data of varying resolution and evaluation of the pixels for forest amount.. The result showed that it was possible to differentiate according to the density of the forest, and the use of quantitative methods in the remote sensing of forest area and biomass is vital (Iverson *et al. op cit.*).

Relating geomatics applications to the North American context, the monitoring of landscape change (largely forest fragmentation and urban encroachment) is one important issue which requires an information base for effective management. Wing and Johnson (2001) conducted a study of the McDonald forest in Western Oregon and showed how forest managers could use geomatics to analyze recreation density information. Wickham *et al.* 2000) describe a geomatics based analysis of the relationship between fragmentation and economic development. As the loss of temperate forests is argued to be a serious concern (as also argued by Wilcove *et al.*, 1986; Opdam, 1991; and Wickham *et al.*, 1997) their study investigates the hypothesis that forest fragmentation can be quantitatively related to urbanisation. In the case study of the southside economic region of Virginia, USA, the results showed that there was a moderate correlation between forest fragmentation and the degree of urbanisation pressure. It was argued that this finding is similar to the results of other studies (LaGro and DeGloria, 1992; Turner *et al.*, 1996) which show that the extent of landcover change declines with increasing distance from

urban areas. An important note is however made that many studies consider a situation with a single urban centre. More complex is a situation where there are several urban centres each exerting a pressure the forest ranges from several points, an issue that Wickham *et al.* (2000) argue must be more fully investigated.

These research tools have also been applied to zoogeographical research. The common view is that habitat destruction leads to animal species decimation and even local extinction, as is well described by Tilman *et al.* (1994). Some studies have integrated the methods of the field sciences and geomatics to investigate this hypothesis. A particularly interesting study of this type was that of Mace *et al.* (1999). The objective of this research was the development of "a method for evaluating the cumulative effects of human activity on grizzly bear *Ursus arctos* habitat in Montana" (*ibid.* 367). TM satellite imagery, radio collaring of bears and categorisation of human activities by roads, trails and movements were analysed with geomatics software, revealing land-use/mammal relationships.

1.3. Environmental History, Sustainable Development, Conservation and Geomatics Research in Canada.

1.3.1. Environmental History of Ontario, Canada.

The section takes Canada as a case study, with principal focus on Ontario. Canada a vast country (9.98 million km²) with complex mountain systems, lowland plains and the world's longest coastline (71, 261 km). It has a phytogeography dominated by forest (48 percent). Tundra (28 percent) and grasslands (3 percent) also exist (Maini and Carlisle,

2000). There have been variable impacts on the environment of this vast country, with much of the change occurring during the twentieth century.

Assessing current knowledge on the environmental history of Ontario, Larson *et al.* (1999; 1993) argue that "we have only faint glimpses, left by early witnesses and deduced from archaeological digs, tree rings and pollen cores, of the condition and character of the woodlands of Ontario south and east of the Canadian Shield at the time of first contact by Europeans." Nevertheless, Keddy (1993) described the vegetation patterns of eastern Ontario at the time of European settlement (based on the notebooks of surveyors of the time) and related the vegetation cover to the geology. The dominant species in areas over Precambrian bedrock were combinations of white pine (*Pinus strobus* L.), hemlock (*Tsuga canadensis* (L.) Carr) and sugar maple (*Acer saccharinum* L.). Over clay plains the common growths comprised Sugar Maple (*Acer saccharinum* L.) and American Elm (*Ulm americana* L.), with less common occurrences of Balsam Fir (*Abies balsamea* (L.) Mill), and White Pine (*Pinus strobus* L.). On limestone and till plains, Sugar Maple (*Acer saccharinum* L.) Beech (*Fagus grandifolia* Ehrh.), Elm (*Ulmus americana* L.), Hemlock (*Tsuga canadensis* (L.) Carr) were common, while on sand plains Sugar Maple (*Acer saccharinum* L.) and Hemlock (*Tsuga canadensis* (L.) Carr) were dominant. These old vegetation patterns may be represented today by remnant forest stands (Dugal, 1980; Brisson *et al.*, 1992; Keddy, 1993; White, 1990b; Larson and Melville, 1996), but in some cases the diversity of the current remnants may not entirely reflect the range of species in the lost stands (Foster *et al.*, 1996).

Trigger (1994) notes that before 1700 the landscape of southeastern Ontario was mostly forest, with occasional prairie, savanna, alvar, open wetlands and on good soils, aboriginal agriculture. In the eighteenth century, colonisers and foreign disease decimated native populations. This allowed the regeneration of forest stands in agricultural lands, the result being the observation of such regenerated stands by early loyalists and surveyors. Reference to the notes and maps by these surveyors show about 98.7 percent of the land was forest. The other vegetation were savanna, prairie and/or alvar (Bakowsky 1998). Similarly, wetlands were largely swamp (Snell, 1996).

Concerning the link between these original stands and present formations, Larson *et al.* (1999, 7) describe deforestation as one of the key forms of environmental change in Ontario during the last two centuries: "more of the original woodlands of Ontario south and east of the Canadian Shield have been removed since European settlement than has been the case with any other major ecosystem". Factors for forest losses during this period included clearing and burning, lumber working and exports, and the opening of canals, railways and sawmills. "The nineteenth century left the southern Ontario forest species-impoverished, fragmented and a fraction of its extent before 1800" (Larson *et al.*, 1999, 46) referring to the Ontario Department of Lands and Forests, 1963).

This included a 90 percent conversion of originally wooded area to nonforested landscape by 1920. This occurrence is described as a "low point in the history of Southern Ontario forests" (*ibid.*). Factors for the landscape change included intensive cutting, overgrazing,

water and stream pollution and destruction. A historical description by a traveller (Trail 1833, 22) noted:

"On coming first to this country nothing surprised me more than the total absence of trees about the dwelling houses and cleared lands, the axe of the chopper relentlessly levels all before him. Man appears to contend with the trees of the forest as though they were his most obnoxious enemies; for he spares neither the young sapling in its greenness, nor the ancient trunk on its lofty pride; he wages war against the forest with fire and steel".

Recently however, there have been signs of the expansion of wooded areas in the peri-urban and rural contexts of Ontario. The factors for these changes are plantation development, fencing, public education, stream protection and changing agricultural practices (Larson *et al.*, 1999). The tendency to concentrate cultivation on the agriculturally suitable lands has resulted in a decline of over 25 percent of agricultural land after 1941, with the conversion of some less profitable farms to woodland. Also the number of livestock grazing has decreased by over 20 percent, with drops of over 50 percent in the Greater Toronto area. These changes have enabled an expansion of wooded areas. There was a five percent expansion of forest east and south of the Canadian Shield. In certain areas, by 1978 (especially in the east and south) between 40 and 70 percent of the townships had more than 20 percent of their areas covered by woodlands, while in other areas (mainly in the southwest) there were serious losses of woodland (*ibid.*)

Larson *et al.* (1999, 9) nevertheless point out that "where reforestation occurs, most of it is still just fields planted to trees. Those areas may naturalise over time, but they will never become woodlands like the original forests of the region". The result may be "structural simplification" (*ibid.* 9). There is also a high degree of fragmentation, due to housing, roads, pylons and clearings. The fragmentation of the areas south and east of the Canadian shield is the highest for any part of the Great Lakes Region, with the additional problem of the increasing immaturity of trees (the average age being 47 to 53 years). Therefore, as noted by Riley and Mohr (1994), there have been three main effects on woodlands over time: growth of younger stands and pioneer species; fragmentation and homogenisation or reduction in species numbers.

The production of more comprehensive environmental assessments of the Ontario landscape (both within and outside protected areas) is therefore important. Gray and Demarco (1995, 191) argue that "Ontario is at a crucial point in its ecological history", as a result of decades of urban and agricultural expansion, and the resultant decimation of the pre-colonial biodiversity. "Only small remnants persist to remind us of what once was" (*ibid.*). In some areas, as Mosquin (2000) writes, tree cutting has decimated forests, but this was sometimes balanced by farm abandonment and biodiversity recovery. Bocking (2000) also mentions the other side of the story: despite the severe effects of human occupancy on the landscape, the perception of the value of nature and biodiversity has increased, along with the increased valuation of previously undesired species.

1.3.2. Sustainable Development in Canada.

The ideas on sustainable development are relevant to the Canadian context, especially in the light of the events described above, which are not limited to Ontario. Hengeveld (1995, 3) argues that "sustainable development has become a key goal and functional underpinning of federal public policy in Canada". Quon *et al.* (2001) mention five points for effective environmental planning in a study of the ecological projects in Waterloo: (1) establishing the political and ecological context; (2) using ecologically appropriate objectives and practices; (3) using comparative multidisciplinary and cross scale approaches; (4) using adaptive planning and implementation; (5) establishment of strong communications both within and outside the project environment. Maxwell *et al.* (1997) point out the principal issues that must be developed for future sustainable development: more baseline data on environmental concerns, especially terrestrial, marine and hydrological ecosystems, research on first order impacts (meaning long term, multidisciplinary research on ecological change) and sensitivity analysis (research into more indirect effects and integrative effects of second and third order impacts) which requires integrated analysis including remote sensing. The ideas represented in these works are broadly analogous to the ecologist's ideas on sustainable development described above.

Three key human activities have been described as affecting biodiversity and biogeographical dynamics in Canada: forestry, agriculture and urbanisation. Middleton (1994a) conducted an incisive analysis of the impacts of forestry on the Canadian environment. Forests are key to the Canadian economy and they cover nearly 50 percent

of the country. Eight hundred thousand people, 350 communities and \$18 billion annually is dependent of the forestry industry. There is acknowledgment among stakeholders of the necessity of sustainable exploitation and management of these forests. The result of this concensus includes the National Forest Policy of the Canadian Council of Forest Ministers (1992), the Forest Roundtable on Sustainable Development and National Round Table on the Environment and the Economy (1993), and the Comprehensive Forest Policy Framework for Ontario (Ontario Forest Policy Panel 1993).

According to Middleton (1994a, 53) a "remarkable consensus is emerging at least at the level of theory". This is based on the following points: (1) a focus on the total forest ecosystem (rather than just trees) for policy and management; (2) the protection of the ecosystem as the priority, both for biodiversity and extractive industry; (3) natural levels of variation must be used for the maintenance of biodiversity, with the acknowledgment that this is also beneficial for the forestry industry; (4) the need for a broad and comprehensive information base, with spatial and temporal scales, as the basis of the implementation of policies and the continual monitoring and evaluation. These emerging foci are oriented towards the following questions: (1) do permanent changes occur in the local forest sites because of forestry activities? (2) are there also changes in the landscape configuration due to forestry? (3) can biodiversity information be integrated into forest management and monitoring?

Sustainable forestry requires that trees be harvested to allow the maintenance of the landscape configuration. This means that the trees removed should equal the regrowth, in

such a way that the pattern, proportion, size and spatial distribution of the patches are generally maintained. The coexistence of the forestry industry and biodiversity is thus maintained. There was moderate success in the 1980s and 1990s. Middleton (1994a: 51) notes that over 80 percent of the forests cut during this period had successfully regenerated, but that "this is still not adequate".

One relevant development is the establishment of conservation areas under the Model Forests Program, which were established in the early 1990s (NRC/CFS, 2000). There are several such forests in Eastern Ontario, Western Newfoundland, Waswani, Cree, Bas St. Laurent, Long Beach and Fundy. The management of these areas is supported by research on ecosystems, biodiversity, soil and water conservation, under the National Forest Strategy (1998). Various stakeholders are included in the formulation of management strategies: industry representatives, landowners, government officials, parks employees, aboriginal people, academic institutions, environmental organisations and labour groups. An example of the type research conducted in such areas is the grizzly bear research project, located in the Foothills Model Forest in Jasper National Park in Alberta. The objective of the research (lasting from 1999 to 2003) is to develop land management systems that would support the conservation of grizzly bears. Data on bear locations is integrated with habitat information, to allow the effective assessment of the sustainability of the conservation areas (NRC/CFS, 2000). The Eastern Ontario Model Forest is another example. This area covers over 1.5 million hectares and includes parts of the regional municipality of Ottawa Carleton. About 34 percent of this area is productive forest, and it includes a resident human population of around one million (NRC/CFS, 2000b).

Another relevant issue concerns the recognition of the importance of wildlife corridors, allowing animal migration and dispersal of plant species between isolated habitat patches (Suzuki, 2001). This is particularly important where extensive forest fragmentation has occurred. Research has shown that such corridors help improve the survival chances of some species. Suzuki cites the example of red squirrels in 19th century Scotland. There, forest fragmentation resulted in the isolation of some squirrel populations. This contributed to inbreeding. During the 1950 to 1980s, the growth of treed corridors linking the forest patches allowed mixed breeding of these populations. DNA analysis provided evidence of this. Suzuki however adds that corridors may enable the faster spread of diseases and are difficult to construct.

Agricultural practices are also important factors for landscape change (Mineau and McLaughlin, 1995). In southern Canada especially, there has been a major change in the landscape, as most farmed land was covered by forest stands in the past. The loss of habitat and animal species occurs due to the processes of agricultural intensification (tree cutting, tillage, burning) (Beechey *et al.*, 1999). Loss of habitat is argued to be a major factor for the increased endangerment of many species of animals in Canada (Mineau and McLaughlin, 1994; Askins, 1994; Diamond and Fillion, 1987; Furness and Greenwood, 1993; Kingsmill, 1993).

Nevertheless, agriculture may play an important role in the maintenance of biodiversity. The main method concerns the integration of non-agricultural plant species within

cultivated landscapes, allowing the construction of habitats for animals as well. These methods include:

- (1) the restoration of inactive agricultural land to natural habitat. This action is supported by predictions that show that the required farmlands for Canada may be reduced (Girt 1990) despite disputes as to the feasibility of biodiversity development (e.g. Cairns 1988).
- (2) the maintenance of riparian corridors where rivers flow through agricultural land, which may allow the movement of wildlife;
- (3) the encouragement and protection of non crop habitats near farmland, is also essential;
- (4) hedgerows may also be created as a "compromise" between the creation of low cost soil and moisture protection and the creation of habitats (Mineau and McLaughlin 1995).

Urbanisation is also an important factor for landscape change in Canada. Cities "are home to almost half of Canada's threatened or endangered species" (Middleton, 1994b, 116). Despite this fact, cities affect their contexts with noise, air and water pollution, tourist invasion of habitats, roads that cut through habitat corridors and the creation of parks and Greenbelts that may have simpler biodiversity than the prior landscapes. The urban

corridor of Quebec City to Windsor (including Montreal, Ottawa and Toronto) coincides with the existing deciduous forest zone. Urbanisation has affected the wildlife of this zone to the extent that almost 50 percent of the endangered species in Canada are from this area (Environment Canada, 1991). These cities also have wide spheres of influence, in which their impacts are pronounced. Winds and streams carry pollutants far beyond city boundaries and roads and other structures replace areas of potential forest growth.

Despite this situation it must be noted that urban areas are complex mosaics of different features, with different possibilities as habitats and contexts of biodiversity variation. Urban areas may vary from biological deserts (e.g. pavements and mowed lawns) to small, moderately rich ecosystems (e.g. abandoned industrial areas and ravines and old parks) (Middleton, 1994b). In some cases, habitat generalists such as the Common Tern *Sterna hirundo*, Massasauga rattlesnake *Sistrurus catenatus* and the Peregrine Falcon *Falco peregrinus* are enabled in their survival by utilising urban features for their needs (Morris *et al.*, 1992; Johnson and Menzies, 1993). Middleton (1994b, 117) notes that "substantial remnants of the original ecosystems, sometimes significantly altered, remain in most Canadian cities". He cites examples of Stanley Park in Vancouver, Mount Royal in Montreal and the Leslie Street Spit in Toronto Harbour, the latter containing 150 plant species (as also noted by Hough, 1984).

For sustainable urban planning and management, which is responsive to the needs of biodiversity, several possibilities are suggested. Firstly there must be a deeper understanding of urban areas as mosaics of different habitats, within a larger

configuration. The areas of high biodiversity within the city must be interconnected, and connected to the peri-urban and rural environments, allowing the movement of animals and the spread of plant species. Secondly, there must be an integration of this concept of interconnected ecological patches within urban mosaics into urban planning, for the development of biologically sustainable urban areas (as argued by Middleton, 1994b, see also Merriam, 1987; Davies, 1991; Doering *et al.*, 1991; Whitwell *et al.*, 1992).

1.3.3. Conservation in Canada.

Stephenson (1994, 201) writing on the issue of conservation in Canada, provides an analysis that serves as an incisive link between the concept of sustainable development and the implementation of conservation policy:

"secure high-quality protected areas are the core of a hierarchically connected network including satellite natural areas, linkages, and compatible surrounding land (and water) uses. This network would be designed as part of a planned land-use mosaic and, along with contributions from agricultural, forestry and human settlement lands, would ensure insitu biodiversity conservation".

This is envisaged as the bedrock of ecological, social and economic sustainability. Such parks "are associated with a range of spiritual, educational, experimental and economic benefits" (*ibid.*). Stephenson (1994, 202) further argues that the role of conservation areas within sustainable development is "as much a philosophical position as it is a scientifically testable hypothesis". Such conservation areas serve as both baselines for comparison with non protected areas and areas where the needs of biodiversity override

commercial and/or sporting exploitation, allowing instead limited, sustainable harvests, low intensity recreational activities, and low impact research. Also discussed is the core conservation area concept (as described by MacArthur and Wilson, 1967; UNESCO, 1988; Shafer, 1990; Robertson-Vernes, 1990). Here the core area under conservation is surrounded by buffer zones grading outward in land-use intensity. This avoids the fragmentation that results on protected area borders where the proximate land-use mosaics undergo intensification of human use. Also included in this concept is the protection of linkages (forest corridors, for example) integrated into the land-use (as described by Sewell *et al.*, 1993, and Ontario's Sewell Commission) which would be essential for the sustainability of the biodiversity of the core protected areas.

In terms of the practical implementation of these concepts, there is considerable attention to conservation and environmental legislation in Canada. This is at the level of the federal government (national parks, some territorial lands and resource exports/imports and bird migration) and provincial governments as well (which manage most of the local resources). The demands on the environment have increased due to the growing, mainly urban population (Maini and Carlisle, 2000, 2). These authors note that "during the past 25 years, Canadians have become more aware of the nation's resources and the alarming long-term consequences of this continuing process". There is a growing concern for biodiversity management, species protection (Barker, 1997; Munro, 1997) and sustainable forestry (Kimmins, 1997). As noted above, it has been argued that North American Parks situated near urban centres suffer from pressures from urbanisation (noise, air and water pollution, tourist traffic and infrastructural expansion) and this

awareness has served to increase the incentive for conservation planning (Machlis and Tichnell, 1985; Mitchell, 1994; Solecki, 1994; Page *et al.*, 1996; Patrimoine Canadien, 1998).

The monitoring of human movements within protected areas is also important. Tourism is an important activity in such areas. Fortin and Gagnon (1999) write about National Park management and the social impacts of conservation, taking as an example park/community relations in the environs of the national parks in the Saguenay region of Quebec. Here the specific problems include tourist traffic, urbanisation and resultant pollution and degradation, as also revealed in studies such as Hales (1991) and Solecki (1994) on the Pinelands Reserve and Page *et al.* (1996) in Banff National Park. The creation of trails, which can contribute to the growth of weeds, compact soil, repulsion of interior bird species and the attraction of edge species, are also problems (Hickman, 1990). It is argued that the main issue is the increasing difficulty in the meeting of the conservation objectives (Mitchell 1994; Fortin and Gagnon 1999). Frequent reference is made to the importance of the planning, management and monitoring of parks (reference is also made to the related works of Bidol and Crawfoot, 1991; Hough, 1991; Solecki, 1994; Lane *et al.*, 1997).

The monitoring of wildlife interactions is also an important aspect of the new awareness of environmental issues. For example, Koh *et al.* (1999) give a case study of the grazing impacts of white tailed deer on the vegetation in south western Ontario forests. In Rondeau Provincial Park it was discovered that heavily grazed areas differed from

enclosed areas in terms of dominant plant species. Non-native plant species dominated the grazed areas. Heavy deer grazing prevented tree regeneration, which resulted in increased understorey light levels. This also influenced the "normal recovery of native plant species" (*ibid.* 187). The study concluded that management of deer numbers is not enough to ensure vegetation recovery. There must also be a management of the canopy closure to ensure the regrowth of the native plant species.

Similar studies of predators support new management strategies. Theberge *et al.* (1999) conducted a twelve-year study of wolves in Algonquin Provincial Park. The study shows results of interactions between wolves, people and the environment. The population of wolves declined by about 32 percent over the period. This was largely due to killing by humans in areas adjacent to the park. Wolf migration in response to deer migration and the inability of the habitat to support all the wolves within the protected area influenced the contacts between wolves and humans. The study concluded that the park management "is failing to adequately protect the biological and ecological integrity of the wolf population" (*ibid.* 199). Proposed solutions include the creation of buffer zones around the park.

It must however be noted that the level of environmental awareness current seen in Canada has not always existed. Hummel (2000) gives an incisive chronology of the development of conservation thought in Canada. Native cultures, mainly composed of migratory bands of hunters are described as the main conservationists prior to the 18th century. The low population density at this time prevented a major modification of the

environment. This era was followed by the "Free Reserves Period" (1670s to 1885) during which the British and French colonists utilised forest resources to ensure a constant supply of ship building timber. Kerr (2000) notes that European explorers found abundant game, fish, fur and meat. There was no perceived need for conservation due to the vastness of the land.

The next period was termed the "land reserves period" (1860- 1885), during which the dominant land based activity was land sales controlled by the state and the church, for the establishment of railways, universities and schools. The land sales and land taxes were a major source of government income. During this period, the first Canadian naturalist club was founded in Ontario (1863). However, as noted by Kerr (2000), the British North America Act of 1867 did not mention wildlife conservation as an issue. The next period was described as the "resource reserve period" (1880 to the present). Hummel describes this period as a time when the emphasis was on the judicious use of wildlife, rather than on preservation and protection. During this time, several protected areas- parks; preserves, bird sanctuaries and forest reserves were set up.

The remaining periods are described as overlapping, with different starting dates but with contemporary relevance. The fourth period, called the "Recreation Reserves Period" (1885 to the present) saw the establishment, mostly near urban areas, of historic sites, parks and fish and game reserves. The fifth period, the "Nature and Wilderness Reserves Period" (1960 to the present) when the emphasis has been on the preservation of natural areas and ecosystems, without necessarily including recreation or resource use as an

issue. Wildlife conservation successfully protected animals such as the white tailed deer, wapiti, beaver, sea otter and pronghorn (Kerr, 2000). Currently conservation work includes populations surveys for distribution trends (including photographic methods) the granting of variable special use rights to wildlife, and the foundation of the committee on the status of Endangered Wildlife in Canada (COSEWIC) (*ibid.*).

Amateur naturalists who described the features of the environment (for example William Wordsworth, Belany, Lord Byron and Jean Jacques Rousseau) enabled the evolution of conservation in Canada. Also influential where the works of American workers such as James Fenimore Cooper, Henry David Thoreau, Ralph Waldo Emerson, and others including John Muir and Gifford Pinchot. The faster development of the American conservation movement was probably due to the more rapid exploitation of that area of North America, which allowed a quicker perception of the negative effects of resource exploitation. This led to the establishment of Yellowstone National Park, the first such area, in 1872. The philosophy of open exploitation lasted longer in Canada. The first national parks in this country were the Banff (1885) and Yoho and Glacier (1886) (Kerr, 2000).

The Canadian National Parks Act was passed in 1930. However, the pre-1945 focus on national and provincial parks was followed in the post-war years by a greater focus on recreational parks. The expansion of environmental interests in the 1960s, from naturalists groups to institutions led to the establishment of the National and Provincial Parks Association of Canada (1963) the Sierra Club in Canada (1970), the Canadian

Audubon Society (1971) and the Canadian Nature Federation. The intergovernmental Committee on the Status of Endangered Wildlife in Canada also started some work on endangered species (1978).

Overall, there are about 2800 protected areas of all classifications in Canada. These include National, Provincial and Territorial parks and reserves (Stephenson 1994). Within these there are 39 national parks in Canada. These range in size from 8.7 km² to 44 802 km², covering 224, 466 km² or approximately two percent of the total area of Canada (Woodley and Carruthers, 2000, 6). The major function of these parks, as expressed in the 1988 amendments to the National Parks Act, is the preservation and protection of "ecological integrity" (*ibid.*). These authors describe ecological integrity as a "condition where the structure and function of an ecosystem are un-impaired by human activity and are likely to persist". They however, point out that "while national parks have existed for over a century, establishment of their boundaries was often done without sufficient understanding of what is now termed ecological integrity." (*ibid.*)

Issues that must be considered include external pressures (such as agricultural and forestry activities) and internal pressures (such as tourism) and the territorial needs of wildlife which may supersede or transcend parks boundaries. A practical position taken by Parks Canada is the practice of an ecosystem-based approach to management. This integrates information on physical, society and biological systems, which may also be termed a "broad, consensus-based approach to land management", with a threefold objective (*ibid.*):

- The integration of park and protected areas with the adjoining landscapes.
- Pay attention to the links at scales larger than the "traditional scales" utilised in park and protected area management (*ibid.*)
- Allow the incorporation of different social values into schemes for landscape utilisation and protection.

Ontario is an interesting area for the application of conservation methods, as there is a relative neglect of such "non disaster" areas in the mainstream phytogeographical and conservation literature. Most similar works (e.g. Fairhead and Leach 1995 in Guinea and Tiffen *et al.* 1994 in Kenya) are based on areas of perceived disasters: deforestation, desertification and socioenvironmental degradation. There is insufficient research on the processes of change in areas of less visible environmental modification in less "problematic" countries. For this reason, few analytical studies seek to offer suggestions for more effective management applications. An exception is the work of Lister and Kay (2000), who argue for a system termed adaptive planning and management in Ontario, which may have generic applications. This system emphasises flexibility in the analysis of temporal change, integration of scientific methods with values, and multiple tools of research and management. This approach is intended to ameliorate a major problem with current management approaches, namely the failure to recognise the dynamics of changing ecosystems.

In the literature on protected areas in Ontario, the main methods of environmental assessment described are field research and social surveys. There is a paucity of studies that incorporate geomatics into IR, despite the fact that strong recognition has been given to the need for scientific methods for the assessment of protected areas. Most studies appear to be based on species inventories, or large-scale landscape classifications and analysis (Lister and Kay, 2000). For example, Brownell and Larson (1995) describe natural area evaluation in Ontario since the mid-seventies, an example being the study by Cuddy *et al.* (1976) which involved the ranking of over 600 natural areas along the Niagara Escarpment. The criteria used in the ranking were: representation, uniqueness, habitat and species diversity, quality and condition, homogeneity, size, buffering capacity, rare species and species of biogeographical interest. In the early 1970s, the International Biological Programme used similar parameters to examine hundreds of sites in Ontario. In the 1970s, the Ontario Ministry of Natural Resources (OMNR) (Parks and Recreational Areas Branch) had the objective of protecting certain natural landscapes in Ontario. In 1994, the Natural Heritage Information Centre was set up by the Ontario Ministry of Natural Resources and the Nature Conservation in Peterborough to collate information on the species and communities in Ontario. Extensive studies also exist in the Regional Municipality of Ottawa-Carleton (same as the City of Ottawa after amalgamation), on Federal lands and within the City of Ottawa (Brownell 1993).

1.3.4. Geomatics Applications to the Canadian Environment.

As noted above, the issues of sustainable development, conservation and environmental history are embedded in a spatial and temporal dimension, within the Canadian context.

Sustainable development necessarily relates to the management of a land-based resource, with specific extents and for definite periods. One practical measure taken to support sustainable development, namely conservation practice, must also establish fixed core areas where land-use is regulated. It must ascertain the spatial relations within these areas and also their links with other similar areas. Also investigated must be the effects of dynamics in proximate areas on their border zones. A methodology for developing a fuller understanding of the landscape, that of environmental history, which combines landscape ecology and history, within the larger area of environmental geography, must also have strong spatial and temporal foci. Therefore the issue of assessment and measurement emerges. Field measurements, social surveys and historical records have all been utilised as methodologies within the different sciences, and geomatics are now being developed as the synthesising framework and methodology for a more critical, quantifiable and accurate measurement of environmental change and consequently of socioenvironmental relations.

The development of geomatics in the Canadian context was an important development, as before this application, the information necessary for resource management was based on hand drawn charts, statistical tables, and maps. The earliest land surveys of the Canadian national parks were conducted with Environment Canada's Lands Directorate's Canadian Geographic Information System (CGIS) and also some information from Agriculture Canada's Canadian Soil Information System (CANSIS). The development of commercial geomatics applications on microcomputers allowed the application to issues in national

parks all over Canada, especially for ecosystem management. There are over 30 geomatics sites at levels that include Headquarters, Regional Offices, national parks, heritage canals and historic sites (Woodley and Carruthers 2000). These authors give a list of current applications: wild population census, ecological mapping, forest fire research and protection, insect and disease impact assessment, wildlife migration modelling, habitat management, coastal zone management, emergency measures preparedness, pollution monitoring, eco-tourism development, biodiversity analysis, land-use planning, temporal changes analysis, habitat fragmentation analysis and environment impact assessment. Furthermore, they note that "this is not an exhaustive list"(*ibid.* 6).

1.4. The City of Ottawa (the historic County of Carleton/Ottawa-Carleton).

The section narrows the focus to the National Capital Region of Ottawa, Ontario. Here also forest change is an important issue. Larson *et al.* (1999) give statistical estimates of woodland/scrubland change in eastern and southern Ontario, including 34 counties and/or regional municipalities. Comparison of the general changes with those of the Ottawa-Carleton area is shown in Table 1.1 below.

Table 1.1. Comparison of Deforestation in Southeast Ontario and Ottawa-Carleton.

County/Regional Municipality	Woodland area as a percentage of the total area.		
	1978	1955 to 1978 change	Pre-settlement
Total Area of the Municipality.	25.5	5.0	70.1
Ottawa-Carleton (subset)	34.7	11.23	52.4

Source: Adapted from Larson *et al.*(1999, 48).

The result shows that the Ottawa-Carleton area had a higher than average wooded area in 1978, and a higher than average reforestation rate between 1955 and 1978. The historical records show that this area was dominated by forest during the nineteenth century. The Historical Atlas of Carleton County (HACC, 1879, iii) notes that

"the forest growth of the County of Carleton consisted of nearly every variety of tree and plant known to this latitude... the growth was in many places very dense. Hardwoods of every kind, pine, elm, basswood etc. abounded on the drylands, while the low ground-and this comprised a large proportionate area of the county- was covered with dense growths of tamarack and cedar".

Brunton (1988: 17) argues that there is evidence that over three centuries ago, the area was "an unending sea of trees" These included red pine (*Pinus resinosa* Ait), white pine (*Pinus strobus* L.) and jack pine (*Pinus banksiana* Lam.) along the Ottawa river, the areas surrounding the current airport, and the Gatineau hills. Maple tree (*Acer saccharum* Marsh. and *Acer rubrum* L.) forests were also dominant stands.

It is then noted that the areas of first settlement were the highlands. The Ottawa valley, one of the first sources of lumber was "very soon stripped of its merchantable pine". The presence of other usable species influenced the desire "to cut, slash and burn as much and as fast as possible" (*ibid.*). Reid (1990, XIVIII) concurs: "in the Ottawa valley, the combination of a vast supply of large, mature trees- red and white pine, oak and elm, and a river system for transporting them, generated an export trade in square timber, deals and sawn timber unmatched in the Canadas".

In the case study area, the Greenbelt of the City Ottawa, monitoring and constant management of the protected areas are currently inadequate. This area is part of the National Capital Region, covering 20,000 hectares in eastern Ontario, within the Saint-Laurent Ecoregion (Wickware and Rubec, 1989). Largely covered by deciduous forests more than 300 years ago, this area was documented as being under less than 30 percent forest in 1880. Forest losses were due to logging, farming and settlements. Currently, vegetation of the area is mixed with farmland and urban features.

The establishment of the Greenbelt follows the pattern evolved in the Greenbelt concept. The English idea of the Greenbelt was exemplified by the 1938 Greenbelt Act, which created a 35,000 hectares belt of, protected land around London, England to divide the countryside from the city (Herington (1990). In the National Capital Region of Canada, according to the Greenbelt Master Plan (1996, 115) "the Greenbelt is a legacy of one of the most far-sighted city plans of the twentieth century: the 1950 Plan for the National Capital developed by Jacques Greber". The objectives were to restrict urban growth,

create and protect recreational areas and create space for urban expansion (NCC 1991). The National Capital Planning Committee, further developed these ideas and added the objective of establish satellite cities such as Kanata to decongest the Ottawa metropolis. In 1961, the National Capital Commission (NCC) made an agreement with the government of Ontario, which led to the reforestation of large areas of marginal and abandoned farmland. From 1958 to 1966, the Greenbelt gradually expanded and currently covers 20350 hectares, of which the NCC owns 14,950 (*ibid.*). The estimated cost was \$33 million, mainly for land purchases.

Several conservation areas are located in the Greenbelt area (Brunton 1988). Table 1.3 below shows the main areas, as described by Brunton (1988,121-178). Other conservation areas listed by Brunton (1988) include Sawmill Creek, Frank Ryan Park, Vincent Massey Park, Hampton Park, Champlain Bridge and Islands, Rockcliffes Airbase Woods, Lemieux Island, Upper Duck Island and Victoria Island. These areas managed by the National Capital Commission rather than the larger organisations such as Parks Canada and Environment Canada. Brunton divides the current landscape of the National Capital Region (NCR) into seven classes: upland forest, meadows and barrens, farm and country, forested wetland, open wetland and lakes and rivers. Table 1.2 below summarises the features of these areas. Lists of common plant and mammal species in these areas are given in the appendix.

The Greenbelt Master Plan (1996) classifies the landscape of this area according to conservation and land-use. There are core natural areas, where the main function is ecological conservation. Natural area buffers are zones created to protect the core natural areas. Natural area links are zones of forest or mixed vegetation that link the natural areas, through farm or semi urban areas. There are also cultivated areas, where the dominant land-use is farming or forestry. The policies on the land-use cover forestry, agriculture, commercial, residential, transportation, utilities, recreation and waste management land-use, as well as cultural landscapes, water resources and the limitation of mineral extraction (*ibid.* 55-73)

Table 1.2. Habitats and Landscapes in the Regional Municipality of Ottawa-Carleton.

Landscape	Characteristics
Upland Forest	Tree covered, no seasonal water cover, mainly White Pine and Sugar Maple.
Meadows and Barrens	Young shrubbery, sapling growth, open grasslands, bare rock flats, relict prairies and raspberry thickets.
Farm and Country	Cornfields, sod farms, sheep and cattle pasture and weed species.
Urban Landscape	City built up areas, parks and suburbs, mixed trees and urban features.
Forested Wetland	Tree covered land subjected to occasional, seasonal or semi permanent flooding, such as silver maple, cedar and ash swamps, black spruce and larch bogs
Open Wetland	Non forested land permanently wet or flooded. Cat tailed marshes, alder thickets sedge meadows and peat bogs and fens.
Lakes and Rivers	Permanently flooded with no standing vegetation, but floating and submerged aquatic plants species, examples are beaver ponds, creeks, and rivers/lakes.

Source: Brunton (1988:13-14).

Table 1.3. Conservation Areas in the City of Ottawa.

Conservation Areas	Brief description
Mill of Kintail Conservation Area	Mainly sugar maple forest, with some eastern hemlock, white cedar swamps, yellow birch, and drier clumps of bur oak, basswood and green ash
The Burnt Lands	Alvars (natural spring flooded meadows), also spruce, fir poplar, birch and conifer wetlands.
Constance Bay Sand Hills	Sandy hills, with jack pine in places
Carp Hills	Oak stands, young poplar and birch, beaver ponds
Shirleys Bay	Cat tail marsh, upland forest, and maple swamp
Stony Swamp Conservation Area	Sugar maple, wetlands, pine plantations (high plant diversity)
Still water Creek	Silver and Black maple dominate
Andrew Haydon Park	Mudflats, wetland vegetation
Britannia Conservation	White pine, oak-maple woods
Pinhey Forest Reserve	Silver maple swamp, red maple, poplar and red pine
Carlington Woods	Maple, oak, hickory, basswood, with scrubby fields
Malborough Forest	Hardwoods, coniferous and white cedar mixed stands, alvar clearings, a permanently flooded fen
Baxter Conservation Area	Red maple swamp, white cedar, black walnut
Rockcliffe Park	Oak, elm, ash and sugar maple, clumps of hackberry and white cedar
Green's Creek Conservation Area	Silver maple swamp, hardwoods with witch hazel, eastern hemlock stands
Lower Duck Island	Silver maple forests, with ostrich ferns, and drier hackberry forest
Mer Bleue Conservation	Peat and heath swamp, black spruce, tamerack, poplar and birch on sand outcrops, red maple forests, beaver ponds
Pine Grove Trail	Trembling aspen, white birch, green ash, red maple, white pine, and shrubland.

Source: Brunton(1988; 141-178).

The Stony Swamp conservation area is a good example of an area where there is not enough published information, despite the perceived necessity for more accurate assessment of environmental change. Covering 1,811.6 hectares, the precise location of Stony Swamp is south and southwest of Lynwood Village, Nepean, to the west of the Rideau river and Ottawa, between that city and Kanata, Ontario (Brunton 1997). Figure 1.6 shows the extents of the area. The Stony Swamp Conservation Area is the largest area of contiguous forest in the Greenbelt. There is a variety of land-use in the area: woodland, wetlands, agriculture, quarries or residential (RMOC, 1997). The strong ecological status of the area is a factor behind its popularity as a recreation area. Table 1.4 shows visits by vehicular traffic to during the month of December, 1999. The main visited areas are the various trails in the Conservation Area, shown in Figure 1.3.

Table 1.4. Vehicles Visiting Stony Swamp Trails (December 1999).

Day	Number of Vehicles
Monday	531
Tuesday	534
Wednesday	585
Thursday	565
Friday	519
Saturday	719
Sunday	817
Total	4269

Source: NCC (1999).

The 1991 City of Ottawa Vegetation Cover Classification classifies the land cover in Stony Swamp into deciduous, coniferous, mixed and swamp forests, plantations and open wetlands. Over 500 natural plant species are found here, which comprises one of the highest levels of biodiversity for any conservation area in the Greenbelt. Aikman *et al.* (1998, 49) note that the vegetation of Stony Swamp comprises a "diverse mosaic of vegetation which is part of the Great Lakes-St. Lawrence vegetation region." This is mainly a mixed deciduous and coniferous association, with common species being Yellow Birch (*Betula alleghaniensis* Britt.), Sugar maple (*Acer saccharum* Marsh.), Eastern White Cedar (*Thuja occidentalis* L.), White Spruce (*Picea glauca* (Moench) Voss), Balsam Fir (*Abies balsamea* (L.) Mill.) and Largetooth Aspen (*Populus grandidentata* Michx.). According to the RMOC (1997), Stony Swamp represents an area of high ecological significance, and it contributes to the conservation of regional biodiversity. It is one of the areas that received a high assessment under the Natural Environment Systems Strategy (Brownell and Larson, 1995).

Figure 1.1. Location of the Study Area in Ontario, Canada.

Source: ArcCanada (1999).

Figure 1.2. Location of the Stony Swamp Conservation Area and the Western Greenbelt.

Figure 1.3. Location of Trails in the Stony Swamp Conservation Area.

Brunton (1997) conducted a reconnaissance level assessment of certain conservation areas in the Ottawa-Carleton area, as part of a larger process to establish a Natural Environment Systems Strategy for the Regional Municipality of Ottawa-Carleton. Prior to this assessment there was little field information in the area. The classification for Stony Swamp, intended to reveal the biodiversity of the area, is shown in Table 1.5 below.

Table 1.5. Evaluation of Stony Swamp Conservation Area.

Area Evaluation Summary		Significance		
Criteria	None	Low	Moderate	High
Landscape Attributes	X			
Common Vegetation community/Landform Representation				X
Rare Vegetation Community/Landform representation.				X
Endangered, threatened, and rare species.				X
Vegetation Community/landform diversity.				X
Seasonal Wildlife Concentrations		X		
Hydrological Features				X
Condition of Natural Area				X

Source: Brunton (1997).

Despite these positive assessments of the status of Stony Swamp as a conservation area, field studies have revealed some problems. As noted by the NCC (1995, 27) "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". Wildlife corridors are slowly being cut off by urban expansion. The degradation of large forested areas into smaller stands is currently a serious problem in the surrounding areas, west of the Rideau river. This has developed due to the establishment of utility corridors, rail lines, highways, agriculture and rural estate subdivisions. The demographic and physical expansion of the two proximate urban areas, Kanata and Bells Corners has been fairly rapid. Table 1.6 below shows the population growth in Kanata and Bells Corners.

Table 1.6. Population Growth in Kanata and Bells Corners (1951-2001).

Year	Kanata	Bells Corners
1951	639	No data
1956	824	328
1961	968	2,846
1966	1,886	5,023
1971	5,822	5,945
1976	8,009	7,235
1981	19,728	8,685
1986	27,519	8,745
1991	37,344	9,575
1996	47,909	9,935
2001	60,300	9,850

Source: Census 1956-1996; 2001 estimated on building permits.

The recent rapid population growth is due to the fact that the western Greenbelt in the former Nepean Township accommodates several private firms such as Bell Northern

Research and Nortel that contribute to the regions economic development. Over 6000 advanced technology jobs are located in this sector. Bell Northern alone has been given approval to expand its facilities in the Greenbelt to ultimately accommodate 8000 employees on site. The Greenbelt therefore is an important area for research institutions in the City of Ottawa. Population growth is expected to occur in Kanata's north end (National Capital Commission, 1996).

Urban expansion has historical origins. The historical settlement of Bytown and the agricultural development in the area reduced the original forested vegetation and degraded many upland soils, leading to farm abandonment. Brunton (1983) listed the following sequential environmental history of the area.

- In the 1800s, forest areas were destroyed for agriculture, building materials, and fuel.
- The area was settled in 1815. In 1831, Bells Corners was a well-populated hamlet surrounded by agricultural areas.
- In August 1870, the Stony Swamp area and its environs were destroyed by fire.
- Since that time, many of the farmed uplands, which had been cleared for farming, have been abandoned, because the soils are too thin to support commercial crops.
- Some of these regions were converted to pasture, but this was discontinued when the National Capital Commission bought the land for its Greenbelt consolidation programme.
- The abandoned pasturelands were colonised by shrubs etc.

- In the early 1960s, the Ontario Ministry of Natural Resources managed Stony Swamp (under a forest management agreement with the NCC) and planted large areas of the southern area of the swamp with conifers.

The areas planted with conifers are shown on the aerial photograph in Figure 1.4 below.

The three detailed case studies of landscape change in Stony swamp are cited here: those of Milton *et al.* (1998); the Macoun Club (various dates); and Spiwak (1996). Milton (1998) continues this chronology and classifies the vegetation into closed and open forests, and treed and open pastures as shown in Table 1.7 below.

Table 1.7. Vegetation History of Stony Swamp.

Date	Generalised vegetation description and change.
1960	Uplands open, scattered forest stands, woodlands largely confined to wetlands and some escarpments. Fields and the rural road network still visible. Designated a conservation area: planting of conifers in abandoned areas by Ontario Ministry of Natural Resources
1973	More proximate urban and transport infrastructure. Conifer plantations on abandoned pasture. Expansion of closed canopy forests, wetland forests and open water.
1984	More reforestation and expansion of wetlands. Also more urban expansion.
1993	More forest expansion, in certain areas, and also urban expansion.
1998	Irregular expansion of forest. Some natural forest expansion, but mostly restricted by agriculture and plantations. Beavers have created more open water.

Source: Adapted from Milton (1998).

Figure 1.4. Conifer Plantations in Stony Swamp (2001)

Source: NCC (2001).

As the vegetation of Stony Swamp has been strongly altered over recent decades, it may be described as very disturbed vegetation rather than conserved or even natural (Aikman *et al.*, 1998). These chronologies however, are insufficiently precise, and it is difficult to determine the exact extent of landcover change. Only generalised assessments may be derived. Questions therefore arise as to whether the computer based analysis of time series images would reveal a sequence of change related to these changes and allow a more effective assessment of the land cover dynamics. In particular, has the sequence of change in the 1990s been towards forest degradation or expansion?

Spiwak (1996) examines landscape change in the Stony Swamp area, using aerial photographs dated 1964, 1970, 1977, 1987 and 1994. The two main landscape changes identified over this period were: (1) increased forest cover inside the conservation area, mostly at the expense of agriculture; (2) and deforestation in the surrounding areas, largely due to urbanisation. Spiwak describes the change in the Stony Swamp area as "an unusual type of change for land in a peri-urban location"(*ibid.*8): rather than the common sequence of change from "natural" vegetation to farmland to disused agricultural land to urban features (as noted by studies such as Ulliman, 1992 and Weaver *et al.*, 1980). The reforestation was due to land-use decisions made by the NCC. However, the fact that Stony Swamp is linked to the surrounding areas (wildlife corridors) means that the effects on the surrounding vegetation may also have impacts on the conservation area ecosystem.

Spiwak's methodology classifies the land in Stony Swamp and its environs into twelve classes: open water; non forest wet; non forest dry, dry forest, pine plantation, wet forest, bare soil, agriculture, residential, under construction, commercial industrial, institutional and extractive industries. This classification scheme was developed by the Regional Municipality of Ottawa-Carleton (RMOC) maps covering 1991 Urban Land Use, and 1995 Natural Vegetation in Ottawa-Carleton. The thirty year span of the study period is justified because the earlier images are dated prior to the inclusion of Stony Swamp in the Greenbelt. After the air photo analysis, using geomatics, the results were classified according to the year, as shown in Table 1.8 below. The principal losses were of cultivated land, which was replaced in many instances by urban features and forest.

Spiwak (1996: 145) makes the important point that given current levels of modification, eventually the forest vegetation outside the conservation area will be replaced entirely by urban land, the result being that "Stony Swamp Conservation Area will become a forested island surrounded by urban development".

Table 1.8. Results of Spiwak's Analysis of Landscape Change in Stony Swamp.

Date	Change in area currently covered by Stony Swamp	Change in area outside conservation area.
1964	Mainly patchy dry forest and non forest dry, large areas of agricultural land.	Mainly farmland, non forest dry and dry forest. Small urban areas.
1977	Increase in dry forest, wet forest, non-forest wet, pine plantations. Decline in farms	Similar change, but greatest in non forest dry, also in extractive and residential, decline in farmland
1987	Dry forest still dominant, declines in non-forest dry, wet forest and farms.	Gains in construction and residential land, losses of dry and wet forest, non forest dry and wet, and pine plantation
1994	Dry forest still dominant, futher declines in farms, little change in wet forest and non forest dry and wet	Gains for urban and extractive land, declines in dry and wet forest, non forest wet and dry

Source: Adapted from Spiwak (1996).

The Macoun Club's works on Stony Swamp are mainly written by Rob Lee, between 1985 and 1998. The methodology was to divide the area of interest into vegetation types based on species and moisture: open wet and dry, brushy wet and dry, deciduous wet and dry, and evergreen wet and dry, the information being based on intensive field surveys (Lee, 2001.). Records of mammal presence are also documented, included evidence of mammals now not normally found in the area, such as black bears. Mammals currently

documented as present include: porcupines (*Erithozon dorsatum dorsatum*), white tailed deer (*Odocoileus vigianus borealis*), racoons (*Procyon lator lator*), red (*Tamiasiurius hudsonicus loquax*), grey squirrels (*Sciurius carolinenesis pennsyulanicus*) and coyotes (*Canis latrans*). The field studies conducted in time series also document extensive vegetation change; expansion of coniferous and deciduous stands and decline of farmlands (the Little Bear, 1988-1989; Lee, 2001).

One factor that affects the density of forest canopies in this region is the occurrence of periodic ice storms. This has an impact when ice is deposited in large amounts on tree branches, which may cause breakage of branches or even topple trees (Van Dyke, 1999). Long term damage results with more than 75 percent crown loss (Smith and Shortle, 1998), which may result in the death of trees (Whitney and Johnson, 1984; Bruederle and Stearns, 1985; Haur *et al.*, 1993). In 1998 a severe ice storm occurred in eastern Ontario (Environment Canada, 1998). Nielson (2001) notes that this ice storm damaged a number of red pine (*Pinus resinosa* Act.) plantations in Eastern Ontario. Many other species also recorded some damage. These included aspen (*Populus* spp.), black cherry (*Prunus serotina* Ehrh.), white birch (*Betula papyrifera* Marsh.), basswood (*Tilia ameriana* L.), American beech (*Fagus grandifolia* Ehrh.). Less damage was caused to hardwoods, such as sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), red oak (*Quercus rubra* L.) and bitternut hickory (*Carya ovata* Mill. K.Koch).

The Ontario Ministry of Natural Resources and Natural Resources Canada have conducted extensive surveys on the effects of ice storms (especially the devastating storm of 1998) on the coniferous and deciduous forests of the Greenbelt. This has some implications for the recent changes in the Stony Swamp Conservation Area. The Forest Research Conference (2000) (as described by Nielsen, 2001) focused on climate change in relation to the frequency of ice storms, and survey and monitoring methods for the study of recovery rates at scales from the landscape to the single plant. Also examined was the response of forest vegetation, effects on forest fauna, treatment methods and management methods. The map in Figure 1.5 shows that the Greenbelt experienced varying amounts of damage, ranging from light to severe. In the Western Greenbelt, there was light damage north of the 417 and west of Bells Corners. South of Bells Corners (including much of Stony Swamp) there was light to moderate damage (Nielsen, 2001).

Figure 1.5. Areas of Ice Storm Damage in Eastern Ontario (1998).

Source: Natural Resources Canada, Canada Forest Service (2001).

1.5. A Description of the Study Area.

This section describes the study area, with support from the literature review above. The following sub-areas are described as sections within this larger scenario.

- ***The Stony Swamp Conservation Area.*** This area is presented in the detail, as it represents the focus of the research. The change in this area is mainly forest expansion, in both patches and continuous configuration.
- ***Bells Corners.*** Bells Corners is the main urban feature in the study area. The early photographs show this town as a mere cluster of buildings, which slowly developed into a small town. The design of the town is marked by a large number treed avenues, may have resulted in an absolute increase in the number of trees compared with the farmlands and isolated forest patches upon which Bells Corners was built.
- ***The Parks Area.*** This area, which lies south and south west of Bells Corners, is mixed forest and grassland. It comprises Arbeatha Park, and mixed forest/grassland areas. The main form of change appears to be forest expansion.
- ***The Fallowfield/Quarry Area.*** This area covers the southwestern borders of the Conservation Area, and is close to the settlements of Cedarhill Estates, Orchard Estates, Fallowfield Village, Fraservale, Pheasant and Barrhaven. The current features reveal an interesting mix of urban, agricultural and forest developments, surrounding the quarry.

- ***The Kanata Interface.*** This area covers the Bridlewood urban development east of Eagleson Road and the area stretching from Shirley's Bay, south to Robertson Road. Also considered are those areas, currently covered by the town of Kanata which lie to the immediate west of Eagleson and Herzberg Roads.
- ***The Ottawa-Kanata Interface.*** This area lies to the east of Shirley's Bay, and north and east of Bells Corners, south to Cedarhill Estates and Barhaven. This area displays a patchy change between forest and grassed lands.

The division of the study area into zones reflects the historical development of the forested, farmed and urbanised areas. The development of Ottawa, Kanata and Bells Corners, which largely replaced farmed areas, resulted in a different form of change than that of the Conservation Area, where forests replaced farmed areas. The area currently covered by the quarry also shows a different type of change; from cultivated areas were converted to open bareground. In this work, forest is defined as those areas where the vegetation with a distinct bole or several branched boles, eight or more metres in height comprise the dominant vegetation form. Areas of mixed urban and treed features are classified as mixed urban. Farmed areas are those areas covered either by crops or grass, which appear to be under immediate or recent cultivation, or controlled grazing.

Therefore, these areas (the Ottawa-Kanata interface, the Kanata interface, the Quarry-Fallowfield area and Bells Corners are examined as part of the environment of the Stony Swamp Conservation Area. The configuration of the landscape around the protected area

is important for its ecological sustainability. Corridors, along roads, river valleys, hedgerows, plantations, and fallow fields may allow the movement of animals and also plants species that have restricted methods of propagation. The pattern of urbanisation and agricultural development may either seal off a conservation area, or allow contacts with the wider ecosystem. From the perspective of the sustainability of the Stony Swamp Conservation Area, this provides an important justification for examining the wider changes in the contiguous landscape.

Therefore, the issues the presentation of the environmental description in this chapter clusters around the following questions:

- What type of landscape change has occurred in Stony Swamp Conservation Area, based on the evidence of the aerial photographs?
- What type of landscape change has occurred in the area surrounding the conservation area?

This section uses a Landsat image dated 1999, aerial photographs dated 1955, and several field photographs for identification purposes. Figures 1.6 show the study area and its environs in 1999, Figure 1.7 shows the divisions and Figure 1.8 shows the roads used for dividing the area. Figure 1.9 shows the points where the field pictures were taken. Figure 1.10 shows a sample of the field photographs.

Figure 1.6. The Study Area (1999).
1955

1999

Borders

2000 0 2000 4000 Metres

Figure 1.2. The Study Area (Divisions).

Figure 1.8. Road Map of the Study Area.

Figure 1.9. Location of a Sample of the Field Photographs.

Figure 1.10 (a). Field Photographs.

(a)

(b)

Conifers and grass. This area is very visible in the Landsat image.

(c)

(d)

Open grassed clearings and conifers.

(e)

Large, very old oak tree in younger maple wood.

Figure 1.10 (b) Field Photographs.

(f)

Red Pine Plantation

(g)

Maple Stands.

(h)

Exposed rock, and cedars.

(i)

Evidence of deer browsing on cedar.

Figure 1.10 © Field Photographs.

(j)

Dried Beaver lake.

(k)

Parks area (Arbeatha Park).

(l)

Trees damaged by the 1998 ice storm.

(m)

View from quarry north on Moodie Drive.

An overview of the presentations of the materials this chapter supports the following points.

- The evidence of change. There was clear evidence of environmental change in the selected areas, but this was very patchy and difficult to generalise. The absence of retreating or advancing forest/grassland boundaries in large-scale linear formation makes assessments difficult. The vegetation change is patch dynamic, created either by conscious planting, the cessation of cultivation and/or cutting for urban development, or simple protection from development.
- Forest expansion, urbanisation and agricultural change were clearly the main forms of change. Urbanisation was very pronounced, with the pattern being the surrounding of many parts of the Greenbelt. Farmland retreated, mainly being replaced by urban features. Forest plantations appear to have contributed to forest stand change.
- The existence of links and corridors for ecological conservation was not very clear. The configuration of the protected area, surrounded by areas of high human proximity, including roads, residential neighbourhoods, commercial zones and farms does not provide evidence of the type of corridors that could be frequently utilised by wildlife. Hence perhaps, the frequent use of roads by mammals and the frequency of accidents (Brown 2001).

- The need for more accurate measurements and quantification. The patchy nature of the changes supports the need for more accurate measurement. One technique for the assessment of the changes would be overlaying of the time series images, covering the entire study area. Smaller subsets of this area, representative of particular forms of change as described in this chapter would also need attention. This type of assessment, using the tools of geomatics, is described in the next chapter.

1.6. Summary.

This chapter has examined certain key concepts, methods and case studies concerning socioenvironmental relations, in the global context and also in the Canadian case. In the process four key themes were discernible, and each of them were related to a gap in the literature on a Canadian case study.

Firstly, the construction of models of environmental change involves a degree of subjectivity, and hence it is difficult to arrive at a consensus. In this case, sustainable development is posited as the key background concept for the assessment of current environmental history and the practice of conservation, which in turn may be understood better with incisive tools of analysis, such as IR and geomatics supported by field methods. However, there is only a very general consensus on what exactly sustainable development is and hence no real agreement on how it may be measured or manifested through conservation policy. Interdisciplinary methods, and consideration of multiple view points have a particular strength, as this allows the selection of the strengths of each

discipline (on the grounds that the sum of knowledge methods tends to be better than the parts) and the integration of these into a framework with explanatory possibilities. There are insufficient case studies that explore how these concepts might be implemented in a practical case.

Therefore, the second point is that IR has complemented, or even replaced narrower studies that look only at small parts of the complex subject. By emphasising multiple methodologies, wider perceptions of the environment are possible. There has been a strong attempt in the ecological sciences to assess the human impacts on ecological processes and forms and to integrate these into the appraisal of the impacts of natural factors. Therefore, the perception that environmental history is about the temporal changes in the total social and natural milieu, and the changes through time, is gradually strengthening. This is supported by studies in widely varying contexts that test the generic application of this approach. Many of these studies are restricted to "disaster" areas in the developing nations, with few Canadian cases. Also, the need for the quantifiable accuracy of method that allows generic comparison has gradually developed.

This leads to the third point. It is apparent that broad studies are more likely to challenge existing, narrower and more specialised studies if there is accuracy in measurement, synthesis and results. This is especially true where such accuracy and quantification is in a format suitable for each of the involved disciplines. The role of geomatics is thus emphasised in this context as multifaceted. It is integrative, in the sense that it is capable

of analyses and syntheses, utilising data derived from both social and natural sciences. It also enhances comparability, as the analyses are capable of formatting such data for ready comparison across disciplinary boundaries. By enhancing accuracy, it enables more accurate measurement and quantification than is possible in more qualitative studies. The progressive development of this integrative methodology has however not resulted in universal application. There are still many contexts where the utilisation of this method would be helpful in examination of environmental change.

This leads to the fourth point. Despite the considerable work that has been done on the Canadian environment, there are not enough integrated studies of the rapidly changing contexts of Ontario. This region is undergoing comparatively fast environmental change. Significant gaps exist in current knowledge of the integrated change in this region. The broadly based methodology described above is remarkably well positioned to make a contribution to this problem. The next chapter will explore this possibility, by suggesting a methodology that seeks to make a contribution to the theoretical and methodological issues above, and to current knowledge of environmental change in Ontario.

Chapter Two. The Theoretical Framework and Methodology.

2.1. Introduction.

The research problem and objectives of the current research, based on applications of IR and geomatics, necessitate the development of a broad research theoretical framework and methodology. This chapter describes the theoretical framework and methodology that informed the research data collection, design and analysis upon which the succeeding chapters are based. The factors involved in the choice of the research methodology included the availability of the time series images covering the study area, the theoretical basis described in chapter 1, the historical records and narratives available and the lack of similar research carried out in the area. The key topics described are:

- The theoretical framework and the justification for its adoption and design.
- The selection of the study area.
- The selection of the data to be used and the methods used to acquire and analyse them.

2. 2. The Theoretical Framework.

An examination of the contemporary literature on environmental change and socioenvironmental relations in Canada's protected areas reveals the existence of some gaps in knowledge. These knowledge gaps have inhibited the development of effective conservation policies and monitoring efforts. Problematic issues include:

- Insufficient studies based on the analysis of time series images, which allow quantifiable analysis of chronological change.
- The lack of integrated studies, synthesising the approaches of both social and natural sciences to allow a broader understanding of landscape change.
- Even where such integrated studies exist, there is little attempt to integrate geomatics into the methodology.
- The focus on one aspect of the landscape (e.g. urban expansion or forest change), rather than relations between two or more such features, hinders the understanding of holistic land-use issues.
- Critical studies of multi-directional environmental change are rare. Most studies are narrowly based on the relationship between a set of factors and changes of one feature in the landscape (a case in point being the work of Wickham *et al.* (2000) on the relationship between forest fragmentation and economic activities).
- The Ottawa Greenbelt in particular has not been subjected to a critical analysis utilising such an integrated methodology.

The theoretical framework developed in this thesis seeks to make a contribution to the filling of these gaps. The framework is based on the undeveloped idea provided by Burgi and Russell (2001) which seeks to analyse landscapes through the linking of landscape ecology and history through studies of human impacts over time. This utilises common terms or "interface categories" (*ibid.*12), exemplified by the study of periods of socioenvironmental relations and the investigation of the environmental impacts, within

these periods. Crumley (1998), Russell (1997) and Scoones (1999) also touch on this approach, but is a topic currently neglected in the research literature (Meine, 1999).

Within this theoretical framework, there is both an ecological and historical dimension. The ecological element is based on the new, disequilibrium ecological paradigm, which as described in Chapter One, is based on the idea that the chaotic, non linear and multidirectional characteristics of environmental relations cannot be fully understood using the rigid tools of classical ecology. There is a need for a more flexible methodology based on an increased focus on environmental history, variation in space and time, and also scale, structure and agency. The social dimension of the research is based the description of the social methodology in Burgi and Russell's thesis, where social actors are described as modifying the environment during periods of differentiated socioenvironmental activity.

The current study, however argues that merely to study the "human impact" on the environment as "a way of bridging the disparity gap" between a field science such as landscape ecology and a social science such as history is not enough. For academic as well as practical value, there must be a methodology that's enables the synthesis of materials derived from both natural and social science research methodologies, which allows both scientific rigor and historical value. The research methodology used in this thesis utilises geomatics, supported by field studies and historical data. This provides a practical methodology that allows the integration of ecological data (images of

phytogeographical change and field data) with that of social history (images of urbanisation and agriculture, and mapping of patterns revealed by social surveys).

The merit of such an approach is that IR methodologies are "still rare", as noted by Burgi and Russell (2001). Meine (1999, 1) also notes that "natural scientists and historians may gaze upon the same landscape, but they see different things and draw different lessons from what they see".

2.3. The Selection of the Study Area.

The selection of this study area was based on the following points:

- The perception of a gap in the knowledge about environmental change in the western Greenbelt based on a literature search.
- Discussions with officers at the National Capital Commission, the City of Ottawa and the Macoun Club (an NGO), which pointed to the Western Greenbelt as an area of prime importance to the conservation of medium and small sized mammals and birds, and also for forest stands.
- The interesting mix of dynamics in the Ottawa region (rapid urbanisation, tourism development and land-use change) all in a relatively small area, offers an good case study to test methods for the study of similar issues at larger scales elsewhere.

- The mosaic of land-uses in the area makes it extremely difficult to rely on image based, visual analysis of landscape change. This makes a strong case for the quantification allowed through geomatics, in conjunction with field studies.
- The lack of an organised body of information on the area. Numerous organisations have studied the area (the National Capital Commission, the City of Ottawa and the Macoun Club, students enrolled at Carleton University), but there has been no attempt to combine the various studies into a coherent document covering all aspects of the landscape change.

2.4. The Information Sources.

The following sources of information were consulted.

- Satellite images (Landsat TM, dated 1994 and 1999). Despite the poorer resolution of these images (pixels are 30 m wide) compared with aerial photographs, these images displayed as infrared and visible bands allowed feature identification. This was complementary to the aerial photographs and the field derived data.
- Aerial photographs (dated 1934, 55, 64, 70, 77, 87, 94, 99). These black and white photographs were the main materials for the historical analysis. The 1934 aerial photograph provided only partial coverage (the Ottawa/Kanata interface, Bells Corners and the Parks area).

- Maps (urban, vegetation and farming) dated 1879, and 1991. These map the plotting of field data such as mammal sightings, visited areas, monitored areas, and observed changes. Maps displaying these some variables as points were created in ArcView.
- Field measurements (field photographs, vegetation observations). These utilised field digital photographs to allow the identification of features recorded in the more recent aerial photographs and satellite images. Variables examined were evergreen/deciduous stands, farmland/grassland, swamps and moist areas, ground exposure and mammal sightings.
- Historical literature. This comprised old maps and descriptions of landscapes, mostly during the 19th century. The information from these sources was compared with the later time series images and maps.
- Demographic data. This data (covering population increases for Bells Corners and Kanata) was added for linkages between population growth and urbanisation, as revealed by the changes in settlement size as seen in the aerial photographs.
- Consultation with stakeholders. Four main sets of stakeholders were identified: administrators (especially in the NCC), explorers, tourists and residents.

2.5. The Analysis Methods.

2.5.1. The Software.

The software programmes used were PCIWorks and IDRISI. The aerial photographs were saved in JPEG format and opened in PCIWorks. These were then registered to a common grid and mosaics created by joining the images. Features were then digitised into polygon vector files in IDRISI for the creation of theme maps. The pixels in the images appeared in various colours according to the features they represented. Identification of the features was aided by the consultation of maps and aerial photographs and field information derived from the literature. ArcView was used for the creation of points on the maps.

2.5.2. The Classification of the Areas.

Based on the analysis of these information sources, five attribute classes were selected.

- Urbanised areas: comprising buildings, roads, pavements other concrete infrastructure. These appeared white in the visible band images in both the aerial photographs and satellite images, and sky blue in the colour infrared (CIR) images. This classification included urbanised areas containing a large amount of vegetation. These comprised areas where buildings, roads and pavements existed in close proximity with tree lined avenues, parks, grassed edges and suburban gardens. These areas appeared mottled dark and light grey in the visible band images and mottled purple in the CIR images.

- Light vegetation areas. These areas include: (1) lightly grassed areas, mainly cleared farms, but also certain denuded areas in non-farmed areas. These were coloured brown in the visible band images and green in the CIR images. Where there was a significant presence of vegetation, a greenish or reddish tinge could be discerned in the visible and CIR images respectively; (2) Farms and grassed areas, distinguished by colour (green shades in the visible and red in the CIR images) showing the presence of vegetation, and fine texture, which distinguished them from the rough textured forested areas. Farms and grassed areas were classed together as it was difficult to distinguish cereal crops from dense grass.
- Dense vegetation areas. These areas include: (1) Coniferous and deciduous forest. Forest appeared as blotches of variably dark green (visible band images) and of crimson (CIR images). Coniferous stands were generally darker than deciduous forest. (2) Swampy forest. These were areas of dense vegetation and swamp or water. Moist forest areas were included because of their spectral similarity: these areas were darker than the surrounding vegetation.
- Open water, mainly ponds and bogs. These appeared black in the images, and in the CIR images contrasted strongly with the red coloured vegetation.
- The Quarry Areas. These comprised large expanses of bare soil and rock surface, limited largely to an area north of Fallowfield Road, south of the Stony Swamp Conservation Area, and west of the 416 highway.

The parameters examined for the study were:

- The percentage of forest cover compared with other land-use cover (grass/farm, urban).
- The degree of change between the time series images.
- The possible changes between the forest, grass and urban cover.

2.5.3. The Cross-tabulation of the Images.

The classified maps created for each of the years were overlaid and cross-tabulated to produce multi-change matrices. The procedure for the cross-tabulation is as follows: the earliest dated image maps (1934 for the northern section of the study area, and 1955 for the whole area) was cross-tabulated with the most recent (1999) for the total coverage. Areas of greatest change were noted. Then the image maps created were cross-tabulated according to the pairs (1934, 1955; 1955, 1964; etc.), to create a chronology of change and also to establish the periods of different change. The maps were also subdivided into the sub-areas in the above list and the same procedure was followed for each of these areas, allowing for comparison. For visual comparison, theme maps were created with polygons representing areas of great (for example total change from farm to forest), medium (more patchy change) and small change (barely visible). The data provided by the matrices was also used to create line graphs in Microsoft Excel. These illustrated the trends in graphical format. The results of this analysis are presented in Chapter Three.

2.6. Summary.

This chapter has described the methodology employed for the current research and the theoretical and practical justifications for this choice. The approach developed from perspectives described in the literature on environmental management and geomatics, together with the awareness of gaps in the knowledge of the conservation areas of Ontario in general and of the western Greenbelt in particular. The main objective was to develop a methodology that would contribute to increased understanding and utility in these areas, and to offer a constructive model for generic application.

The main theoretical framework was based on the undeveloped idea of Burgi and Russell (2001) that seeks to integrate methods of landscape ecology and history. This thesis seeks to find common ground in between the methods of these two disciplines, to allow integrated analyses. The integration is found in "interface categories" which describe those terms, which offer common relevance to the two disciplines, in this case defined as "periods", which are episodes during which socioenvironmental interactions have a particular character. The methodology utilises a wide time frame (1934 to 1999) which covers several periods of both social and environmental change in the rapidly developing National Capital Region. This provides useful data for testing of possibilities of this paradigm.

The ecological dimension of the research was based on the new, disequilibrium, ecological paradigm. This approach bases an analytical method on the "chaotic fluctuations", nonlinear, multidirectional and dynamic changes in the environment. There

is increased emphasis on environmental history, spatial and temporal variation, which creates patch dynamic change. The methodology supports this paradigm by utilising time series images that reveal multidirectional change in the landscape ecology, when subjected to geomatics analysis.

The social side of the research was also based on Burgi and Russell's work, which utilises the term "actors" to describe the specific set of human actions that obtain during the periods, based on the questions on the impacts of the actors. The methodology supports this paradigm, using analysis of temporal change in urban features in the images, and also the input of social data from historical records, which may allow the integration through image overlays and cross-tabulation, with the other data inputs.

A very important addition was the geomatics based methodology. In the theoretical discussion by Burgi and Russell (2001). In the current study, the synthesis of the information from both natural science (biogeography and landscape ecology) and social science (history and urban/agricultural sociology) was based on geomatics. This allowed the integration of multiple sourced information (both ecological and social) to produce documented formats that illustrate, quantify and analyse the dynamics described in the new ecological paradigm. Increased accuracy is imparted, both by the analytical possibilities of the geomatics and the utilization of time series, remotely sensed images.

In the development of such a broad methodology, it is possible that there will be problems integrating the information, and assessing the reliability of the results. One

method to reduce this possibility is to illustrate the strong points of the methodology (the generic merit and applicability of multiple sourced analysis, the strength of multiple viewpoints, and the greater importance of these advantages over the problems of integration). To use this method progressively, there must be an analysis that provides competent socioenvironmental analyses, and also a comparative format that demonstrates the greater utility of such a integrated methodology over the narrower studies based on a single discipline. This is attempted in the following chapters.

Chapter 3. Geomatics Based Analysis of the Time Series Images and Field Data.

3.1. Introduction.

This chapter presents the results of the geomatics analysis, as follows.

- Tables. These present changes in the percentage composition of dense and light vegetation, urban features, open water and quarry in the sub-areas of the study area.
- Line graphs. These show the same information as the tables, but the relative trends of change are more evident (rather than the detailed percentage figures in the tables).
- Matrices. The cross-tabulation of the classified theme maps shows multidirectional change, for example, gains and losses between dense and light vegetation.
- Overlaid images. These show the data in the matrices in spatial format. They therefore complement the matrices by showing the location of the multidirectional change. The gains and losses described above may be seen as coloured polygons.
- Point maps, which overlay point data on the theme maps. Areas of deer kills and beaver activity are thus displayed in relation to the land cover polygons.

3.2. Landscape Change in the Study Area (1955- 1999).

3.2.1. Theme Maps.

Dated theme maps of the are presented below (Figures 3.1 to 3.9).

Figure 3.1. Feature Map of the Western Greenbelt (1955).

Figure 3.2. Feature Map of the Western Greenbelt (1964).

Figure 3.3. Feature Map of the Western Greenbelt (1970).

Figure 3.4. Feature Map of the Western Greenbelt (1977).

Figure 3.5. Feature Map of the Western Greenbelt (1987).

Figure 3.6. Feature Map of the Western Greenbelt (1994).

Figure 3.7. Feature Map of the Western Greenbelt (1999).

3.2.2. Line Graphs of Landscape Change.

This section presents the data derived from the cross-tabulation of the classified images as line graphs. This change is shown in tabular form in the next section on matrices, to provide a link with the matrices. The first image, Figure 3.8. shows change in the whole area. This change shows an increase in urban and forested areas, and a decline in the farm/grassed areas. Figure 3.9 shows change in Stony Swamp. Here the main change is the increased area under forest, a decline in light vegetation, and a slight increase in urban areas and open water. The forested area is far higher in proportion than in the combined study area. Figure 3.10. shows change in Bells Corners. Here it is basically a replacement of light vegetation by urban features. Figure 3.11 shows change in the Parks area to be mainly forest expansion. Figure 3.12 shows the expansion of urban and quarry features in the quarry area, and the decline of vegetation. Figure 3.13 shows change in the Kanata interface to be largely a decline in vegetation and an increase in the urban areas. Figure 3.14 shows the slight decline of light vegetation in the Ottawa-Kanata interface.

Figure 3.8. Line Graph of Landscape Change in the Study Area (1955-1999).

Figure 3.9. Line Graph of Landscape Change in Stony Swamp (1955-1999).

Figure 3.10. Line Graph of Landscape Change in Bells Corners (1934 -1999).

Figure 3.11. Line Graph of Landscape Change in the Parks Area (1934-1999).

Figure 3.12. Line Graph of Landscape Change in the Fallowfield/Quarry (1955-1999).

Figure 3.13. Line Graph of Landscape Change in the Kanata Interface (1955-1999).

Figure 3.14. Line Graph of Landscape Change in the Ottawa-Kanata Interface (1934-1999).

The results for the whole study area are presented below in Table 3.1. For the period 1955 to 1999 the following percentage changes were apparent.

Table 3.1. Landscape Change in the Study Area by Percentage (1955-1999).

Classes	Date						
	1955	1964	1970	1977	1987	1994	1999
Urban	2.9	7.2	11	12.2	18.6	21	24.7
Light Veg	79.7	71.3	66.8	58.6	52.2	48.8	43.3
Dense Veg	16.9	20.6	21.5	26.4	25.5	26.3	28.3
Quarry	0	0	0.7	1.4	3	3.2	3.1
Water	0	0	0	0.5	0.6	0.7	0.4
Total	100	100	100	100	100	100	100

3.2.3. Matrices and Images.

The tables below show the results of the cross-tabulation of the images. Also displayed are images showing spatial changes in the images. Table 3.2. shows the cross-tabulation of the results for 1955 (columns) against 1999 (rows) based on the percentage of total area (approximated to the first decimal point: changes less than 0.1 are taken to be insignificant). The table shows the following:

- There has been very dynamic landscape change between 1955 and 1999. Comparison of similar classes for the two dates shows that in no case was more than 50 percent of the area under any category in 1955 still under the same category in 1999. The figures were two percent for urban areas, 40 percent for light vegetation, and about 10 percent for denser vegetation.

- The largest change was urban expansion into areas of light vegetation (farmland, grassed meadows, and light shrubland).
- Possibly due to the small amount of dense vegetation in the earlier period (which was shown in the classified maps dated 1955 to 1977) there was very little urban expansion into areas of dense vegetation (two percent of the total study area which was under dense vegetation in 1955 was under urban land use in 1999).
- There was also significant expansion of dense vegetation (forest, dense tree/shrub combinations and shrubby wetland) into areas previously under lighter vegetation

The result may be summarised as: a large decline of farmland and related cover (80 to 44 percent); an increase in urban areas (3 to 24.7 percent); and an increase in forested areas (16.9 to 28.3 percent). Other changes were either minimal or virtually non-existent.

Table 3.2. Landscape Change in the Study Area (1955-1999).

Classes	Urban	Light Veg	Dense Veg	Quarry	Total 1999
Urban	2.7	19	2.8	0	24.7
Light Veg	0.1	39.6	3.7	0	43.3
Dense Veg	0.2	17.6	10	0	28.3
Quarry	0	1.9	1.1	0	3.1
Water	0	0.3	0.2	0	0.4
Total 1955	2.9	79.7	16.9	0	100

Figure 3.15. Image Overlay Showing Land Cover Change (1955 and 1999).

The legend is as follows:

1= Urban.

2 = Light Vegetation.

3 = Dense Vegetation.

4 = Quarry.

5 = Water.

The first column is the first year, and the second column is the second year. Therefore, the second number represents a feature replacing a feature represented by the first.

The following matrices show the changes that occurred between the dates represented by the images.

Table 3.3. Landscape Change in the Study Area (1955-1964).

Classes	Urban	Light Veg	Dense Veg	Quarry	Water	Total 1964
Urban	1.7	5.4	0.2	0	0	7.2
Light Veg	1	66.2	4.1	0	0	71.3
Dense Veg	0.2	7.4	12.7	0	0	20.6
Quarry	0	0.5	0.2	0	0	0
Water	0	0	0	0	0	0
Total 1955	2.9	79.5	16.9	0	0	100

The main changes represented in this table are the losses of areas of light vegetation to urban areas (5.4 percent) and dense vegetation (7.4 percent). The loss of dense vegetation to urbanisation was minimal (0.2 percent).

Figure 3.16. Image Overlay Showing Land Cover Change (1955 and 1964).

The Legend is as follows:

1 = Urban.

2 = Light Vegetation.

3 = Dense Vegetation.

4 = Quarry.

5 = Water.

Table 3.4. Landscape Change in the Study Area (1964-1970).

Classes	Urban	Light Veg	Dense Veg	Quarry	Water	Total 1970
Urban	5.7	4.9	0.3	0	0	11
Light Veg	1	60	5.5	0.2	0	66.8
Dense Veg	0.3	6.2	14.5	0.1	0	21.5
Quarry	0	0.1	0	0.5	0	0.7
Water	0	0	0	0	0	0
Total 1964	7.2	71.3	20.4	0.8	0	100

Table 3.4. shows the change to be principally a slight increase in dense vegetation and a small decline in light vegetation. Urbanisation was also evident, with the main inroads being on light vegetation, rather than dense vegetation. However, both light and dense vegetation lost stands to each other (6.2. and 5.5 percent respectively). Therefore, what might be termed deforestation or reforestation was not linear during this period.

Figure 3.17. Image Overlay Showing Land Cover Change (1964 – 1970).

The Legend is as follows:

1 = Urban.

2 = Light Vegetation.

3 = Dense Vegetation.

4 = Quarry.

5 = Water.

Table 3.5. Landscape Change in the Study Area (1970-1977).

Classes	Urban	Light Veg	Dense Veg	Quarry	Water	Total 1977
Urban	8.7	3.1	0.5	0	0	12.2
Light Veg	1.9	53.1	3.6	0	0	58.6
Dense Veg	0.2	9.2	16.9	0.1	0	26.4
Quarry	0	0.5	0.3	0.6	0	1.4
Water	0	0.4	0.1	0	0	0.5
Total 1970	11	66.5	21.5	0.8	0	100

Table 3.5. shows a similar trend to Table 3.4. There was a slight decline in the area of light vegetation, and increases in urban areas and dense vegetation. Urbanisation made inroads principally into light vegetation, and as in the previous period, dense and light vegetation replaced each other. Light vegetation (mainly meadows and farms) remained the dominant land cover.

Figure 3.18. Image Overlay Showing Land Cover Change (1970 and 1977).

The Legend is as follows:

1 = Urban.

2 = Light Vegetation.

3 = Dense Vegetation.

4 = Quarry.

5 = Water.

Table 3.6. Landscape Change in the Study Area (1977-1987).

Classes	Urban	Light Veg	Dense Veg	Quarry	Water	Total 1987
Urban	10.8	6.4	1	0	0	18.6
Light Veg	1	44.3	6.4	0.1	0.1	52.2
Dense Veg	0.3	7	17.9	0.1	0.1	25.5
Quarry	0.1	0.7	0.9	1.3	0	3
Water	0	0.1	0.2	0	0.3	0.6
Total 1977	12.2	58.6	26.4	1.4	0.5	100

Table 3.6 shows a continued decline in the area covered by light vegetation and an increase in denser vegetation. There were however similar gains and losses between light and dense vegetation (7 and 6.4 respectively). There was also an increase in urban coverage, mostly into areas covered previously covered by light vegetation.

Figure 3.19. Image Overlay Showing Land Cover Change (1977-1987).

The Legend is as follows:

1 = Urban.

2 = Light Vegetation.

3 = Dense Vegetation.

4 = Quarry.

5 = Water.

Table 3.7. Landscape Change in the Study Area (1987-1994).

Classes	Urban	Light Veg	Dense Veg	Quarry	Water	Total 1994
Urban	15.3	4.2	1.5	0	0	21
Light Veg	2.5	41.5	4.3	0.3	0.1	48.8
Dense Veg	0.6	6.1	19	0.3	0	26.3
Quarry	0.1	0.3	0.5	2.3	0	3.2
Water	0	0.1	0.2	0.1	0.4	0.7
Total 1987	18.6	52.2	25.5	3	0.5	100

In Table 3.7, the trends of the earlier tables continued. However, there was a small decline in the area covered by denser vegetation, for the first time.

Figure 3.20. Image Overlay Showing Land Cover Change (1987-1994).

The Legend is as follows:

- 1 = Urban.**
- 2 = Light Vegetation.**
- 3 = Dense Vegetation.**
- 4 = Quarry.**
- 5 = Water.**

Table 3.8. Landscape Change in the Study Area (1994-1999).

Classes	Urban	Light Veg	Dense Veg	Quarry	Water	Total 1999
Urban	19.8	3.8	0.8	0.3	0	24.7
Light Veg	0.7	38.6	3.7	0.1	0.2	43.3
Dense Veg	0.5	5.9	21.5	0.2	0.2	28.3
Quarry	0	0.2	0.2	2.5	0.1	3.1
Water	0	0	0	0	0.3	0.4
Total 1994	21	48.8	26.2	3.1	0.8	100

Table 3.8 shows the continuation of the trend of change displayed in the earlier tables.

Urban and forest expansion continued, associated with the expansion of the quarry area.

Figure 3.21. Image Overlay Showing Land Cover Change (1994- 1999).

The Legend is as follows:

1 = Urban.

2 = Light Vegetation.

3 = Dense Vegetation.

4 = Quarry.

5 = Water.

3.3. The Stony Swamp Conservation Area.

This section takes a more detailed snapshot, examining the landscape change in Stony Swamp Conservation Area from 1955 to 1999. The first table shows the changes of features in the conservation area from 1955 to 1999 (Table 3.9). The matrix in Table 3.10 shows that there has been an increase in urban features within Stony Swamp. There has also been a high exchange of light vegetation and dense vegetation (6.2 percent from light to dense and 38 percent from dense to light). Dense vegetation also lost some area to urbanisation. This result, evaluated in conjunction with the overall percentage of the two vegetation classes (dense vegetation 29.6 to 60.4 percent 1955 to 1999, and light vegetation 68.7 to 29.8 percent 1955 to 1999) shows a largely linear expansion of forest in this area. Both light vegetation (5.9 percent) and dense vegetation (0.5 percent) lost some area to urban expansion.

Table 3.9. Landscape Change in Stony Swamp by Percentage (1955 to 1999).

Classes	Date						
	1955	1964	1970	1977	1987	1994	1999
Urban	1.5	1.5	1.9	4.1	6.9	7.2	7.6
Light Veg	68.7	63	62.1	43.8	37.6	34.6	29.8
Dense Veg	29.6	35.4	35.7	50.2	53.8	56.1	60.4
Quarry	0	0.1	0.1	0.2	0.2	0.2	0
Water	0	0	0	1.3	1.5	1.7	0.8
Total	100	100	100	100	100	100	100

Table 3.10. Landscape Change in Stony Swamp (1955-1999).

Classes	Urban	Light Veg	DenseVeg	Quarry	Water	Total 1999
Urban	1.2	5.9	0.5	0	0	7.6
Light Veg	0.1	23.5	6.2	0	0	29.8
Dense Veg	0.1	38.2	22.3	0	0	60.4
Quarry	0	0	0	0	0	0
Water	0	0.4	0.4	0	0	0.8
Total 1955	1.5	68.7	29.6	0	0	100

Examining the change according to the periods covered by the time series images, certain trends may be noted. Between 1955 and 1964, there was a significant loss of dense vegetation to light vegetation (6.1 percent), but this was less than the reverse gain (11.7 percent). Both types of vegetation lost some area to urbanisation (0.7 percent light vegetation and 0.2 for dense vegetation) with minimal gains into urban areas, probably due to the establishment of parks and treed avenues. The dynamic nature of vegetation change in this period may be seen in the figures where columns and rows for similar features meet. Despite the fact that 68.7 percent of the study area in 1955 was under light vegetation (and the corresponding figure in 1964 was 63 percent) and only 58.6 percent of the study area was occupied by the overlap. The same conclusions may be reached concerning dense vegetation: there was an overall increase from 29.6 percent and 34.5 percent, but only 23.2 percent of the area represented an overlap between coverage for the two dates. This points to gains and losses, rather than mere expansion.

Table 3.11. Landscape Change in Stony Swamp (1955-1964).

Classes	Urban	Light Veg	Dense Veg	Quarry	Water	Total 1964
Urban	0.5	0.7	0.2	0	0	1.5
Light Veg	0.5	56.3	6.1	0	0	63
Dense Veg	0.4	11.7	23.2	0	0	35.4
Quarry	0	0	0.1	0	0	0.1
Water	0	0	0	0	0	0
Total 1955	1.5	68.7	29.6	0	0	100

Between 1964 and 1970, there was similar trend. The loss of light vegetation to urban growth increased to 1.3 percent and the loss to dense vegetation declined to 9.8 percent. Overall there was a smaller overlap between the light vegetation in 1964 and 1970, then between 1955 and 1964. Dense vegetation hardly changed in area (35.4 to 35.7) although the overlap between these areas was 25.5 percent of the total area of Stony Swamp.

Table 3.12. Landscape Change in Stony Swamp (1964-1970).

Classes	Urban	Light Veg	Dense Veg	Quarry	Water	Total 1970
Urban	0.2	1.3	0.4	0	0	1.9
Light Veg	0.9	51.8	9.4	0	0	62.1
DenseVeg	0.4	9.8	25.5	0	0	35.7
Quarry	0	0	0	0.1	0	0.1
Water	0	0	0	0	0	0
Total 1964	1.5	63	35.4	0.1	0	100

Between 1970 and 1977 there was a far greater vegetation change. The drop in light vegetation from 62.1 percent to 43.8 percent was mainly due to losses to urban areas (2.4 percent), dense vegetation (20 percent) and to a lesser extent to quarries (0.2 percent) and water (beaver swamps, one percent). Dense vegetation areas expanded from 35.3 percent to 50.2 percent. Gains were to light vegetation as noted above and urban 0.2 (mainly expansion of parks and treed areas). There were however some losses: 0.8 to urban, 4.3 to light vegetation. Out of the two extents of forested vegetation (35.3 and 50.2 percent respectively) on the two dates, only 30 percent of the area (or just over 80 percent of their joint area) was common.

Table 3.13. Landscape Change in Stony Swamp (1970-1977).

Classes	Urban	Light Veg	Dense Veg	Quarry	Water	Total 1977
Urban	0.8	2.4	0.8	0	0	4.1
Light Veg	0.9	38.5	4.4	0	0	43.8
Dense Veg	0.	20	30.1	0.1	0	50.2
Quarry	0	0.2	0	0	0	0.2
Water	0	1	0.3	0	0	1.3
Total 1970	1.9	62.1	35.3	0.1	0	100

The changes between 1977 and 1987 were not as extreme. Light vegetation decreased from 43.8 to 37.6 and forested areas increased from 50.2 and 53.8 for the total area. However, it appears that was also due to the greater similarity of gains and losses. Thirty eight percent of Stony Swamp under forest in 1977 was still forest in 1987. The rest of the forest area differences were due to gains and losses. The same applied to light

vegetation. Despite the smaller reduction compared with 1970-1977, there was similarity low overlap less (63 percent of their joint area), compared with 73 percent in 1970 and 1977. This points to increased dynamism of change, despite a reduced overall amount of change between 1987 and 1994, the totals of light and dense vegetation were minimal (53.6 to 56.1, and 37.3 to 34.6 respectively. For dense vegetation the overlaps between the similar areas for the two dates was 73 percent compared with 76 percent in 1970-77, still indicating dynamic gains and losses. Light vegetation lost over 15 percent of its area to dense vegetation, but dense vegetation also lost over 10 percent. A similar trend could be seen in the period 1997-1987 (Table 3.15), with marginal decline in light vegetation and increases in dense vegetation, and similar overlaps between dates.

Table 3.14. Landscape Change in Stony Stony Swamp (1977-1987).

Classes	Urban	Light Veg	Dense Veg	Quarry	Water	Total 1987
Urban	3.6	2.5	0.8	0	0	6.9
Light Veg	0.4	25.7	10.7	0.1	0.5	37.6
Dense Veg	0.1	15.4	38	0.1	0.1	53.8
Quarry	0	0	0.1	0	0	0.2
Water	0	0.2	0.6	0	0.7	1.5
Total 1977	4.1	43.8	50.2	0.2	1.3	100

Table 3.15. Landscape Change in Stony Swamp (1987-1994).

Classes	Urban	Light Veg	Dense Veg	Quarry	Water	Total 1994
Urban	5.2	2.1	0.6	0	0	7.2
Light Veg	1	25.7	7.6	0	0.2	34.6
Dense Veg	0.7	9.7	45.1	0.2	0.3	56.1
Quarry	0	0	0.1	0	0	0.2
Water	0	0.1	0.4	0	1	1.7
Total 1987	6.9	37.6	53.8	0.2	1.5	100

Slight losses to urban areas continued during 1994 to 1999 (Table 3.16), there were further declines for light vegetation 34.6 to 29.5 percent, and increases for dense vegetation (56.1 to 61.9 percent). Again the overlaps showed the dynamism for change for light and dense vegetation (71 percent and 84 percent respectively). Light vegetation still lost more area to dense vegetation (9.8 percent) than the reverse (4.8 percent).

Table 3.16. Landscape Change in Stony Swamp (1994-1999).

Classes	Urban	Light Veg	Dense Veg	Quarry	Water	Total 1999
Urban	3.6	1.9	1.9	0	0	7.6
Light Veg	1.4	22.8	4.8	0	0.5	29.5
Dense Veg	2.2	9.8	49.2	0.1	0.6	61.5
Quarry	0	0	0	0	0	0
Water	0	0.1	0.1	0	0.6	0.9
Total 1994	7.2	34.6	56.1	0.2	1.7	100

3.4. Bells Corners.

The change in the within the present town of Bells Corners area appears to be straightforward. Light vegetation declined from 98 percent in 1934 to two percent in 1999. Urban areas expanded from two percent in 1934 to 100 percent in 1999. This urban classification includes parks, treed avenues, commercial and residential areas. Light vegetation comprised meadows and farmland.

Table 3.17. Landscape Change in Bells Corners by Percentage (1934 to 1999).

Classes	Date							
	1934	1955	1964	1970	1977	1987	1994	1999
Urban	2	5.8	49.9	76.6	88.5	97.5	100	100
Light Veg	98	94.2	50.1	23.4	11.5	2.5	0	0
Dense Veg	0	0	0	0	0	0	0	0
Quarry	0	0	0	0	0	0	0	0
Water	0	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100

Table 3.18. Landscape Change in Bells Corners (1934-1999).

Classes	Urban	Light Veg	Total 1999
Urban	2	98	100
Total 1934	2	98	100

Between 1934 and 1955 there was a marked increase of urban areas, from two to 5.8 percent of the area, at the expense of light vegetation. (Table 3.19). Between 1955 and

1964 (Table 3.20) there was a much greater change. Urban areas increased from 5.9 percent of the 1999 urban area to 49.9 percent of the area. More than half of the area under light vegetation 1955 was urban or under construction in 1964. Light vegetation was reduced from 94.1 to 50.1 of the area.

Table 3.19. Landscape Change in Bells Corners (1934- 1955).

Classes	Urban	Light Veg	Total 1955
Urban	2	3.8	5.8
Light Veg	0	94.2	94.2
Total 1934	2	98	100

Table 3.20. Landscape Change in Bells Corners (1955-1964).

Classes	Urban	Light Veg	Total 1964
Urban	4.9	45.0	49.9
Light Veg	1	49.1	50.1
Total 1955	5.9	94.1	100

The period 1964 to 1970 saw more urban growth (Table 3.21) though not as extreme. Urban areas were now about 77 percent of the area, and light vegetation 23.4 percent. After this (1977- to 1987 in Table 3.22) there was a decline of vegetated areas from 11.5 to 2.7 percent. Very little losses of urban areas to grass etc., could be discovered, these being parkland. The final change (1994 to 1999 -Table 3.23) occurred when the whole area was classified as urban, including small grassed parks and treed avenues.

Table 3.21. Landscape Change in Bells Corners (1964-1970).

Classes	Urban	Light Veg	Total 1970
Urban	47.2	29.4	76.6
Light Veg	2.7	20.7	23.4
Total 1964	49.9	50.1	100

Table 3.22. Landscape Change in Bells Corners (1970-1977).

Classes	Urban	Light Veg	Total 1977
Urban	74	14.5	88.5
Light Veg	2.6	8.8	11.5
Total 1970	76.6	23.4	100

Table 3.23. Landscape Change in Bells Corners (1977-1987).

Classes	Urban	Light Veg	Total 1987
Urban	88	9.5	97.5
Light Veg	0.5	2	2.5
Total 1977	88.5	11.5	100

Table 3.24. Landscape Change in Bells Corners (1987-1994).

Classes	Urban	Light Veg	Total 1994
Urban	97.3	2.7	100
Light Veg	0	0	0
Total 1987	97.3	2.7	100

Table 3.25. Landscape Change in Bells Corners (1994-1999).

Classes	Urban	Light Veg	Total 1999
Urban	100	0	100
Light Veg	0	0	0
Total 1994	100	0	100

3.5. The Parks Area.

The Parks area, situated south east of Bells Corners and north east of Stony Swamp Conservation Area, shows a dynamic form of change. Between 1934 and 1999 (Table 3.26) there was urban expansion, a decline in light vegetation and an increase in dense vegetation. The overlap of each type of vegetation between the two dates was over 90 percent. Table 3.27 shows the cross-tabulation of the areas in 1934 to 1999. Table 3.28 shows changes between 1934 and 1955. There was a small increase in light vegetation and a decrease in dense vegetation between these dates.

Table 3.26. Landscape Change in the Parks Area by Percentage (1934 to 1999).

Classes	Date							
	1934	1955	1964	1970	1977	1987	1994	1999
Urban	0	0	0	0	0	1.5	3	7.9
Light Veg	73.7	76.2	77.5	68.5	63	62.3	51	16
Dense Veg	26.2	23.9	22.5	31.4	37	36.2	46	76
Quarry	0	0	0	0	0	0	0	0
Water	0	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100

Table 3.27. Landscape Change in the Parks (1934-1999).

Classes	Urban	Light Veg	Dense Veg	Total 1999
Urban	0	4.8	3.1	7.9
Light Veg	0	14.9	1	16
Dense Veg	0	53.9	22	76
Total 1934	0	73.7	26.3	100

Table 3.28. Landscape Change in the Parks Area (1934-1955).

Classes	Urban	Light Veg	Dense Veg	Total 1955
Urban	0	0	0	0
Light Veg	0	67.3	8.9	76.2
Dense Veg	0	6.4	17.3	23.9
Total 1934	0	73.7	26.3	100

For the period 1955 to 1964 (Table 3.29) there was an increase in light vegetation while dense vegetation remained approximately constant. Both of these types exchanged similar areas (just over seven and nine percent of the area).

Table 3.29. Landscape Change in the Parks Area (1955-1964)

Classes	Urban	Light Veg	Dense Veg	Total 1964
Urban	0	0	0	0
Light Veg	0	68.4	9.1	77.5
Dense Veg	0	7.8	14.7	22.5
Total 1955	0	76.2	23.9	100

Between 1964 and 1977 (Table 3.30) there was a gradual decline in light vegetation and an increase in dense vegetation. As can be seen from the tables, there was extensive expansion of dense vegetation into areas of lighter growth (these accounted for 10.9 percent of the area between 1964 and 1970 and 13.8 percent between 1970 and 1977). Losses of dense vegetation to light vegetation were lower (two percent in 1964/70 and 8.2 percent in 1970/77). Vegetation change in this area during this period was less dynamic than in Stony Swamp Conservation area. Overlaps between the forest stands between

1964 and 1970 was 78 percent of their joint areas, while in 1970-77 it was 69.5. The corresponding figures for light vegetation were 88 and 83 percent respectively.

Table 3.30. Landscape Change in the Parks Area (1964-1970)

Classes	Urban	Light Veg	Dense Veg	Total 1970
Urban	0	0	0	0
Light Veg	0	66.5	2	68.5
Dense Veg	0	10.9	20.5	31.4
Total 1964	0	77.5	22.5	100

Table 3.31. Landscape Change in the Parks Area (1970-1977).

Classes	Urban	Light Veg	Denise Veg	Total 1977
Urban	0	0	0	0
Light Veg	0	54.7	8.2	63
DenseVeg	0	13.8	23.2	37
Total 1970	0	68.5	31.4	100

Between 1977 and 1994 (Table 3.32 and Table 3.33) there was virtually no change in the vegetation distribution or quantity. However, this trend changed between 1987 and 1994, and by 1999 (Table 3.34) forest vegetation was dominant.

Table 3.32. Landscape Change in the Parks Area (1977-1987).

Classes	Urban	Light Veg	Dense Veg	Total 1987
Urban.	0	1.5	0	1.5
Light Veg	0	61.3	1	62.3
Dense Veg	0	0.2	36	36.2
Total 1977	0	63	37	100

Table 3.33. Landscape Change in the Parks Area (1987-1994).

Classes	Urban	Light Veg	Dense Veg	Total 1994
Urban	0.3	2.7	0	3
Light Veg	0	48.0	3	51
Dense Veg	1.2	11.6	33.2	46
Total 1987	1.5	62.3	36.2	100

Table 3.34. Landscape Change in the Parks Area (1994-1999).

Classes	Urban	Light Veg	Dense Veg	Total 1999
Urban	2.4	4.2	1.3	7.9
Light Veg	0.1	13.5	2.4	16
Dense Veg	0.5	33.3	42.3	76
Total 1994	3	51	46	100

3.6. The Fallowfield/Quarry Area.

The Fallowfield/Quarry area to the south of Stony Swamp Conservation Area is marked by the development of the stone quarry over the period 1964-1999 (Table 3.35). The area under quarrying in 1955 (Table 3.36) was insignificant, and light vegetation and dense vegetation dominated the area. By 1999, the quarry covered 38 percent of this area, urban areas 17.6 percent, and vegetation covered over 40 percent of the area. Between these two dates there was much dynamism of dense vegetation. The overlap of forest areas in 1955 and 1999 was only 12.4 percent, despite the respective coverage of 32 and 21.6 percent respectively. Both types of vegetation exchanged areas, but these changes were gradual. Between 1955 and 1964 (Table 3.37) there was a slight decline in light vegetation (65.8 to 58.4 percent) and in dense vegetation (32 to 30.1 percent). A similar change may be

seen between 1964 and 1970 (Table 3.38): 58.4 to 49.5 and 30.1 and 37.7 percent respectively.

Table 3.35. Landscape Change in the Fallowfield-Quarry Area by Percentage (1955 to 1999).

Classes	Date						
	1955	1964	1970	1977	1987	1994	1999
Urban	1.4	2.1	3.6	5.2	14.3	13.1	17.9
Light Veg	65.8	58.4	49.5	38.1	20.8	23.6	19.1
Dense Veg	32	30.1	37.7	39.1	27.9	23.4	21.6
Quarry	0.8	9.3	9.2	16.7	35.6	37	38.6
Water	0	0	0	0.9	1.2	2.8	2.6
Total	100	100	100	100	100	100	100

Table 3.36. Landscape Change in the Fallowfield-Quarry Area (1955-1999).

Classes	Urban	Light Veg	Dense Veg	Quarry	Water	Total 1999
Urban	1.2	14.8	1.7	0	0	17.9
Light Veg	0	16.4	2.4	0.3	0	19.2
Dense Veg	0.1	9.8	12.4	0	0	21.6
Quarry	0.1	24	14	0.5	0	38.6
Water	0	0.9	1.6	0	0	2.6
Total 1955	1.4	65.8	32	0.8	0	100

Table 3.37. Landscape Change in the Fallowfield-Quarry Area (1955-1964).

Classes	Urban	Light Veg	Dense Veg	Quarry	Water	Total 1964
Urban	0.4	0.9	0.8	0	0	2.1
Light Veg	0.7	47.1	10.2	0.4	0	58.4
Dense Veg	0.2	10.3	19.3	0.3	0	30.1
Quarry	0.1	7.4	1.8	0	0	9.3
Water	0	0	0	0	0	0
Total 1955	1.4	65.8	32	0.8	0	100

Table 3.38. Landscape Change in the Fallowfield-Quarry Area (1964-1970).

Classes	Urban	Light Veg	Dense Veg	Quarry	Water	Total 1970
Urban	0.5	2.1	0.9	0.2	0	3.6
LightVeg	0.9	39.7	5.8	2.1	0	49.5
Dense Veg	0.5	13.8	21.7	1.7	0	37.7
Quarry	0.2	2.2	1.4	5.3	0	9.2
Water	0	0	0	0	0	0
Total1964	2.1	58.4	30.1	9.3	0	100

From 1970 to 1977 (Table 3.39) there was little change in the area covered by dense vegetation, but there were gains (8.7 percent to light vegetation and 1.4 percent to the quarry) and losses (5.2 and 3.8 percent for the same features).

Table 3.39. Landscape Change in the Fallowfield-Quarry Area (1970-1977).

Classes	Urban	Light Veg	Dense Veg	Quarry	Water	Total 1977
Urban	2.3	2.6	0.2	0	0	5.2
Light Veg	0.3	32.4	5.2	0.5	0	38.1
Dense Veg	0.8	8.7	28.2	1.4	0	39.1
Quarry	0.1	5.8	3.8	7.	0	16.7
Water	0	0.3	0.3	0.3	0	0.9
Total 1970	3.6	49.5	37.7	9.2	0	100

Between 1977 and 1987 (Table 3.40), there were drastic drops in the vegetated areas (the gains and losses between the two types of vegetation were almost even at over four percent). These declines were largely due to quarry expansion and urbanisation. There was little change in these total figures for 1987 and 1994 (Table 3.41), except that there was more dynamic change in vegetation distribution. Overlaps for both light and dense vegetation between successive dates were less than 60 percent, indicating dynamic gains and losses. By 1999 (Table 3.42), the quarry was the dominant feature of this area (38 percent) with similar areas under forest and light vegetation. Urban areas also increased.

Table 3.40. Landscape Change in the Fallowfield-Quarry Area (1977-1987).

Classes	Urban	Light Veg	Dense Veg	Quarry	Water	Total 1987
Urban	3.1	10	1.3	0.3	0	14.3
Light Veg	0.8	15.4	4.4	0.2	0	20.8
Dense Veg	0.6	4.8	21.7	0.7	0	27.9
Quarry	0.6	7.6	11.4	15.5	0.4	35.6
Water	0.1	0.3	0.3	0	0.5	1.2
Total 1977	5.2	38.1	39.1	16.7	0.9	100

Table 3.41. Landscape Change in the Fallowfield-Quarry Area (1987-1994).

Classes	Urban	Light Veg	Dense Veg	Quarry	Water	Total 1994
Urban	10.1	1.9	0.5	0.5	0.1	13.1
Light Veg	2.1	11.8	6.3	3.1	0.3	23.6
Dense Veg	0.4	4.6	15.1	3.2	0	23.4
Quarry	1.7	2.6	5.3	27.5	0	37
Water	0	0	0.6	1.3	0.8	2.8
Total 1987	14.3	20.9	27.9	35.6	1.3	100

Table 3.42. Landscape Change in the Fallowfield-Quarry Area (1994-1999).

Classes	Urban	Light Veg	Dense Veg	Quarry	Water	Total 1999
Urban	11	1.3	0.7	4	0	17.9
Light Veg	1.7	14.6	2.7	0	0.3	19.3
Dense Veg	0.2	4.6	14.9	1.8	0.1	21.6
Quarry	0.1	2.9	3.1	30.2	1,2	38.6
Water	0	0	0.2	1.1	1.2	2.6
Total 1994	13.1	23.6	23.4	37.1	2.8	100

3.7. The Kanata Interface.

In this area, there was a strong urban development, from insignificant figures in 1955 to 38 percent in 1999 (Table 3.43 and Table 3.44). The urban expansion was mainly at the expense of light vegetation and to a lesser extent dense vegetation. Between 1955 and 1970 (Tables 3.45 and 3.46) there was little change in the overall totals of light and dense vegetation. Between 1970 and 1977 (Table 3.47) however, there was an increase in urbanisation and a decline in light vegetation. Forested areas also increased. From 1977 to 1999 (Tables 3.48 to 3.50), the urban increase was faster, mainly at the expense of light

vegetation. In this area at this time there was relatively little exchange between dense and light vegetation (never more than 10 percent of the area).

Table 3.43. Landscape Change in the Kanata Interface by Percentage (1955-1999).

Classes	Date						
	1955	1964	1970	1977	1987	1994	1999
Urban	0	0	0	4.5	12.5	35	38.5
Light Veg	86.8	81.1	85.9	75.6	75.8	60	58.4
Dense Veg	13.2	18.9	14.1	19.9	11.7	5	3.1
Quarry	0	0	0	0	0	0	0
Water	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100

Table 3.44. Landscape Change in the Kanata Interface (1955-1999).

Classes	Urban	Light Veg	Dense Veg	Total 1999
Urban	0	30.2	8.3	38.5
Light Veg	0	55.5	2.9	58.4
Dense Veg	0	1.1	2	3.1
Total 1955	0	86.8	13.2	100

Table 3.45. Landscape Change in the Kanata Interface (1955-1964).

Classes	Urban	Light Veg	Dense Veg	Total 1964
Urban	0	0	0	0
Light Veg	0	79.3	1.8	81.1
Dense Veg	0	7.5	11.4	18.9
Total 1955	0	86.8	13.2	100

Table 3.46. Landscape Change in the Kanata Interface (1964-1970).

Classes	Urban	Light Veg	Dense Veg	Total 1970
Urban	0	0	0	0
Light Veg	0	78.5	7.4	85.9
Dense Veg	0	2.6	11.5	14.1
Total 1964	0	81.1	18.9	100

Table 3.47. Landscape Change in the Kanata Interface (1970-1977).

Classes	Urban	Light Veg	Dense Veg	Total 1977
Urban	0	4.5	0	4.5
Light Veg	0	73.2	2.5	75.6
Dense Veg	0	8.3	11.6	19.9
Total 1970	0	85.9	14.1	100

Table 3.48. Landscape Change in the Kanata Interface (1977-1987).

Classes	Urban	Light Veg	Dense Veg	Total 1987
Urban	3.6	7	1.9	12.5
Light Veg	0.9	67.2	7.7	75.8
Dense Veg	0	1.4	10.3	11.7
Total 1977	4.5	75.6	19.9	100

Table 3.49. Landscape Change in the Kanata Interface (1987-1994).

Classes	Urban	Light Veg	Dense Veg	Total 1994
Urban	12.1	16.2	6.7	35
Light Veg	0.4	57.9	1.7	60
Dense Veg	0	1.7	3.3	5
Total 1987	12.5	75.8	11.7	100

Table 3.50. Landscape Change in the Kanata Interface (1994-1999).

Classes	Urban	Light Veg	Dense Veg	Total 1999
Urban	32.2	5.2	1.1	38.5
Light Veg	2.6	54	1.8	58.4
Dense Veg	0.2	0.8	2.1	3.1
Total 1994	35	60	5	100

3.8. The Ottawa-Kanata Interface.

This area experienced urbanisation and forest expansion during the period 1934 to 1999 (Tables 3.51 and Table 3.52). Both of these expansions appear to have occurred at the expense of light vegetation. Urban growth started largely between 1934 and 1955 (Table 3.53), and steadily increased (see Tables 3.54 to 3.59). There was significant deforestation and reforestation, but the latter was much more pronounced between 1964 and 1970 (Table 3.55) when there was significant dynamism of forest stands. In all cases less than 80 percent of the area under forest in any one year was still under forest at the later date. In the period 1934 to 1964 (Tables 3.52 to 3.54) the overlap was less than 60 percent, showing strong dynamism in forest growth.

Table 3.51. Landscape Change in the Ottawa-Kanata Interface by Percentage (1934-1999).

Classes	Date							
	1934	1955	1964	1970	1977	1987	1994	1999
Urban	0	5.3	7.4	14.7	12	21.6	18.3	22.6
Light Veg	95	85.5	84.3	72.2	76.4	67.4	68	62.5
Dense Veg	5	9.2	8.3	13.8	11.6	11	13.7	14.9
Quarry	0	0	0	0	0	0	0	0
Water	0	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100

Table 3.52. Landscape Change in the Ottawa-Kanata Interface (1934-1999).

Classes	Urban	Light Veg	Dense Veg	Total 1999
Urban	0	22	0.6	22.6
Light Veg	0	60.1	1.4	62.5
Dense Veg	0	11.9	3	14.9
Total 1934	0	95	5	100

Table 3.53. Landscape Change in the Ottawa- Kanata Interface (1934-1955).

Classes	Urban	Light Veg	Dense Veg	Total 1955
Urban	0	4.3	1	5.3
Light Veg	0	83.9	1.6	85.5
Dense Veg	0	6.8	2.4	9.2
Total 1934	0	95	5	100

Table 3.54. Landscape Change in the Ottawa- Kanata Interface (1955-1964).

Classes	Urban	Light Veg	Dense Veg	Total 1964
Urban	3	4.4	0	7.4
Light Veg	2	77.6	3.7	84.3
Dense Veg	0.3	3.5	4.5	8.3
Total 1955	5.3	85.5	9.2	100

Table 3.55. Landscape Change in the Ottawa- Kanata Interface (1964-1970).

Classes	Urban	Light Veg	Dense Veg	Total 1970
Urban	6.3	7.7	0.2	14.7
Light Veg	0.7	69.8	1.7	72.2
Dense Veg	0.4	6.8	6.4	13.8
Total 1964	7.4	84.3	8.3	100

Table 3.56. Landscape Change in the Ottawa-Kanata Interface (1970-1977).

Classes	Urban	Light Veg	Dense Veg	Total 1977
Urban	9.9	1.4	0.7	12
Light Veg	4.1	68.1	4.2	76.4
Dense Veg	0.2	2.7	8.7	11.6
Total 1970	14.2	72.2	13.6	100

Between 1977 and 1987 (Table 3.57), forest stands were approximately even, but only about 55 percent of the 1977 figure overlapped with that of 1987- pointing to high losses and gains. It may be seen that during this period the losses and gains to light vegetation were similar. Between 1987 and 1994 (Table 3.38) similar occurrences existed. The losses and gains was mainly to light vegetation. Between 1994 and 1999 (Table 3.39) the changes were similar, despite the gradual increase in forested areas.

Table 3.57. Landscape Change in the Ottawa- Kanata Interface (1977-1987).

Classes	Urban	Light Veg	Dense Veg	Total 1987
Urban	10.4	10.1	1.1	21.6
Light Veg	1.4	61.9	4.4	67.4
Dense Veg	0.2	4.4	6.4	11
Total 1977	12	76.4	11.6	100

Table 3.58. Landscape Change in the Ottawa- Kanata Interface (1987-1994).

Classes	Urban	Light Veg	Dense Veg	Total 1994
Urban	14.7	2.1	0.6	18.3
Light Veg	6.1	58.6	3.3	68
Dense Veg	0.8	5.8	7.1	13.7
Total 1987	21.6	67.4	11	100

Table 3.59. Landscape Change in the Ottawa- Kanata Interface (1994-1999).

Classes	Urban	Light Veg	Dense Veg	Total 1999
Urban	17.7	4.5	0.4	22.6
Light Veg	0.5	58.4	3.6	62.5
Dense Veg	0.1	5.1	9.7	14.9
Total 1994	18.3	68	13.7	100

3.9. Landscape Configuration Change .

This section describes the landscape configuration change and the effects of this change on the existence of wildlife corridors. Here "corridors" describes the dense vegetation connecting other similar areas, which may serve as cover for transient mammals, or facilitate the transmission of plant seeds. The description of landscape configuration is based on classified maps of the study area, considered in time series. The main wildlife represented in this study are the White Tailed Deer (*Odocoileus virginianus borealis*) and Beaver (*Castor canadensis*). The sequence of figures in this section is in the format below.

- An image based description of the linkages of the central forested area, based on line features on the remotely sensed images (1999 and 1955).
- The relation of these points to the land cover changes and overall configuration.
- The current beaver activity based on the expansion and creation of ponds and dams.
- Changes in a case study of a beaver swamp, showing the creation and decline of a pond.
- Deer kills as recorded on the roads in the study area, based on police records.
- The deer density in the area, based on sightings and evidence of habitation.

Figure 3.22. Landscape Configuration and Corridors (1999).

Corridors are those areas where there appears to be easiest passage from one vegetated area to another.

2000 0 2000 4000 Metres

A horizontal scale bar is located below the text. It consists of a black line with white tick marks. The text '2000 0 2000 4000 Metres' is positioned above the bar, indicating the scale of the map.

Figure 3.23. Landscape Configuration and Corridors (1955).

Figure 3.24. Deer Density (2001).

Source: NCC (2001).

Deer density refers to the number of sightings per acre.

Figure 3.25. Deer Accidents (on coloured map) (1994-2000).

Source: Brown (2001).

Each string of dots represents the main road area on which the accidents occurred.

Figure 3.26. Deer Collisions on Landsat Image (1994-2000).

Source: Brown (2001).

2000 0 2000 4000 Metres

The distribution of deer kills is repeated on the Landsat image to give a view of their context within the surrounding countryside.

According to Brown (2000) the number of deer kills caused by with cars along roads in the Western Greenbelt has increased. Table 3.60 below show this.

Table 3.60. Collisions/Road Kill of Wild Animals Between 01 January and 1994 and 31 December 2000.

Year	1994	1995	1996	1997	1998	1999	2000	Total
Total Kill	283	266	390	493	520	551	685	3188
Wild Animals	268	248	363	476	493	536	671	3055
Domestic	15	18	26	17	27	15	14	132
Deer Collision	261	241	355	469	479	502	628	2935
Fatal	0	0	0	0	0	0	0	0
Injury	4	8	8	16	18	17	17	88
Property Damage	257	233	347	453	461	485	611	2847

Source: Adapted from Brown (2000)

The increase in accidents could be due to the narrowing of wildlife corridors, the increased proximity of people, and/or the increase in traffic and the widening of roads.

Beaver activity is also important for the landscape configuration. Beavers change the surface hydrology locally. Where permanent ponds result, trees may be killed, and marsh or open water may expand. The images have shown an increase in open water. Beaver activity is argued to be the main contributory factor behind this development (Anions 2001). The map below (Figure 3.27) shows the current beaver activity in the study area. In some cases, beaver created lakes dry up temporarily. This is illustrated in Figure 3.28.

Figure 3.27. Location of Beaver Activity in 2001.

Source: Horvath and Chabiague (2001).

Figure 3.28. The Reduction of a Beaver Lake (1974-2001).
1. 2001.

2. 1998

3. 1974

Source for the last two pictures: Rob Lee (2001).

As these areas do not all coincide with areas of past beaver activity, it may be argued that more water bodies are developing. In some cases, beaver created lakes dry up temporarily. This is illustrated in Figure 3.28. Here the beavers created a lake in the 1970s, which was still flooded in 1998. In the summer of 2001, it was dried up.

3.10. The Contribution of the Research Results.

The display of matrices and images has shown several points of value to the understanding of landscape change and configuration in the study area:

- Urbanisation. This was clearly powerful force in the area. However, it is not a clear factor for deforestation. Urban expansion was largely into the farmlands and meadows. Very little former forest or relict tree stands were replaced by urban growth.
- Forest expansion was commoner than deforestation. However, in almost every period of forest gain, there were also forest losses, presumably in different areas. This form of multidirectional change could not be documented by data on total landscape percentages: only matrices would illustrate this form of dynamism properly.
- Urbanisation and forest appeared to be competing for space with the areas of light vegetation. Therefore, although there was little replacement of forest by urban areas, it could be argued that the areas that could have been converted to forest growth

(either by plantation development, or natural regrowth or abandoned farms) have instead been urbanised.

- There was pronounced dynamism of vegetation change between dates, regardless of the general direction of change for that classified area. Thus, even in some cases where there was no real change in the area covered by dense or light vegetation, there might be a small overlap between the actual areas covered by that vegetation class between the two images. This applied to light vegetation, but more strongly to dense vegetation. This gave evidence of the relative youth of some new forest stands.
- There has been an increase in open water areas. The research pointed to beaver activity and road building as factors for the change in surface and ground water hydrology (Anions, 2001, Rother, 2001).

Linking these results to the theoretical framework, the thesis began by arguing that four key issues were of particular importance in the assessment of biogeographical change: ecological history; sustainable development; conservation policy and the use of geomatics within the scope of integrated research for the analysis of the effects of such complex dynamics on the landscape. This position was examined with global and Canadian examples. The justification of this approach was that insufficient studies existed on the case study of the Western Greenbelt, incorporating the quantifiable analysis of time series images, integrated research methods and the tools of geomatics. In particular, several unanswered questions were posed, which are repeated below.

- What type of phytogeographical change has occurred in the area?
- Has the rapid urbanisation resulted in deforestation?
- Has the establishment of the conservation area contributed to the reforestation or has it halted deforestation.
- Can geomatics analysis of time series images, supported by inputs from field and literature-based sources, increase understanding of land-use dynamics and landscape change in this area?
- Can this geomatics analysis provide a stronger integrating role for landscape ecology and history as envisaged in the theoretical framework?

The current research has contributed to all these areas, and provided some answers to the above questions.

3.10.1. The Contribution to Environmental History and Ecological Theory.

The paradigm of ecological disequilibrium as applied to environmental history, emphasises multidirectional landscape change. Within this area, there are several hypotheses.

- The broader issue of Environmental History. The hypothesis is that geomatics makes a major contribution to environmental history, especially in the areas on quantification and documentation of multidirectional change.

- The broader issue of the disequilibrium paradigm in ecology. The hypothesis is that geomatics makes a major contribution to the complex and chaotic changes described by this paradigm through multidirectional change matrices and patch scale analysis.
- The concept of multidirectional change and the role of geomatics. The hypothesis is that multidirectional change is a relevant concept.
- The issue of linking social and natural science methodologies for better reading of the landscape, as noted by Scoones (1999) and Burgi and Russell (2001). The hypothesis is that geomatics based analyses of integrated data, covering both natural features and social events and structures, enables a strong degree of integration.

The current case study has made a contribution that supports the approach of Cline-Cole (1995, 172) which holds that the environmental impacts of socioenvironmental relations depend on the "specific historical and geographical conditions which obtain in a given situation". In the current research, these specific historical and geographical conditions include:

- The legislation that created and protects the Greenbelt from activities such as hunting, and unrestricted building and tree removal. In this study, the IR and geomatics analysis has provided evidence of the effectiveness of this legislation. This was demonstrated by comparing reforestation rates in the Stony Swamp Conservation area with forest change outside the conservation area. The matrices made the additional

contribution of documenting gains and losses outsided and within the conservation area.

- The rate of population growth and urban expansion in the western margins of Ottawa. The population growth rate for Kanata and Bells Corners were documented. Also shown was the area of the urban coverage inside and proximate to the Greenbelt. The evidence of urban expansion into old farmland rather than forest illustrates the planned nature of the urban growth. In this case there is little evidence of forest fragmentation due to urban expansion, as described by Wickham *et al.* (1997) in another case study which revealed moderate correlation between forest fragmentation and urbanisation pressure. This was also discussed in other studies (LaGro and DeGloria, 1992, Turner *et al.*, 1996)
- The particular agricultural system, which allowed farmland to be the dominant type of land feature until the 1960s. The growth of agriculture, which occurred during the last two centuries, appears to have been reversed in the Greenbelt. This supports the evidence presented by Larson *et al.* (1999) and Riley and Mohr (1994). It also relates to the study by Middleton (1994b), which emphasises the key interplay between urbanisation, forestry and agriculture in Canada.
- The establishment of plantations. Plantation played an important role in forest expansion within the conservation area. A large proportion of the forest gains into old

farmland was due to this factor. The cessation of most cultivation activities on government owned land, which allowed forest expansion.

- The expansion of quarrying which allowed bare ground to replace former farmland and forest. This is shown to have replaced both areas of light and dense vegetation. There is no evidence from the analysis of substantial reduction of quarry areas. Therefore, quarry areas may be seen as relatively permanent features in the landscape.
- The examination of the landscape configuration also showed a trend, with the gradual encirclement of the conservation area. The existence of corridors previously through cultivated areas, was virtually curtailed in the latest images. This was a startling development, considering the status of Stony Swamp as the key area of continuous forest habitat in the Greenbelt.

These issues relate to social history, as they provide evidence of the impact of environmental awareness. The success of the environmental legislation in enabling the reforestation of the conservation areas reflects the successful development of environmental awareness and orderly urban planning (as described by Maini and Carlise 2000 in a general sense). The success of planning in the Greenbelt is more apparent when compared with the cases examined Wickham *et al.* (2000) and other North American scholars. At the international level the study may be favourably compared with the contexts studied by Fairhead and Leach (1995), and Tiffen *et al.* (1994). In common with these studies, the current research showed that people are capable of reversing

deforestation through multiple stakeholder involvement. This study goes further however, as geomatics and IR allow the documentation of the multidirectional environmental change.

The effects of these occurrences were clearly documented in the analysis of the features captured in the time series images. The analysis of these changes within the study area contributed to ecological theory.

- The frequently low overlap between similar vegetation stands in different dates. This gives evidence of the age of the stands and of the dynamism of regrowth and deforestation, as well as the age of stands. This documented the extent of interference with the successional processes. This interference could take the form of expanding beaver swamps, culling, tree removal and blowdowns. In areas of very low overlaps between forest extents between dates. It may be inferred that the stands are relatively young. However, as is important in IR, such conclusions could only be supported by fieldwork.
- The importance of integrating human activities into the ecological assessment was also revealed. Ecological change in this context could be assessed more completely with measurement of the impacts of human activities, as pointed out by in a broader sense by Wortser (1984) and Scoones (1999). In this case the hybrid methodology (as described by Batterbury *et al.*, 1997) included the assessment of urbanisation,

conservation policy and ecological change, with the tools of geomatics and field studies.

3.10.2. The Contribution to Sustainable Development.

This topic too has several hypotheses that may be relevant.

- The Broader Issue of Sustainable Development. The hypothesis is that geomatics provides a useful tool for the assessment of the sustainability of environmental actions.
- Forest Fragmentation and Urban Proximity. Here the hypothesis is that urban proximity is linked to forest fragmentation (as noted by Wickham *et al.*, 2000, among others).
- The changing configuration of the landscape. The hypothesis is that landscape configuration in particular the interconnectedness of conservation areas is essential for the long term sustainability of biodiversity.

The position of this research is that geomatics allows the measurement of long term interactions between people and environments. These activities may result in enrichment and/or degradation of the proximate ecosystems, as argued by Iyer-Raniga (2000). The main focus of ecological theory regarding sustainable development (to avoid degradation, there must be maintenance of biodiversity and productivity, tolerance of the resilience of

the ecosystem to external influences and the inherent coping with internal, chaotic dynamics) may be more effectively measured with geomatics.

The current research illustrated that biomass productivity was at least maintained in several areas, where for example farmland or meadows were replaced by either forest stands or mixed vegetation. This was the result of either plantation establishment, or natural regrowth in abandoned farmland. The documentation of the multidirectional change provides the evidence for changes in biomass and productivity.

Biodiversity is more problematic, as the research did not document species change over the period under study. There was evidence of the artificial nature of the reforestation. As argued by Larson *et al.* 1999), despite the expansion of woodland in peri-urban Ontario, (due to plantations, fencing, public education and changing agricultural practices) "where reforestation occurs most of it is still just fields planted to trees. Those areas may naturalise over time, but they will never become woodlands, like the original forests of the region...", the result being structural simplification" (*ibid.* 9).

In the current research area, the dynamic, multidirectional changes documented do not appear to have allowed the long time frame necessary for the increased biodiversity. Some forest stands were quite young, the result of either planting or the growth from fallows and shrubbery. It may be inferred however, that mixed landscapes including forest plantations, regrowth forest, shrubbery, fallow meadows, grass patches and farmland would possess a higher biodiversity than farmland alone. By this inference,

biodiversity could be said to be gradually increasing. This would be a multidirectional process, reflected in the gains and losses documented in the analysis.

Hengeveld (1995, 3) made the point that "sustainable development has become a key goal and functional underpinning of federal public policy in Canada". Stephenson (1994, 201) also advocated a heirarchically connected network including satellite areas, *linakages* (italics mine) and compatible surrounding land (and water) uses". The evidence of the changing configuration of urban developments and forest reserves, especially concerning the slow constriction of corridors, questions the role of sustainable conservation planning in the decision making for the area.

3.10.3. The Contribution to Conservation Management.

This represents an important application of geomatics based analysis of environmental change.

- The status of the conservation area. The hypothesis is that geomatics analysis can inform conservation efforts.
- The changing landscape configuration, and the sustainability of the conservation area as a habitat. The hypothesis is that the documentation of landscape configuration and multidirectional landscape is a basis for the development of a well-informed conservation policy.

The current research demonstrated the possible role of geomatics based IR in conservation research. Key issues included the following.

- An assessment of the landscape, prior to the establishment of a conservation area, is necessary for more informed decision-making on the methods for conservation enhancement. The methodology of the thesis enabled this by overlaying the 1999 borders of the conservation area and surrounding landscapes on images representing older landscapes. This allowed the derivation of information on the past landscape and that of the surrounding areas.
- As noted above, landscape configuration was also examined as a changing phenomenon, which has been argued in the literature to be an important factor for the sustainability of protected areas (see for example, Sewell *et al.* 1993). The visual images illustrated clearly the extent to which the central conservation area was linked to the surrounding areas. The shape of the surrounding urban areas in the later images clearly show that corridors are not a priority. The images show the encirclement of the conservation area by urban development, and the gradual destruction of pre-existing potential corridors. The older images showed farmland encircling the conservation area. Questions may thus be asked regarding the sustainability of the conservation area, especially regarding access to mammals. The evidence of road kills of white tailed deer is probably a manifestation of this.

The role of geomatics based analysis of time series images, in the derivation of the information necessary to contribute to the above issues, may therefore be summarised as:

- Quantification and hence greater accuracy for analysis and assessment.
- The documentation of historical change.
- Documentation of both linear and multidirectional change.
- Integration of multiple sourced data into multidisciplinary information bases.

3.11. Errors.

Several errors compromised the accuracy of the results of the research.

Scale and pixel size. The aerial photographs were shot from varying heights, and hence the scale differed (1:50,000, 1:18,000, 1:5,000). This affected the pixel sizes of the scanned images, when they were imported into the GIS packages such as PCIWorks and IDRISI. This further affected the accuracy of the digitising of vector files on the pixel-based features of the raster layers. To offset this, pixel sizes were estimated using known ground features such as road widths. Nevertheless, the accuracy of the digitising was still affected by the varying resolution of the pixels.

Edges. Where there was significant edge in around vegetation patches, some generalisation was necessary, as digitising lines would in many cases cut straight through scalloped edges. The extent of the error depended on the scale of the images and the resultant resolution.

Classification. Various types of land features were difficult to discern in the older images. For example, dry and wet forest and non forest, would clearly be variable, as the extent of wetness or dryness would depend not only on soil or geology but, the rainfall pattern that year, and in some cases the impacts of beavers.

Registration and Landscape changes. Registration of all the images to a common grid was very difficult, due to the lack of common, permanent features in the landscape, and extent of change. Common features used for ground control points are road intersections, corners of large buildings and even farm plots, and large trees. In this case however, these varied between the images, and it was difficult to assess for example if a road had been widened or moved slightly, and hence determine the effect this would have on the registration of the images.

Compatibility. The compatibility of the GIS packages, especially IDRISI and PCIWorks, created problems that may have affected the accuracy of the results. Resolution and registration would be affected when the files were exported or imported from one system to another.

Field work and ground truthing. Fieldwork was conducted from May to December 2001. Slight variations were noted between the landscape in the last image (1999) and the observed field features. For the older images, judgment was essential for identification of features.

3.12. Summary.

This chapter has presented the results of the cross tabulation and overlay of the classified images. The tables and line graphs described the landscape change for the study period. The matrices went further, and displayed the multidirectional change between the dates that resulted from the cross-tabulation of the classified images. The image overlay complemented the matrices, by giving a spatial display of the areas of change. The landscape change displayed in the images was also analysed from the perspective of habitat sustainability and zoogeographical change. Wildlife corridors were identified in the landscape for this purpose. The relevance of the methodology and findings to a more comprehensive environmental history and to the concept of sustainable development and practical conservation was then discussed. The following chapter provides a concluding assessment of the above analysis.

Chapter 4. Summary and Conclusions.

4.1. Introduction.

This thesis has examined land-cover change in the Western Greenbelt between 1955 and 1999 for some areas, and 1934 and 1999 for others. The method was based on the tools of geomatics and integrated research. These included times series aerial photographs and satellite images, field research and photographs, interviews and literature research. The analysis used computer based geomatics methods (IDRISI, PCIWorks, ArcView and Corel Draw). The key themes that influenced the direction of the analysis were the investigation of the role of integrated research and geomatics in the assessment of biogeographical change. Within this focus, the main strands were: the theoretical framework of Burgi and Russell (2001) that sought to integrate methods of landscape ecology and history for the explanation of environmental change; the disequilibrium paradigm in ecology which, among other foci, emphasises multidirectional change; and the concept of sustainable development, applied here to the relationship between landscape configuration and sustainable conservation planning. In addition to the contributions made to the general applications of geomatics to the study of landscape change in the Greenbelt, some contributions were also made to the generic issues of environmental management.

4. 2. A Summary of the Generic Contribution of the Research.

The evidence of landscape change was based on both percentage measurements (the matrices) and visual images (the classified maps and actual remotely sensed images). The

classification of features was broadly based. Dense vegetation included wet and dry forest, dense shrubbery and semi wooded swampland. Light vegetation included farmland, grassland, mixed grass and light shrubbery, and parks. The relationship between these classes over time is important, because studies on landscape change utilising field research and/geomatics tends to emphasis important hypotheses concerning the urbanisation and farm expansion, and deforestation. From these relationships are derived narratives of landscape change and the biogeographical sustainability of conservation areas.

The quantification of complex change. The research showed that the study area had been modified in two main ways: the expansion of forest into former farmland; and the expansion of urban land into farmland. Most of the forest expansion took place within the Stony Swamp Conservation Area, while the urban expansion occurred along the margins of that area, resulting in the development of Bells Corners and Kanata in the 1960s and 1970s. Forest expansion took the form of conifer plantations, and regrowth of deciduous stands in abandoned farmland. Urban expansion comprised the establishment of residential neighbourhoods, industrial areas and new roads.

The linkage between landscape ecology and history was evident. Human activities were closely linked with environmental change. Natural forest growth was not the only factor behind the configuration of the landscape. The policy decisions on the land acquisition and plantation establishment, and commercial activities were key factors behind landscape changes. The sustainability of the conservation area was also questionable, due

to the loss of forested corridors that served as transit zones for wildlife movements. The growth of the urban areas resulted in the encirclement of the conservation area, cutting of the natural links with the forested areas to the south and west.

4.3. The Contribution to Policy Making in Ontario.

Existing knowledge on ecological change in the Greenbelt is principally based on species lists and assessments of the ecological (see for example the comprehensive study by Brownell and Blaney 1997, and Brownell and Larson 1995). Other studies which assess environmental change (for example those of Milton 1998, the Macoun Club 1987-1989 and Spiwak 1996) focus on changes within selected areas within the conservation area, rather than comparisons of the changes within and outside the conservation area. These studies are extremely useful for deriving detailed ecological assessments, but broader studies are required to inform planners on the landscape changes. The current research contributes to the filling of this gap. It gives information not only of multidirectional change, but spatial configuration change. This complements, rather than negates the studies described above.

4.4. The Contribution to Wider Studies.

The current research emphasised the international importance of geomatics based research. This justified the inclusion of a description of some applications to international research. It also allowed an assessment of the role of such global research in the promotion of conservation policy in Canada. The case study may also support similar studies in different countries. Studies of environmental history in many countries have not

adequately utilised geomatics and hence there is insufficient quantification, in many assessments (see Campbell and Palmer-Jones 1999, Fairhead and Leach 1998 for a discussion of this). Factors for this include prohibitive costs of such research, lack of awareness and lack of interest. Studies that demonstrate the usefulness of geomatics research may contribute, especially where lack of awareness and/or interest is the main problem.

The current research is particularly useful for the application of such techniques to tropical environments. This is because the rapid population growth and consequent urban sprawl must be spatially quantified for effective conservation management in peri-urban areas. Also, despite the existence of several strong studies of environmental change (such as those of Tiffen *et al.* 1995, and Fairhead and Leach 1995) many areas have not been fully investigated (Wickham *et al.* 2000).

4.5. Possibilities for Enhancement.

The main area where the current research may be enhanced is species change. Detailed snapshots of species change, where possible, allow more ecologically valuable work to be undertaken. However, such research is difficult for past environments. Pollen analysis is a method that may be used, but this requires more sophisticated tools and longer time frames.

Studies of the entire Greenbelt, using the methods of the current research would also allow more critical assessment of the status of conservation areas within this area. Studies

may also be expanded to areas outside the Greenbelt, which would allow assessments of the Greenbelt compared with non-Greenbelt areas and the possibilities of wildlife corridors being extended into the surrounding countryside.

4.6 Conclusions.

Concluding comments on this study are based on the usefulness of the research for practical application and the points to be considered for future research. An important consideration is the merit of such research for environmental monitoring and assessment, upon which informed and competent decision making on conservation issues may be based. It may be argued that environmental monitoring possibilities exist, based on the above points, especially for the following: (1) the creation of information on the environment, which may be useful for local planning in conservation or urban development; (2) comparisons of variations in landscape cover types, necessary for decision making on land-use restrictions where small scale ecosystems are being degraded; (3) broad bases of spatial data within which more detailed studies may be developed and contextualised.

The above discussion supports the position that geomatics and IR offer a more accurate and quantifiable method of documenting landcover change than field studies alone. Despite possible errors in the analysis, which may have compromised the accuracy of the smaller changes, and the widely spaced dates (more dates would have enabled the development of a more detailed chronology) the results offered much more precision and specification of environmental change than the cited literature. This affirmed the

positions of the international literature (for example, that of Spaeth 1996) concerning the usefulness of this type of multiple tool analysis.

The analysis was able to illustrate a key point, which also could not be discerned from the literature. Multidirectional change, though complex and difficult to measure, could be competently illustrated. Further work, however, must be done to determine the precise factors behind these dynamic, multidirectional changes. For example, few integrated studies appear to document at the species level the types of biogeographical changes described at the broad level in this thesis. The effects of landcover change on the biodiversity are also difficult to assess, without meticulous field verification. We may at this stage only conclude that any change involving forest loss may not be beneficial for the biodiversity of the area.

By comparing the extents of change within the conservation areas, with the surrounding area, the study illustrated the importance of including the immediate surroundings of the conservation areas in the study, rather than the examination of only those areas within the protected areas. This can illustrate the extent of encroachment of change in the environs and hence inform judgments on the possible impacts on the conservation area. The existing literature has made no detailed mention of the extent to which the areas immediately surrounding Stony Swamp Conservation area have been modified over the years. Yet as the current research shows this is important for the assessment of change.

The results of this study show that meticulous work must be conducted over the short term for fuller understanding of the type of environmental change in the area considered. Numerous studies have described the changes in this area and have emphasised linear trajectories of change, either at the local or landscape levels. These studies tend to look at longer periods, which prevent the assessment of short-term change. Short-term change is likely to be less discernible and hence to require more stringent assessments. For wider uses of this type of work, there is a need for more detailed analyses, based on regular field surveys, linked to a comparison of time series images and the use of change detection algorithms that allow the cross-tabulation of spatial data and more accurate error assessment. This will provide more reliable information on the environment. The ultimate objective is more informed decision making on environmental issues to enable effective conservation management.

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Appendix 1. Common Species of Plants in the Western Greenbelt.

American Beech (*Fagus grandifolia* Ehrh.).

Balsam Fir (*Abies balsamea* (L.) Mill.)

Bur Oak (*Quercus marcocarpa* Michx.).

Eastern White Cedar (*Thuja occidentalis* L.),

European Larch (*Laris decidua* Mill.)

Grey Birch (*Betula populifolia* Marsh.)

Ironwood (*Ostrya virginiana* (Mill.) K. Koch)

Jack Pine (*Pinus banksiana* Lam.).

Largetooth Aspen (*Populus grandidentata* Michx.).

Red Maple (*Acer rubrum* L.)

Red Oak (*Quercus rubra* L.).

Red Pine (*Pinus resinosa* Ait).

Scots Pine (*Pinus sylvestris* L.).

Sliver Maple (*Acer sacchrinum* L.)

Sugar maple (*Acer saccharum* Marsh.),

Sugar Maple (*Acer saccharum* Marsh.).

White Birch (*Betula papyrifera* Marsh.)

White Elm (*Ulm americana* L.).

White Spruce (*Picea glauca* (Moench) Voss),

Yellow Birch (*Betula alleghaniensis* Britt).

Yellow Birch (*Betula alleghaniensis* Britt.),

Appendix 2. Common Species of Mammals in the Western Greenbelt.

Beaver (*Castor canadensis*).

Chipmunk (*Tamias straitus lysteri*).

Coyote (*Canis latrans*).

Gray Squirrel (*Sciurius carolinenesis pennsyulanicus*).

Porcupine (*Erithozon dorsatum dorsatum*).

Raccoon (*Procyon lator lator*).

Red Squirrel (*Tamiasiurius hudsonicus loquax*).

White Tailed Deer (*Odocoileus vigianus borealis*).