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Biodiversity and its relationship to potential anthropogenic stressors on the Frontenac Axis, southern Ontario.

Thesis submitted to the
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Université d'Ottawa
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L'Institut de Biologie d'Ottawa-Carleton

0-612-28436-0

ABSTRACT

The purpose of this research was to examine in detail indicators related to biodiversity in the Frontenac Axis region. The Frontenac Axis, south-eastern Ontario, is of unique conservation potential because it is a mainly undeveloped, forested region surrounded by cleared agricultural and urban land. The first chapter explores whether potential anthropogenic stressors such as roads, buildings, human population and deforestation affect forest biodiversity. The second chapter examines coarse woody debris and its contribution to biodiversity, in particular, the diversity of ferns.

I used biodiversity indicators at three taxonomic levels: a complete taxonomic group; functional groups within a taxonomic group; and individual large carnivore species. Species presence data were taken from the 'Atlas of the Mammals of Ontario', the 'Atlas of the Breeding Birds of Ontario', and the 'Herptile Atlas of Ontario'. Black bear (*Ursus americanus* Pallus) and fisher (*Martes pennanti* (Erxleben)) were recorded less often in areas of high road density and cleared forest. I suggest that fisher is a better indicator than black bear because fisher do not adapt to land use change as readily as black bear (Arthur *et al.*, 1989). There was no relationship between the number of herptile or bird species and anthropogenic stressors apparently because observer effort, in number of hours or records, accounted for most of the variation in species richness. Two general conclusions result: the distribution of large carnivorous species was the most useful indicator of biodiversity; and to be useful to ecological studies, it is crucial that volunteer-collected data sets, such as the atlases used in this study, are collected in accordance with a standardized methodology that minimizes the variation in observer effort.

Coarse woody debris (CWD) is an important part of forest processes and much is known about how forestry affects its quality. The second chapter examines how CWD contributes to biodiversity. Ferns were used as an indicator of biodiversity because ferns are diverse, abundant, and an important part of the forest understory, and it is generally assumed that CWD provides habitat for ferns. Data on the amount, size, and decay stage of CWD were collected in the field using transects 50 m in length. I did not find a relationship between the number or abundance of fern species and CWD.

RÉSUMÉ

L'objectif de cette étude était d'examiner en détail les indicateurs relatifs à la biodiversité dans la région de l'Axe de Frontenac. L'Axe de Frontenac, situés au sud-est de l'Ontario, possèdent un potentiel de conservation unique principalement en raison de sa région forestière non exploitée, entourée d'une agriculture distincte et de terrain urbain. Le premier chapître explore les possibilités que les facteurs de stress anthropogéniques potentiels tels que les routes, les édifices, la pollution humaine ainsi que le déboisement puissent affecter la biodiversité des forêts.

J'ai utilisé les indicateurs de biodiversité à trois niveaux taxonomiques: un groupe taxonomique complet; des groupes fonctionnels à l'intérieur d'un groupe taxonomique; et de grandes espèces carnivores individuelles. Les informations concernant la présence d'espèces furent tirées de "Atlas of the Mammals of Ontario", de "Atlas of the Breeding Birds of Ontario", et de "Herptile Atlas of Ontario". L'ours noir (*Ursus americanus* Pallus) et pékan (*Martes pennanti* (Erxleben)) ont été enregistrés moins souvent dans les régions de haute densité rurale et de forêt distincte. Je suggère que pékan est un meilleur indicateur que l'ours noir puisque pékan ne s'adapte pas aussi facilement aux changements de terrain que l'ours noir (Arthur et al., 1989). Il n'y avait pas de corrélation entre le nombre de "herptile" ou les espèces d'oiseaux et les facteurs de stress anthropogéniques, et ce, probablement à cause de la subjectivité de l'observateur, en ce qui a trait au nombre d'heures ou d'enregistrements comptabilisés en grande partie á cause de la richesse de la variation des espèces. Deux conclusions générales en résultent: la distribution des individus, l'espèce clé fût l'indicateur de biodiversité le plus utile ainsi que sa réponse au

stress anthropogénique. De plus, pour être utile aux études écologiques, il est primordial que les données du prochain volontaire soient recueillies en accord avec une méthodologie standard qui minimise l'effort subjectif de l'observateur.

Les débris de bois grossier constituent une part importante du processus et des fonctions de la forêt et sont mieux connus pour leur réaction au stress forestier. Le second chapitre examine la façon dont les débris de bois grossiers contribuent à la biodiversité. Des fougères ont été utilisées comme indicateur de biodiversité parce qu'elles sont diverse et abondantes, et qu'elles font partie du sous-bois de la forêt et qu'il est généralement assumé que les débris de bois procurent aux fougères leur habitat. Des données sur la quantité, la taille et le stade de décomposition des fougères furent comyarlees sur le terrain par sections de 50 mètres de longueur. Je n'ai pas trouvé de relation entre le nombre ou l'abondance d'espèces de fougères et les débris de bois grossiers.

ACKNOWLEDGMENTS

I wish to thank my supervisors and committee members, Paul Keddy, Scott Findlay and Bill Cheliak for their support and direction throughout the project. The herptile data set was provided by Mike Oldham at the Natural Heritage Information Centre. Thanks also to Benoit Malette for a summer of field work. I am truly grateful for the constant support from my laboratory colleagues, Nick Stow, Irene Wisheu, Maureen Toner, Lauchlan Fraser, and Evan Weiher, but especially for the encouragement from my parents and Steven Robinson. Thanks to Paul Clarke and Anthony Francis for statistical advice and to Dan Brunton for answering my questions about ferns. Thanks again to Bill Cheliak, Steven Robinson, my parents, Paul Keddy and Scott Findlay for their comments on early drafts of this manuscript.

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GENERAL INTRODUCTION

There is growing concern about human land uses and their effect on the global environment (e.g. Meadows *et al.*, 1974; Ehrlich *et al.*, 1977; Western and Pearl, 1989; Soule, 1991; McKenzie *et al.*, 1992; Chapin *et al.*, 1996). Our species has changed the environment as far back as the first hunters and gatherers. For example, the American mammoth may have been among the first extinctions in North America for which humans were partly or completely responsible (Vereshchagin and Baryshnikov, 1984; Tudge, 1996). The purpose of this research is to investigate the response of indicators of forest biodiversity to anthropogenic stressors at a scale relevant to management. Appropriate management boundaries might be ecological boundaries such as the watershed of a major river or a major geologic formation. It is at this intermediate spatial level (in between global and local) that disturbance has the greatest consequence (Holling, 1992; Risser, 1995).

In general, in order to enhance our understanding of forest ecosystems and our resource management capability at the regional level, we must explore selected forest ecosystems on a regional scale. By analyzing existing databases and collecting field data, the relationship between anthropogenic stressors and indicators of biodiversity can be quantified. The stress-response approach seeks to understand the responses of ecosystems to particular stresses (Slocombe, 1992). There are many possible responses to stress; for example, changes in nutrient cycling, energetics, community structure, and ecosystem function (reviewed by Slocombe, 1992) and many possible stress-response relationships (Figure 1). With a better understanding of the response to stress at the regional level, we can integrate this knowledge into policy for the management and mitigation of anthropogenic stress.

The three steps in the process are:

(1) to choose a region to study;

(2) to choose a set of anthropogenic factors that potentially adversely affect the forest ecosystem, and;

(3) to define appropriate response variables or indicators.

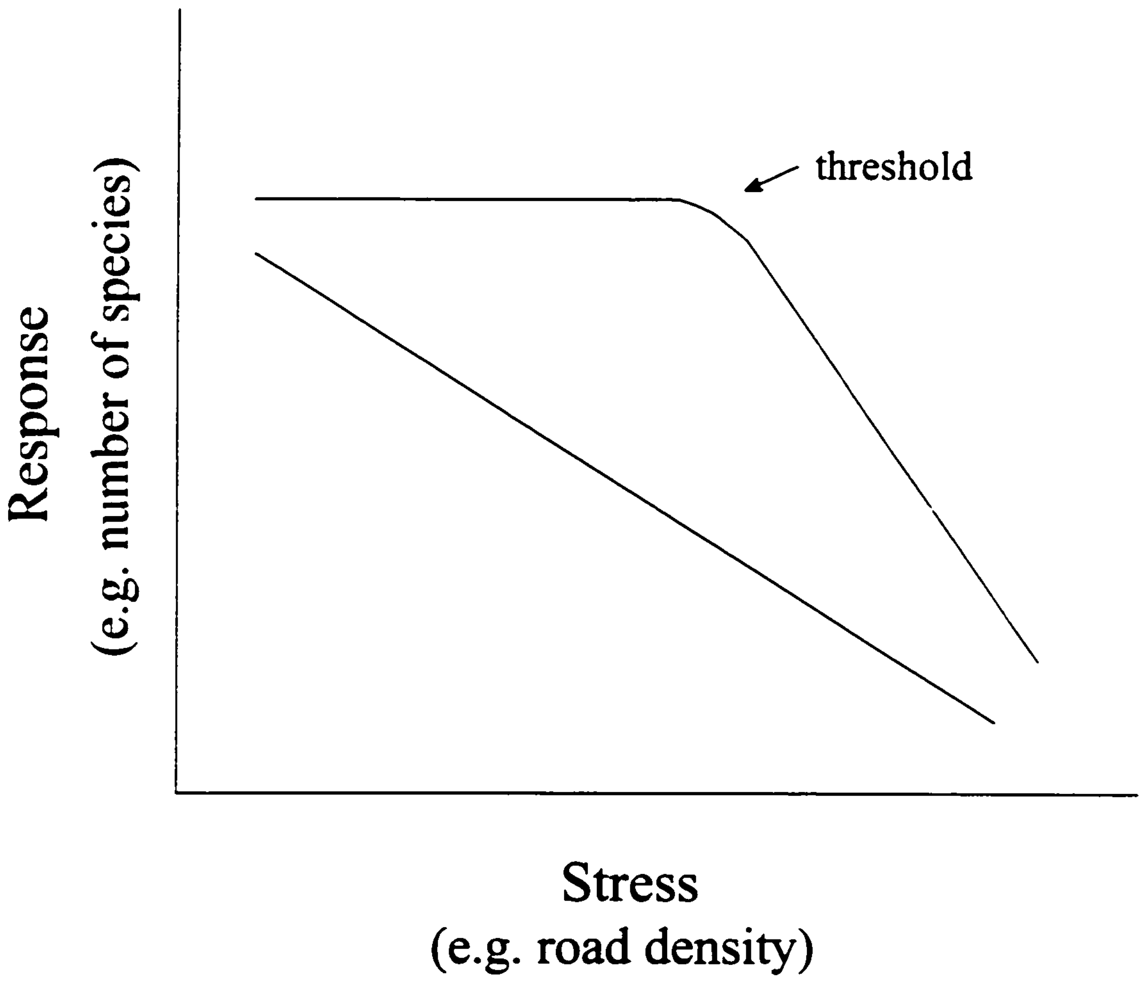


Figure 1: A generic stress-response relationship. There are many possible curve shapes. but to illustrate the general concept of stress-response relationships. I have drawn a linear negative relationship and a threshold situation.

Figure 2: The Frontenac Axis is an extension of Ontario Precambrian Shield (in grey) which meets the Adirondack Dome in New York State. The study area is bounded by the dashed line and includes Universal Transverse Mercator squares within TE, UE and VE.

Figure 2

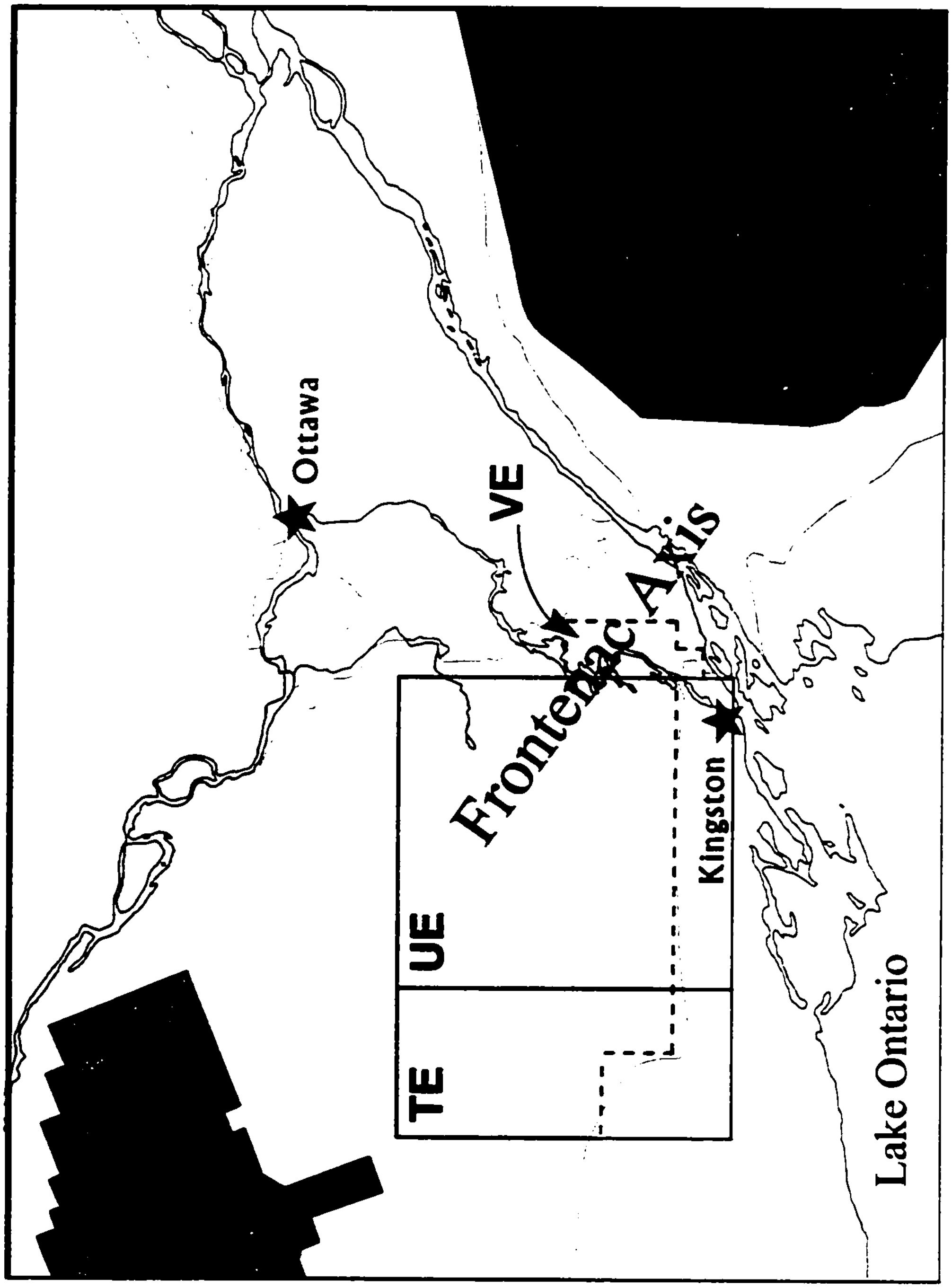
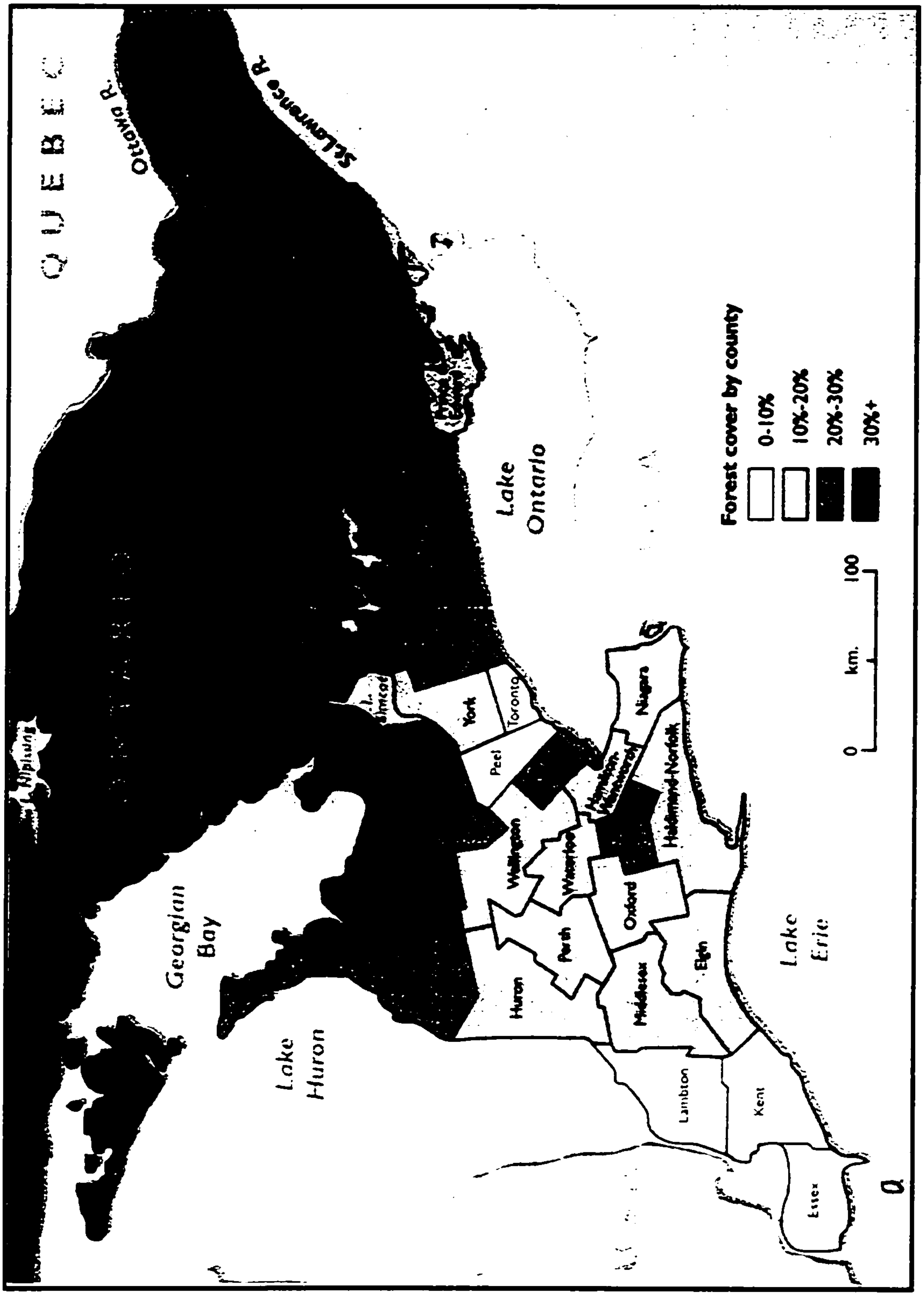


Figure 3: Forest cover in southern Ontario. The counties on the Frontenac Axis have >30% forest cover (from Cadman, 1996).

Figure 3


QUEBEC
Ottawa R.
St.Lawrence R.
ONTARIO
L. Nipissing
Georgian Bay
Lake Huron
Lake Ontario
Lake Erie
L. Simcoe
York
Toronto
Peel
Wellington
Waterloo
Hamilton-Wentworth
Haldimand-Norfolk
Niagara
Oxford
Perth
Huron
Middlesex
Elgin
Lambton
Kent
Essex
Forest cover by county
0-10%
10%-20%
20%-30%
30%+
0 km. 100
a

(1) Study region

The Frontenac Axis refers to an area of Precambrian Shield covering approximately 13,000 km^2 in south-eastern Ontario (Universal Transverse Mercator Grid 18 TE and UE). It is an extension of the Algonquin Highlands which extends from the Eardley Escarpment, through southern Ontario, Canada, to the Adirondack Dome, which forms part of the Adirondack Mountains in New York state, USA (Figure 2). The study area includes the counties of Leeds and Grenville, Frontenac, Lennox and Addington, Lanark, and Hastings.

This region was chosen because the Frontenac Axis is the least degraded north-south corridor of deciduous forest in southern Ontario (which is the most densely populated region in Canada) (Riley and Mohr, 1994; C.J. Keddy, 1995). The delineation of the Axis is obvious from a topographic map or aerial photograph because it is almost entirely covered in mixed forest, compared to the surrounding clay and limestone-based lowlands which have been almost completely cleared for agriculture (Figure 3). Although it is unsuitable for agriculture because of thin and rocky soil, the Axis has the potential to support forestry, outdoor recreation, and wildlife production, according to Canada Land Inventory Maps which were prepared in the 1970's by the Ontario Ministry of Natural Resources, Environment Canada, and Agriculture Canada.

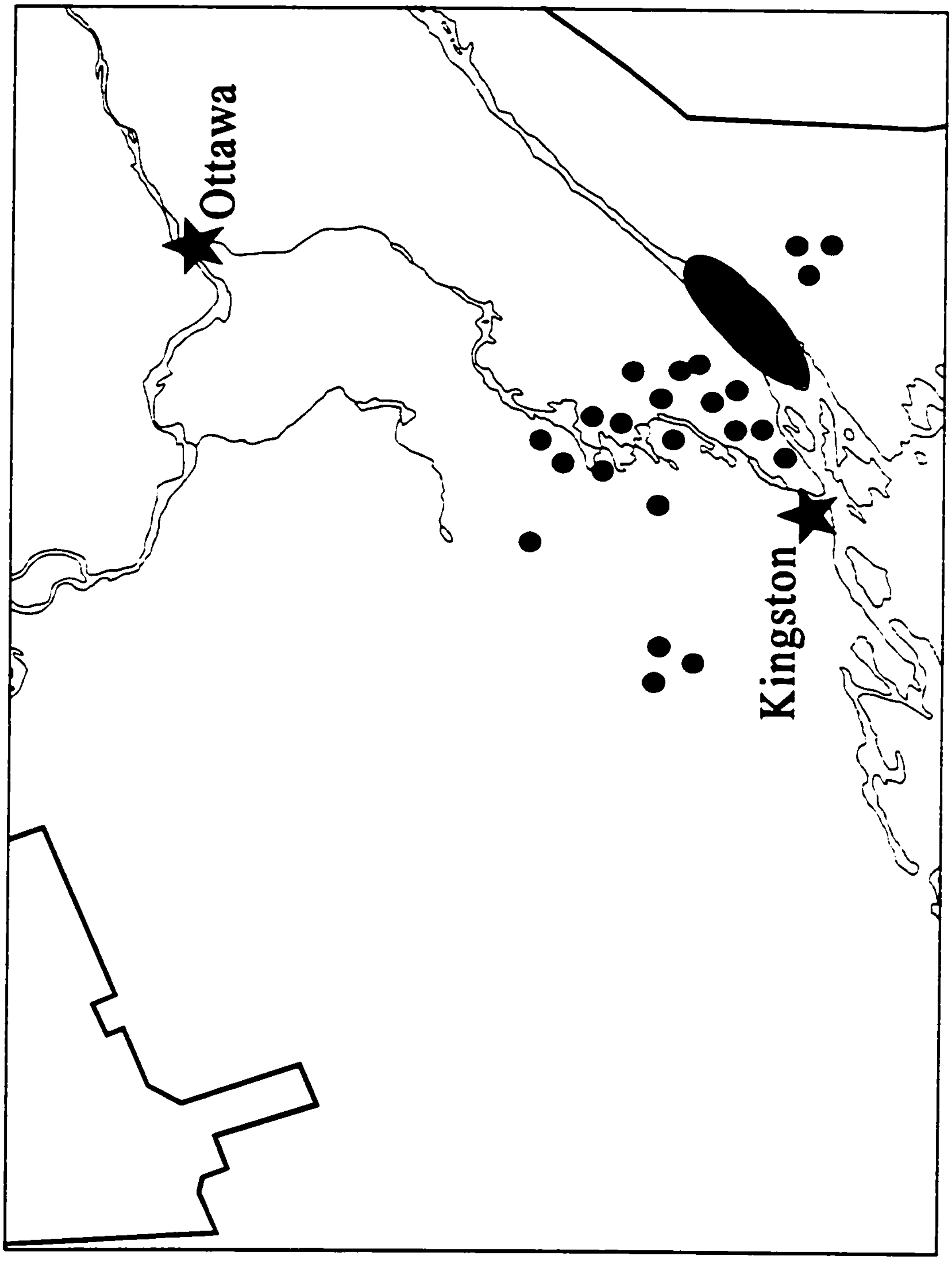
The principal anthropogenic activities in the northern end of the Frontenac Axis are forestry, mining, hydro-electric power generation, tourism, recreation, and wildlife-related activities such as trapping and angling (OMNR, 1997). Recreation is a minor land-use; there are 19 provincial parks with varying levels of habitat protection, and networks of snowmobile and hiking trails, as well as canoe routes. In the south, there is a greater concentration of human settlement, roads, and agricultural clearing. There are no large urban centers on the Axis, but a major highway, the 401, bisects the southern end. Within a system of parks, Areas of Natural and Scientific Interest, and management areas, 80 per cent of the known ecological features have been at least partially represented (C.J. Keddy, 1995). Given the rich biological diversity and the continuous forest cover, the Frontenac Axis is an important place to initiate any conservation efforts in this part of the province. It potentially forms a natural link between two of the largest protected areas in the region, Algonquin Provincial Park and Adirondack State Park.

Ontario Ministry of Natural Resources Site District 6-10 coincides with the Frontenac Axis, and White (1993) has reviewed the physical features and vegetation present. The biological diversity of the Axis has been reviewed by C.J. Keddy (1995). The upland forests are dominated by sugar maple (*Acer saccharum* Marsh.), beech (*Fagus grandifolia* Ehrh.), yellow birch (*Betula alleghaniensis* Britton), red maple (*Acer rubrum* L.) and eastern hemlock (*Tsuga canadensis* (L.) Carr.). (Nomenclature for tree species follows Farrar, 1997). Eastern white pine (*Pinus strobus* L.), red pine (*Pinus resinosa* Ait.) and jack pine (*Pinus banksiana* Lamb.) are common, but associated with dry, rocky ridges and sand flats. Less common southern species include butternut (*Juglans cinerea* L.), bitternut hickory (*Carya cordiformis* (Wang.) K. Koch), white oak (*Quercus alba* L.), white ash (*Fraxinus americana* L.) and black cherry (*Prunus serotina* Ehrh.). There are fragments of forest considered old growth, or nearing conditions characteristic of old growth (White, 1990). The vegetation undergoes a transition from deciduous with Carolinian affinities in the south to mixed with boreal affinities in the north. There are many lakes and wetlands as a result of irregular topography and beaver activity. There are fens, bogs, marshes, and four types of swamps (mixed, deciduous, coniferous, and thicket).

This habitat diversity supports a high diversity of wildlife. The Axis has the highest bird diversity in Ontario with 185 native species breeding (Cadman *et al.*, 1987), eight of which are considered vulnerable by the Committee on the Status of Endangered Wildlife in Canada (1994) [cerulean warbler (*Dendroica cerulea* (Wilson)), short-eared owl (*Asio flammeus* (Pontoppidan)), Cooper's hawk (*Accipiter cooperii* (Bonaparte)), red-shouldered hawk (*Buteo lineatus* (Gmelin)), prairie warbler (*Dendroica discolor* (Vieillot)), yellow-breasted chat (*Icteria virens* (Linnaeus)), least bittern (*Ixobrychus exilis* (Gmelin)), and Louisiana waterthrush (*Sieurus motacilla* (Vieillot))]. (Nomenclature for birds follows Speirs, 1985.) Two species are endangered: the loggerhead shrike (*Lanius ludovicianus* Linnaeus), and Henslow's sparrow (*Ammodramus henslowii* (Audubon)). Of the 54 mammal species, 2 are vulnerable: the gray fox (*Urocyon cinereoargenteus* (Schreber)) and the southern flying squirrel (*Glaucomys volans* (Linneaus)) (COSEWIC, 1994) (Nomenclature for mammals follows Banfield, 1974); and there is concern about declining gray wolf (*Canis lupus* L.) populations in the southern part of the Axis. Seventeen amphibians and 17 reptiles occur on the Axis (Keddy, 1995) and of these, the common musk turtle (*Sternotherus odoratus* (Latreille, 1801)), map turtle (*Graptemys geographica* (Le Sueur, 1817)), and spotted turtle (*Clemmys guttata* (Schneider, 1792)) are vulnerable (COSEWIC, 1994). There are 33 rare plant species, such as pitch pine (*Pinus rigida* Mill.), which enter Canada only

Figure 4: Pitch Pine (*Pinus rigida* Mill.) distribution in southern Ontario (Vander Kloet, 1973). Occurrence is concentrated in the Thousand Islands region (in grey) and moves into Canada along the Frontenac Axis.

Figure 4



along the Axis (Figure 4) (Vander Kloet, 1973). A number of exotic invasives have been introduced, such as purple loosestrife (*Lythrum salicaria* L.), European frog-bit (*Hydrocharis morsus-ranae* L.), and common buckthorn (*Rhamnus frangula* L.).

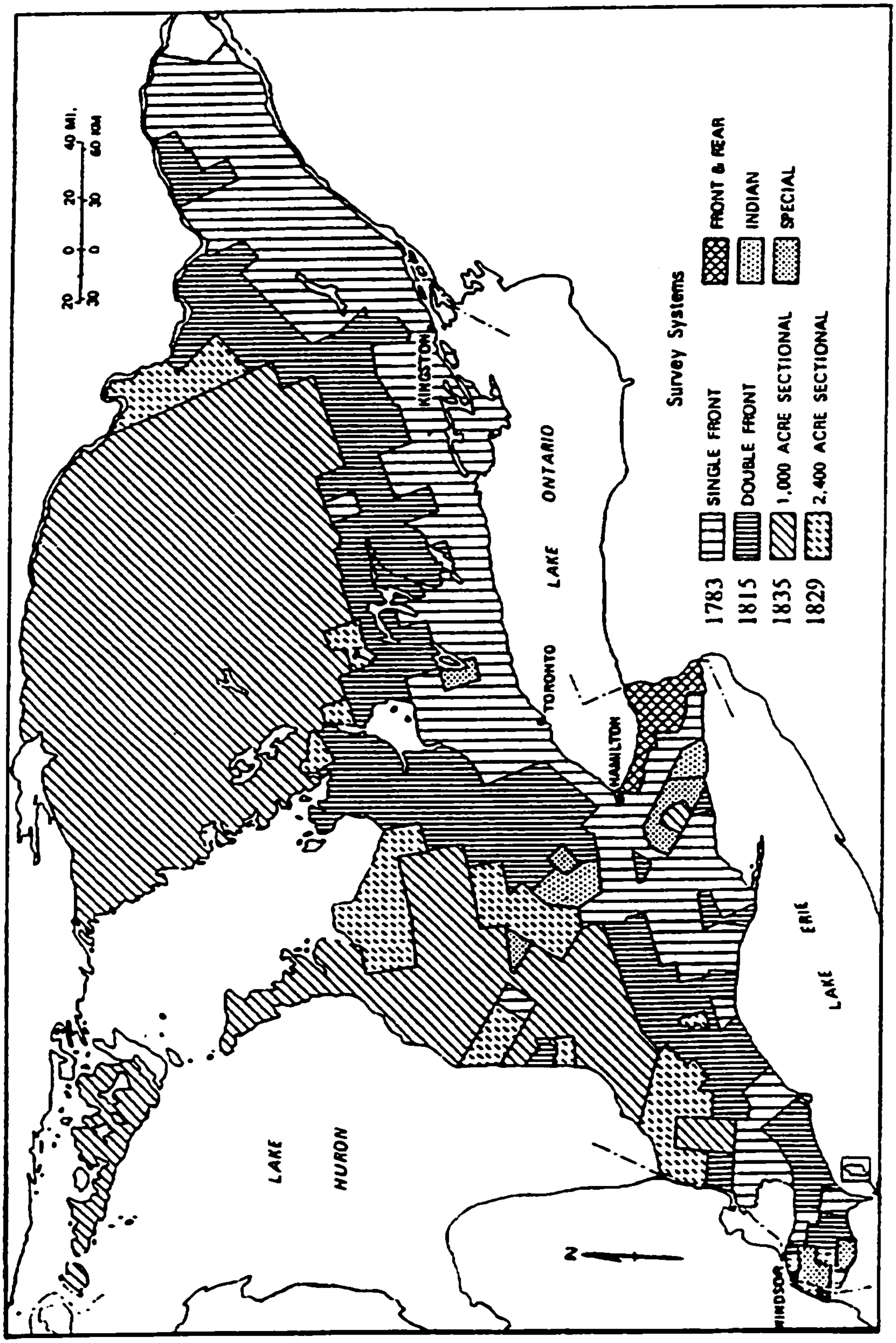
The history of Ontario and the Frontenac Axis area

A brief history of the study region may give some insight into the events that lead to the present condition of the land, and has been described by Choquette (1984). French explorers and fur traders first reached Ontario in 1610. The flourishing fur trade necessitated fortified trading posts of which Fort Frontenac (1673) was the first. Although strategically placed at present-day Kingston to protect French territory from the British, the British captured Fort Frontenac and subsequently all French forts by 1763; Canada was then officially under British rule. In 1791, two independently governed colonies, Upper Canada and Lower Canada, were formed, only to be combined again as the province of Canada, in 1841. In 1867, the province of Ontario was formed.

The early settlements were formed by immigrants. During the American Revolution (started in 1775), Loyalists immigrated to Canada from America, and in the few years after the Treaty of Versailles (1783), British, Scottish, and Irish Loyalists poured into Canada. The Loyalists were encouraged by the British government; they were given land, tools, livestock, provisions, weapons, and clothing to carve communities from the wilderness. Crown land was organized into townships before the settlers arrived and Figure 5 shows the wave of settlement northwards from the late 1700's to mid 1800's. Members of the military were given the most land, and towns such as Perth were settled mainly by these people after the War of 1812. Lanark county and Peterborough

Figure 5: Settlement history of southern Ontario. The first townships were those along the St. Lawrence River and were single front surveys. Double front survey was an attempt to standardize the lots at 100 acres. The last area to be surveyed was northern Ontario (From C.J. Keddy, 1993).

Figure 5


Survey Systems
1783 SINGLE FRONT
1815 DOUBLE FRONT
1835 1,000 ACRE SECTIONAL
1829 2,400 ACRE SECTIONAL
FRONT & REAR
INDIAN
SPECIAL
LAKE ONTARIO
LAKE HURON
LAKE ERIE
KINGSTON
TORONTO
HAMILTON
WINDSOR
N
20 0 20 40 MI.
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were settled by the poor Scottish and Irish immigrants (Bothwell. 1986).

When settlers received their land. it was forested. The first thing they did was to clear it for crops. animals. barns. and houses. They could earn money quickly by burning the forest for potash. Early Ontarians disliked the forest and destroyed it expeditiously. as Muro noted in his 1881 book. *Backwoods of Ontario*:

> 'Forest Management' ... with us in the backwoods - and indeed through nearly the whole of Canada - ... consists of stupid extermination. The doom of every standing stick. with the exception of the sugar-bush and the cordwood reserve. is to be cut down and cast into the fire. A stranger is struck with the monotonous appearance of the country. Walking along the concession line. not a tree relieves the eye. except the uniform belt of woods in the rear of the clearings. (Muro. 1881 in MacGillivray. 1985).

They associated it with still-prevalent malaria and wild beasts. saw it as a barrier to neighbours. thought it dangerous to cattle and people. and believed that clearing it would produce a milder climate (MacGillivray. 1985).

By the mid-19th century. the timber trade was booming. overtaking the fur trade and further fueling immigration from Europe. The reason for the boom was that Britain desperately needed wood since its traditional source had been disrupted by the Napoleonic Wars. and offered a preferential tariff exempt from tax: the era of squared white and red pine had begun. In the second half of the century, sawn lumber dominated the trade. In total. from 1867 to 1899. 28 per cent of Ontario's revenue was from timber.

Technology and industrialization were the major driving forces between 1820 and 1880. and transportation was the focus. This period was the Golden Age of the Canals and of the Railways. The Rideau Canal was built between 1826 and 1832 to link Bytown (now Ottawa) to Kingston. Three railways were built between 1855 and 1886 to ship sawn timber to the south: Bytown and Prescott, Brockville and Ottawa, Kingston and Pembroke (C.J. Keddy, 1993). Railroads brought new settlements, farming communities, logging camps, mining, and expanded agriculture. The increased accessibility to the Frontenac axis, afforded by railroad, supported mining. The Canadian Shield contained deposits of gold, silver, iron, lead, nickel, mica, graphite, andesite, feldspar, talc, phosphate, and others. By 1906, mineral revenues were 58 per cent of Ontario's tax income (Osborne, 1995). Roads became more important in the latter half of the century: the Hastings road was opened northwards into shield country of south central Ontario in 1856, and the Mississippi road extended east into the north west corner of Lanark county (C.J. Keddy, 1993; Shaw, 1994).

The role of fire and later, fire suppression, is discussed by C.J. Keddy (1993). Fire was deliberately set by farmers to clear the land, and was associated with logging operations. Sparks and coals from coal-burning railway engines frequently caused forest fires. The fire of 1870 affected Darling, Pakenham, Lanark, Ramsay, and Montague townships. By the early 1900s, fire suppression caused a lower than natural fire frequency.

The past 200 years of land use has affected ecological processes: clearing affected run-off and ground-water retention: agriculture brought exotic species, soil erosion, pollution, and loss of wetlands; mining added toxic elements to the water and soil: over-fishing depleted lake stocks; and urban expansion contributed to pollution and high water demand (Osborne, 1995). The great forests are gone. The Frontenac Axis area is poor farmland due to thin, impoverished, drought-prone, acidic, and infertile soil, and those who were able to leave their farms did so as early as the 19th century (Bothwell, 1986; White, 1993). Because of its lack of agricultural potential, it has experienced limited landscape modification from farming and development. Today, the largest town and village are Gananoque (5,000) and Bancroft (2,000) respectively (C.J. Keddy, 1995). Forest cover has actually increased in the past century because of farm abandonment and fire suppression, but cottage development has increased 1.5 to 7 times over the period from 1925 to 1994 (C.J. Keddy 1995).

(2) Potential anthropogenic stressors

A stressor is a factor which has a detrimental influence on an ecological community or ecosystem (Odum, 1985) and humans have had a wide range of detrimental effects upon ecosystems (Carson, 1962; Meadows *et al.*, 1974; Ehrlich *et al.*, 1977; Odum, 1985). The most noticeable physical anthropogenic stressors on our landscape are transportation corridors (roads and railways) (e.g. Freemark *et al.*, 1995), human population (e.g. Happold, 1995), urbanization (e.g. Blair, 1996), and clearing of forest (e.g. Greenberg *et al.*, 1995).

Roads:

There is a growing consensus that roads cause loss of forest biodiversity through habitat destruction and fragmentation. On a landscape level, fragmented habitat will support smaller populations of a given species which leads to both reduced genetic diversity and local extinction (Reh and Seitz, 1990; Haila *et al.*, 1993; Turner, 1996;

Turner 1997). The direct effects of roads include road-kill, animal behaviour modification, isolation of populations, pollution, and changes in hydrology (Lagerwerff and Specht, 1970; Oxley *et al.* 1974; Mader, 1984; Klungness, 1995). Each of these effects individually is cause for concern, but in most cases they occur simultaneously, and the cumulative result is a degraded ecosystem (Klungness, 1995).

The major indirect effect of roads is increased human access. This leads to over-exploitation of plants and animals, removal of coarse woody debris, changes in fire patterns, edge effects, invasions of exotic species, and land development (Klungness, 1995; Forman and Hersperger, 1996). The most damaging indirect effect of roads may be that they allow access to forests for settlement. People move in and alter the surrounding landscape by clearing it for agriculture and grazing, harvesting timber, and managing the forest for non-timber products (for example maple syrup, tourism, and recreation).

Human population and urbanization:

Increasing land development (such as roads, settlement, agricultural land, and plantations) is the result of human population growth. Humans already dominate over 95 per cent of the terrestrial environment, using 50 per cent for agriculture, 20 per cent for forest plantations, 25 per cent for settlement (Harvey and Pimentel, 1996). On the global level, explosive increase in human population is an important, if not the most important, environmental concern (Coates, 1992). Population in a country can serve as an indicator of anthropogenic threats to biodiversity (Sisk *et al.*, 1994). For example, mammal populations in Africa have declined because of pastoralism, hunting, disease control, and habitat modification; all of these are caused by increased human population (Happold,

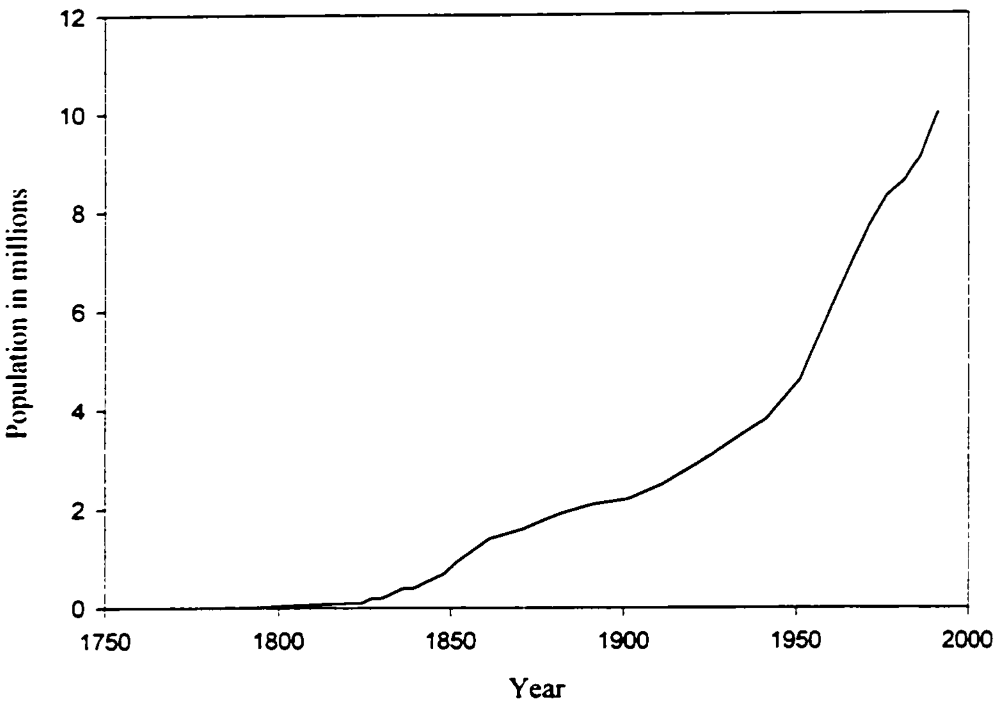

Figure 6: Population growth in Ontario from 1784 to the most recent census. Sources: Galzebrook, 1968; Armstrong, 1985; Bothwell, 1986; Minister of Industry, Science and Technology, 1994.

1995). There is a positive correlation between regional human population growth and loss of habitat caused by deforestation (Allen and Barnes, 1985; Rudel, 1989). This increasing pressure on wildlife and habitat is thought to be unsustainable, especially for large predators and migratory birds (Soule, 1991). In Ontario, the human population has increased exponentially since settlement (Figure 6).

Clearing of forest:

A recent analysis of fragmentation in Canada found that the forests of the southern end of the Frontenac Axis are 75 to 100 per cent fragmented, while in the northern end, they are 25 to 50 per cent fragmented (Rubec *et al.*, 1993). A review of the literature shows that nearly all case of tropical rain forest fragmentation has lead to a local loss of species because of reduced habitat quality (Turner, 1996). At current rates of tropical forest destruction, it is estimated that 2 to 8 per cent of Earth's species will become extinct in the next 25 years (Reid, 1992). Habitat destruction alone accounts for 36 per cent of all extinctions for which causes are known (World Conservation Monitoring Centre, 1992).

I predicted that these three anthropogenic land uses would act as stressors on the biodiversity indicators outlined in the next section. These anthropogenic factors are relatively easy to measure, and action may be taken to mitigate their effects, or their construction may be prevented altogether.

On the global scale, factors such as latitude, elevation, precipitation, nutrient gradients, salinity, annual evapotranspiration, disturbances, and net primary productivity are correlated with biodiversity (Currie and Paquin, 1987; World Conservation

Monitoring Centre, 1992; Ricklefs and Schluter, 1993; Huston, 1994). I have assumed, however, that the Frontenac Axis (a 13,000 km^2 area) is not large enough to be affected by these factors, and as a result, they are not discussed. However, on a local scale, underlying bedrock determines soil characteristics such as pH, mineral fraction, texture, and chemical composition, and in turn, the soil may affect primary productivity, decay rates, and plant composition. In Chapter 2, the presence of marble bedrock was noted to see if fern diversity or CWD varied with the underlying rock composition.

(3) Response variables: the indicators

In an attempt to address concerns about global development and natural resources, more research is being directed towards sustainable development. The Bruntland Commission (1987) defined sustainable development as "... development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs." If development is sustainable, they say, it empowers the community, maintains or improves the economy, and retains ecological integrity. From a less anthropocentric point of view, a sustainable ecosystem is one that, over the normal cycle of disturbance events, maintains its characteristic diversity of major functional groups, productivity, soil fertility, and rates of biogeochemical cycling (de Groot, 1992; Chapin *et al.*, 1996).

Because forests are a renewable resource, the importance of sustainable development was immediately recognized by the forestry sector. In 1992, the United Nations Conference on Environment and Development (UNCED) focused world attention on sustainable forest management. The Commission on Sustainable Development was set up to evaluate UNCED's impact on forests, and one of their goals is to encourage countries to develop national-level criteria and indicators to strengthen biological inventory and monitoring for sustainable forest management and the conservation of biodiversity. The first step towards a set of global criteria and indicators was the Helsinki Process, initiated in 1990 by 31 European countries. The Government of Canada, through the Canadian Council of Forest Ministers (CCFM), started the Montreal Process in 1993 to design a scientifically rigorous set of criteria and indicators to monitor forest management. The working group, consisting of 12 countries which represent 90 per cent of the world's temperate and boreal forests, produced the 1995 Santiago Declaration and the final version of the criteria and indicators (Appendix 1). The seven criteria and their indicators use economic, environmental, and community values to integrate science with forest management. Sustainability is the goal.

As defined by the CCFM, a 'criterion' is a condition or process by which sustainable forest management may be assessed. It consists of a set of related indicators which are monitored periodically to assess change. In general, a good indicator is one that is easy to measure, ecologically meaningful, representative of an ecological process or function, represents the entire community rather than one entity, and is valued by society (Keddy *et al.*, 1993). Indicators should also have early warning capability, have results that are reproducible (Munn, 1993), be applicable over a wide geographic area, give continuous assessment over a wide range of stress, and be independent of sample size (Noss, 1990). We are far from having a comprehensive indicator list and desirable levels for each ecosystem type (Vora, 1997). A two-volume proceedings on ecological indicators summarizes recent development and implementation of ecological indicators for policy, regulation, and monitoring (see McKenzie *et al.*, 1992), and there have been many suggestions of suitable indicators for issues such as biodiversity, ecosystem health, and sustainable forestry (see Noss, 1990; Forest Ecosystem Management Assessment Team, 1993; Vora, 1997).

The first CCFM criterion is the conservation of biodiversity and the indicator suggested by the CCFM is the number of forest-dependent species. I chose to use biodiversity indicators at three taxonomic levels (complete taxon, functional groups, and species) to determine which one was the most informative. I then investigated the ability of CWD to provide habitat for ferns, thereby contributing to understory plant diversity.

Indicators of biodiversity

A major environmental issue facing ecologists is the effect of land use on biodiversity. The United Nations has identified loss of biodiversity as a global concern, and the Convention on Biological Diversity signed at Rio de Janeiro in 1992 promotes conservation of biodiversity and the sustainable use of global natural resources. On the global scale, biodiversity is declining at a rapid pace as a result of habitat destruction, fragmentation, over-exploitation, spread of exotics, pollution, and climate change (Western and Pearl, 1989; Soule, 1991; Estrada *et al.*, 1994; Turner, 1996).

Ecosystem functions and processes contribute to human welfare by providing 'goods and services'; for example, genetic diversity provides sources of genes for pest resistance in crops (Costanza *et al.*, 1997). As biodiversity decreases, the quality of human existence declines; loss of diversity means a loss of agricultural, economic, and medicinal potential values, and possibly a change in climate (Ehrlich and Ehrlich, 1981;

Huston, 1994; Noss and Cooperrider, 1994). Further, key processes such as litter decomposition, nitrogen fixation, pollination, and seed dispersal will not occur if species influencing these functions are absent (Schulze and Mooney, 1993; Schowalter, 1995; Naeem *et al.*, 1995; Mooney *et al.*, 1996; Lawton, 1997).

The definition of biodiversity, which is a contraction of biological diversity, is more complex than it first appears. It can be measured at three levels -- species, ecosystem, and genetic (Wilson, 1992; Noss and Cooperrider, 1994). The species is the fundamental unit of the study of biology (Wilson, 1992) and it is the most simple to measure. On the species level, one may count the total number of species, the species within a taxon or functional group, or even the individual species occurrence. These measures were used in this study. Diversity can also include measures of relative abundance (Pielou, 1975) but since abundance data were not available in this study, the presence and number of species were the only measures used.

The total number of species occurring in an area is commonly used as an indicator. Typically, this approach is not practical in large areas because some taxonomic groups, such as invertebrates, are poorly understood due to taxonomic complexity and lack of accessibility (Schowalter, 1995). Functional groupings may make more sense than taxonomic groupings because the diversity and redundancy within groupings are critical for ecosystem response to change, and communities are more stable and predictable when viewed in terms of functional groups (Levin, 1997). Functional groups within taxa are sets of species based on attributes related to how they interact with each other and their ecosystem requirements. They can give a more complete picture of which associations of species are responding to stressors than can the total number of species

(Walker, 1992; Schulze and Mooney, 1993; Huston, 1994; Risser, 1995; Conroy and Noon, 1996).

Focusing on distributions of particular species may be appropriate if the species is key, highly vulnerable to stress or of political or legal interest (for example, the northern spotted owl) (Forest Ecosystem Management Assessment Team, 1993; Lindenmayer and Norton, 1993). 'Keystone' species, such as starfish, are those that play crucial roles in ecosystem processes and whose loss causes dramatic cascading effects (Paine, 1966; Bond, 1993). 'Umbrella' species, such as large carnivores, are those that require a large area of land and a diversity of resources to maintain viable populations, and in protecting them, species that also require those habitats and resources will also benefit (Landres *et al.*, 1988; Launer and Murphy, 1994; Noss and Copperrider, 1994).

The concept of indicator species has been challenged for at least two reasons: information on individual species may provide little information on overall ecosystem trends (Odum, 1971; Noss, 1990) and one may not be sure of what the presence of a species indicates (Kremen, 1992). Further, sometimes endangered species are used as indicators, but focusing on endangered species may remove conservation resources from broader issues. Ehrlich (1996) argues that it is usually too late and too expensive to save them, and it is inevitable that species will be lost.

Biodiversity and coarse woody debris

Coarse woody debris is decaying fallen logs and stumps, greater than 2.5 cm in diameter, on the forest floor, and standing dead trees (Harmon *et al.*, 1986). It represents a substantial, yet little studied accumulation of energy, carbon, and nutrients in forest ecosystems and has an important role in ecosystem processes including energy flow, nutrient cycling, hydrology, timing and severity of insect infestations and fire, and soil and sediment transport and storage (Cline *et al.*, 1980; Franklin *et al.*, 1981; Harmon *et al.*, 1986; Stewart and Burrows, 1994). Coarse woody debris provides habitat for microbes, invertebrates, fungi, amphibians, reptiles, small mammals, ferns, and tree seedlings (Harmon *et al.*, 1986; Kimmins, 1997). Birds such as grouse use CWD in mating behaviour, and wrens nest near CWD (Kimmins, 1997). The use of snags as nesting places for cavity-nesting birds is well documented (reviewed by Fischer and McClelland, 1983). One hundred and seventy-nine vertebrate species (57 per cent of breeding species) have been estimated to use CWD in Oregon and Washington states (Harmon *et al.*, 1986).

CWD is affected by timber harvest; typically, recently clear-cut stands have a large amount of small-diameter, quickly-decayed slash, and as the stand matures, CWD becomes larger in size but reduced in volume (Bormann and Likens, 1979; Lambert *et al.*, 1980; Tritton, 1980; Lang, 1985; Spies *et al.*, 1988; Harmon and Hua, 1991; McCarthy and Bailey, 1994). 'Tidier and less wasteful' logging of the past 50 years has reduced amounts of CWD and reduced protection of the forest floor from erosion and mechanical disturbance (Graham *et al.*, 1994).

In Chapter 2, I investigate the role that CWD plays in maintaining biodiversity. Ferns are assumed to use CWD as substrate, particularly for generation, and are therefore one possible indicator for the biodiversity function of CWD. If ferns require CWD to establish, and species diversity of ferns is related to quantity or quality of CWD, then it follows that removal of CWD from forests by forestry practices will decrease structural heterogeneity and cause changes in populations of organisms that depend upon CWD (e.g. Soderstrom and Jonsson, 1992; Richardson and Henderson, 1993; Means *et al.* 1996 and references therein).

The dependency of plant species on CWD has not yet been thoroughly studied, although much work on tree seedling establishment has been done (Harmon *et al.*, 1986; Harmon and Franklin, 1989; Marra and Edmonds, 1994; Kimmins, 1997). Ferns are often found growing on old, decaying, mossy logs (W. Wagner, Personal communication), but there have been no studies to confirm that they require a certain size or amount of CWD to succeed. Unlike seed plants, the fern life cycle is heteromorphic, consisting of a diploid sporophyte and a haploid gametophyte. The sporophyte develops from a fertilized egg in the archegonium of the gametophyte. Because of gametophytes' small size, they are very difficult to find in the field and there have not been many studies concerning their ecology and habitat requirements. The sporophyte, however, is abundant and ubiquitous. There are 48 species of true ferns occurring in the study area (Pringle, 1987) because of the diverse terrain and the fact that northern and southern range boundaries meet here (Macdonald, 1974). This is a large enough number to give variety, but a small enough number to learn quickly and thoroughly. Ferns are easily identifiable from spring to fall, and therefore make a practical indicator group for understory plants.

Some species of ferns are mycorrhizal and may represent important nutrient sinks. Little work has been done on ferns, but another understory plant, the spring ephemeral *Erythronium americanum* Ker. accounts for a very small proportion of the net primary production in the Hubbard Brook Experimental Forest ecosystem, but it may significantly influence the nutrient dynamics of the system. Nutrients are taken up from the early spring runoff. and when the plant senesces. the nutrients are released back into the system (Muller, 1976). In this example, a seemingly inconsequential species affects an important ecosystem process. In the same way, mycorrhizal ferns may be important contributors to nutrient cycling, especially if they are associated with the reservoir of high concentrations of nitrogen and phosphorous within CWD (Lang and Forman, 1978).

Vogt *et al.* (1995) found that conifer seedlings most often grew on CWD because of their mycorrhizal symbiotic associations, whereas understory plants had over 96% of their root biomass in the soil, and did not appear to utilize CWD. For the same reasons, we might expect mycorrhizal ferns to grow on CWD. Non-symbiotic nitrogen fixation and ectomycorrhizae occur in CWD and so the more CWD present, the more nitrogen fixation possible by symbiotic or non-symbiotic means (Jurgenson et al. 1987 and 1992; Graham *et al.*, 1994).

CWD could be suitable habitat for ferns because it provides elevation above litter and a moist site throughout the summer for the gametophyte to establish and develop into a sporophyte. It is difficult for some tree seedlings to establish under dense understory or on a dried-out forest floor. Rotting logs provide both elevation towards light above thick moss or litter, and moisture during the summer dry periods because they hold water better than soil or humus (Harmon *et al.*, 1986; Harmon and Franklin, 1989; Marra and Edmonds, 1994; Kimmins, 1997). Debris also disrupts air flow and provides shade, insulating and protecting new forest growth. In moist climates, downed logs are sometimes known as 'nurse logs' because of the quantity of established seedlings growing on them.

CHAPTER ONE: BIODIVERSITY AND ITS RELATIONSHIP TO POTENTIAL ANTHROPOGENIC STRESSORS

INTRODUCTION

The objective of this chapter is to quantify the relationship between some anthropogenic factors (road, building, and human population density, and forest loss) and indicators of biodiversity. Loss of biodiversity is a recently popularized concern and the first CCFM criterion is the maintenance of biodiversity. I hypothesized that the biodiversity indicators would respond negatively to the anthropogenic factors on the Frontenac Axis. I predicted that species will be absent and therefore species richness will be lower in highly stressed areas.

In this study, complete data were not available for rare plants or insects, therefore, the total number of species occurring on the Frontenac Axis could not be calculated. Instead, I divided biodiversity into three levels; (1) complete taxonomic group (e.g. herptiles), (2) functional groups (e.g. ground nesting birds), and (3) indicator species (e.g. large carnivores).

Three levels of biodiversity

(1) Complete taxonomic group - herptiles

It is argued that amphibian populations are declining around the world as a result of anthropogenic factors such as habitat modification or loss (Blaustein and Wake, 1990; reviewed by Blaustein *et al.*, 1994), although not all species and regions appear to be affected (Pechmann *et al.*, 1991). Amphibians are particularly sensitive because of their permeable skins, pattern of embryonic development, population biology, and complex interactions in communities (Wake, 1991). The life-cycle of amphibians is complex and involves aquatic and terrestrial life stages, therefore, they need both suitable wetland and terrestrial habitat. Reptiles are less restrictive in their habitat than amphibians because they give birth or lay eggs on land, and are covered in scales or scutes enabling them to live away from moisture -- although turtles spend most of their time in wetlands. Temperature is the major limiting factor for a reptile. In this study, amphibian and reptile species were combined in a list of 38 species of herptiles that occur on the Frontenac Axis (Appendix 2). The number of species is not large, nevertheless herptiles are an important component of the vertebrate fauna because of the high numbers (for example, 2,950 salamanders per ha) and fraction of vertebrate biomass (2.6 times higher wet wt. than birds) they attain (Burton and Likens, 1975). Nearly all reptiles are predators, and both reptiles and amphibians are a food source for vertebrates and invertebrates.

Roads contribute to the mortality of reptiles and amphibians through direct mortality, desiccation, increased exposure to aerial predation, habitat fragmentation, facilitation of illegal human collection, and acting as barriers to movement. For example, black rat snakes (*Elaphe obsoleta obsoleta* (Say, 1823)) thermoregulate on warm roads where many are accidentally or deliberately killed (Dodd *et al.*, 1989; Langley *et al.*, 1989; Bernardino and Dalrymple, 1992). Roads and their effects reduce both amphibian and reptile density and species numbers (Reh and Seitz, 1990; Fahrig *et al.*, 1995; Boarman and Sazaki, 1996; Fowle, 1996; Means, 1996; Findlay and Houlahan, *in press*). In fact, tunnels have been constructed in Texas to facilitate road crossing for herptiles such as the spotted salamander (*Ambystoma maculatum* (Shaw, 1802)) and the Houston toad (*Bufo hustonensis*) (Jenkins, 1996). On the other hand, some snakes may actually benefit from forest clearing because they prefer rock ridges and garbage piles.

I predicted that the total number of herptile species would be negatively related to anthropogenic stressors such as road, building and human population density, and the loss of forest and wetland habitat.

(2) Functional groups - for birds

As a taxon, birds are well-studied, and there is evidence that anthropogenic stressors adversely affect them. For example, a recent study found that bird species suffer reduced population density adjacent to roads, varying with noise load (Reijnen *et al.*, 1995; Reijnen and Foppen, 1995). Small width corridors through forests, such as roads, powerlines and railways, were found to create traps for forest-interior Neotropical migrants because they do not avoid such habitats, but at the same time avian nest predators and parasites are attracted to the corridors (Rich *et al.* 1994). Many studies have found that tropical forest fragmentation leads to a local loss of bird species (reviewed by Turner, 1996).

I assigned 130 species of birds to 4 functional groups based on migratory strategy, habitat and nesting preference, and diet (Appendix 3) (using Cadman *et al.*, 1987; Muller, 1995).

Long-distance migrants: Birds species which winter south of the Gulf of Mexico were considered long-distance migrants. They are affected by habitat loss, fragmentation, and edge effects due to anthropogenic activities in both breeding and overwintering grounds (Landres *et al.*, 1988; Freemark *et al.*, 1995).

Habitat and Nesting: Nesting groups were based on where the nests are commonly found: either in dead, standing trees (snags) or on the forest floor. 'Ground-nesters', for example, are particularly sensitive to forest perturbation, because the nests are easily found and disturbed by domestic animals (cows, dogs, and cats) and wild foxes, a species benefiting from human land use (Nilsson, 1984). The list of snag- or ground-nesting species included only those species normally inhabiting the forest interior, because interior habitat is degraded or lost through land development and settlement, while edge species may benefit from fragmentation (Rich *et al.*, 1994).

Diet: The 12 species that eat mostly terrestrial vertebrates were classified as carnivorous species (Appendix 3). Higher trophic levels are known to be more sensitive to stress (see discussion below).

I predicted that the number of bird species within the functional groups, migrants, snag-nesters, ground-nesters and carnivores, would be negatively related to anthropogenic stressors such as road, building and human population density and the loss of forest habitat.

(3) Individual species - large carnivores

Species in higher trophic levels are thought to be more vulnerable to extinction because they usually have low population densities and low reproductive rates (Hummel, 1990; Turner, 1996). For example, small amounts of habitat degradation can have highly non-linear negative effects on populations of Yellowstone National Park grizzly bears (Doak, 1995). Large predators often respond to ecological stress before other species are affected because mortality is additive rather than compensatory in small populations (Hummel, 1990; Ruediger, 1996).

When home ranges are large relative to habitat fragments, animals must expand their ranges to forage, which increases travel costs and ultimately reduces fitness (Ehrlich, 1996). Because their home ranges are extensive, large carnivores inevitably come into contact with roads and highways. Direct mortality, displacement, and avoidance behaviour of large carnivores has been well documented, and the indirect effects of roads such as habitat loss, fragmentation, and increased hunting are acknowledged causes of carnivore decline (Ruediger, 1996 and references therein).

Populations of large carnivores such as coyote (*Canis latrans* Say), gray wolf (*Canis lupus* L.), black bear (*Ursus americanus* Pallus), cougar (*Felis concolor* L.), grizzly bear (*Ursus arctos horribilis* Ord), wolverine (*Gulo luscus* L.), and lynx (*Lynx canadensis canadensis* Kerr.) are negatively affected by roads in national parks (Gibeau and Heuer, 1996). Of this list, only the coyote, gray wolf, and black bear occur on the Frontenac Axis and were considered. Coyote is an extremely adaptable species and in some cases actually thrives under human influence (Gibeau and Heuer, 1996) and is considered only to contrast with wolf. Fisher (*Martes pennanti* (Erxleben)) also occurs on the Frontenac Axis. I will consider the gray wolf, black bear, and fisher separately.

Gray wolf: A typical wolf pack in Ontario occupies a fixed home range, 100 to 300 km^2 in area and therefore have low densities (Mech, 1970). For example, in Ontario, the average density was one wolf per 16 km^2 (Mech, 1970). A wolf population is not controlled by natural predation, rather starvation, disease, rabies, and distemper are important checks. Historically, humans have used traps, snares, aerial hunting, and poisoning to kill wolves. These techniques are extremely effective both because the wolf travels in packs, and because they occur in such low densities. Kill levels have been as high as 1 in 5 in Ontario (Hummel, 1990). The major causes of wolf mortality, however, are roads and highways (Paquet, 1993; Purves *et al.*, 1993). Wolf populations have been dwindling and they are now extirpated from the southern most part of Ontario (Hummel, 1990; C.J. Keddy, 1995). I predicted that wolves were more likely to occur in areas with low levels of anthropogenic stress.

Black bear: The American black bear is a member of the family Ursidae, order Carnivora. Their typical diet consists of 77 per cent vegetable matter (twigs, leaves, berries, fruit, and roots), 15 per cent carrion, 7 per cent insects (ants, grubs, and beetles), 1 per cent small mammals (mice, cottontails, and deer fawns), and other items such as fish and garbage (Banfield, 1974; Kurt *et al.*, 1990). They have large home ranges and typical density is one bear every 15 km^2 (Banfield, 1974). Being semi-arboreal, they normally live in large tracts of coniferous or deciduous forest, and are potentially adversely affected by forest clearing and other land-uses (Banfield, 1974; Dobbyn, 1994; Kurt *et al.*, 1990). I predicted that black bears would occur preferentially in areas of low anthropogenic stress.

Fisher: Fisher is a member of the family Mustelidae, order Carnivora. They are probably best known for their predation on porcupines. Their diet is 80% mammals such as red squirrels, flying squirrels, voles, hares, shrews, porcupines, and 8% deer mice, fish, birds and fruit (Banfield, 1974; Kruska, 1990). Their home range is about 16 km in diameter. Preferred habitat is climax coniferous forest near water courses but they will venture into subclimax deciduous and old burns (Arthur *et al.*, 1989). Dens are made in hollow trees, logs, crevices, brush piles or under boulders. They are secretive and seldom seen, but their fur is valuable and excessive hunting has resulted in a province-wide decline (Dobbyn, 1994). A cooperative management plan between trappers and the Ontario Ministry of Natural Resources, and re-introductions have resulted in a recovery of the historical range and population (Dobbyn, 1994).

DATA COLLECTION

Biodiversity indicators

The Universal Transverse Mercator Grid (UTM) coordinate system was used to compare data for all atlases. The basic unit at a 1:50,000 scale is a 10 X 10 km square area.

The herptile data set was the precursor to the Herptile Atlas of Ontario, an unpublished project of the Natural Heritage Information Centre in Peterborough, Ontario. Records were based on sightings and calls. The data set included detailed information on where and when each species was found, and by whom. With this, a measure of observer effort was calculated for each UTM block. All data are provided in Appendix 4.

The Atlas of the Breeding Birds of Ontario (Cadman *et al.*, 1987) was the result of four years of data collection by volunteers throughout Ontario. Observers filled out one data card for each square every year. Only breeding bird species were used and breeding evidence was classified into 3 levels: possible, probable, and confirmed breeding. I chose to use probable and confirmed breeding observations only. Species were categorized based on life history information given in the Atlas of the Breeding Birds of Ontario. The functional group of carnivorous birds was narrowly defined as a bird whose diet consists of greater than 50 per cent of land-dwelling vertebrates. Ground-nesters were those species who occupied the forest interior and constructed nests at ground-level. Snag-nesters were those species who occupied the forest interior and nested in cavities in standing dead trees. Migrants are species who winter south of the Gulf of Mexico. Observer effort data were published as a range of the number of hours spent in each quadrat. I used the mid-point of the range as the observer effort for each block. All data are provided in Appendix 5.

Data concerning large carnivores were taken from the Atlas of the Mammals of Ontario (Dobbyn. 1994). which was a compilation of data obtained from institutions and volunteers. Trapping records from as far back as 1900 were used and in some cases. records could not be pinpointed to a single square (and are included in my data set). Volunteer surveys were conducted over a two-year period. The data were recorded three ways: voucher specimen or photograph. observation without proof (trapping records. observation). and observation of distinctive signs (vocalization. tracks. scat). There were no reliable estimates of observer effort made (that is. the number of hours spent observing per block or the number of records per species). All data are provided in Appendix 6.

Anthropogenic factors

Road, building and human population density were used. Road density was calculated by measuring road length directly from topographic maps (1984, 1994 Topos of Canada. Department of Energy. Mines and Resources. 1:50,000) within a UTM (10 x 10 km) block. Roads were classified as either loose-top, hard-top or trail. Road density varied from 15 km to 99 km per 100 km^2 (Figure 1.1). Buildings were counted directly from the topographic maps. Because towns are indicated by pink, and individual buildings are not shown, it was noted only that a town was present in each 10 x 10 km square. Human population was estimated using the most recent Statistics Canada population counts for census subdivisions (Cat No. 93-304, 1986-1991) by using the proportion of the county population that occurred in a 10 x 10 km UTM square. This is a very coarse estimate because it assumes that population density is even throughout a county, which it is not.

Linear regressions were used to determine if there was a relationship between the response variables and the potential stressors. Logistic regression was used to determine if the presence of large carnivores was related to anthropogenic factors. Systat 5.0 and 7.0 (Systat 1990-1992 and 1997) software packages were used for the statistical tests.

Forest cover was estimated from topographic maps (1:50,000). A transparency with evenly spaced dots was laid on a selection of 10 x 10 km blocks (representing the two extremes of forest cover). The proportion of dots falling on forest, 'marsh' and cleared land were calculated (open water was not included in the calculations). 'Marsh' was wetland habitat identified on the topographic maps as swamp or marsh.

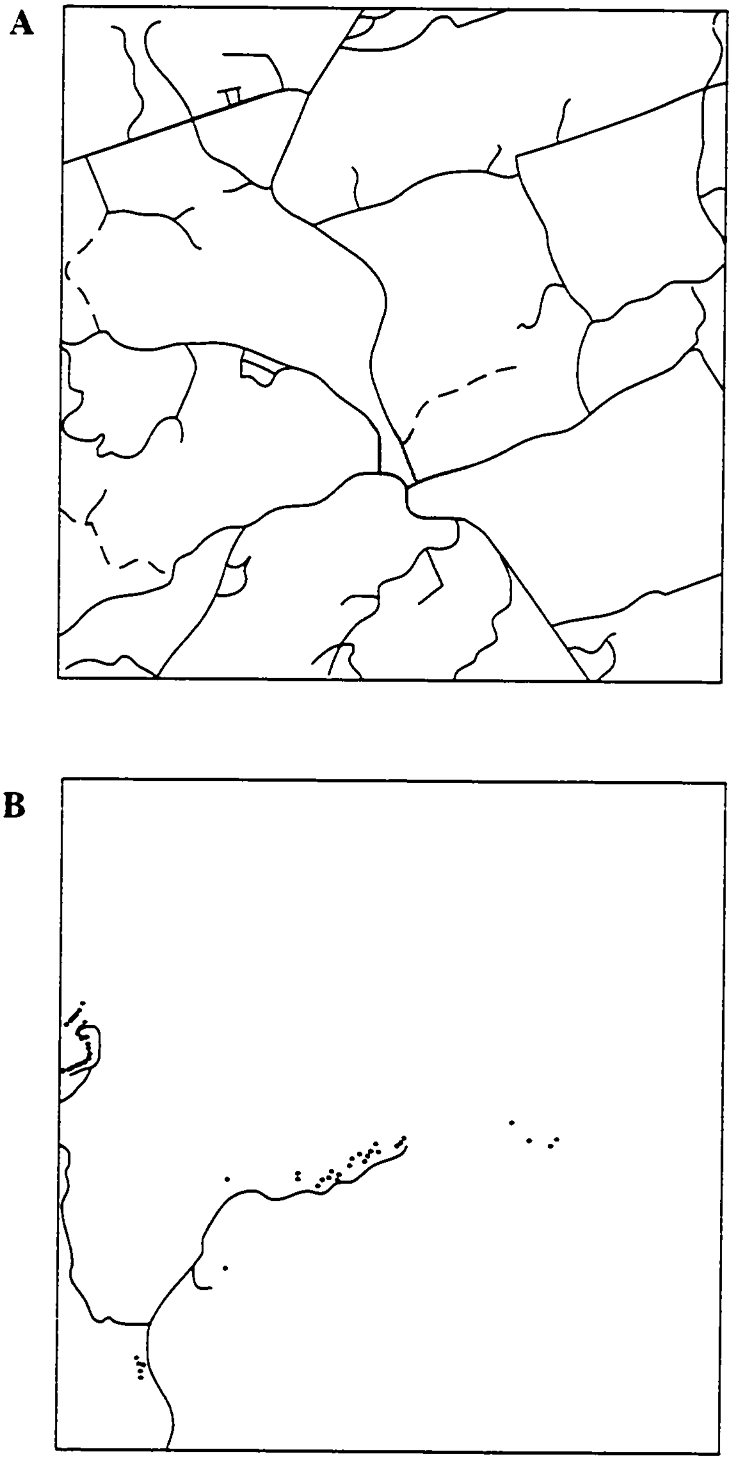

Figure 1.1: 100 km^2 blocks within a) Universal Transverse Mercator TE 79 with 99 km of roads and 875 buildings not including the town (not shown), and b) Universal Transverse Mercator TE 75 with 15 km of roads and 74 buildings. These two squares represent two extremes of road and building density at this scale.

RESULTS

All human-use factors were significantly correlated with each other, with the exception of trails (Table 1.1). The trails group was the least consistent of the anthropogenic factors, because the map symbol for trails included a range in types, such as farm driveways, All Terrain Vehicle trails, logging roads, and abandoned railway beds. Because road, population, and building density were significantly correlated with each other, these variables were interchangeable. Road density was the most important stress factor for a few reasons. First, it was the most accurately measured stress variable because it was easy to measure directly from maps, as opposed to human population, which was estimated, and number of buildings which could not be counted in towns. Second, it is the construction of roads which allows human settlement (buildings and people). Forest cover was negatively correlated with trails, total road density and building density.

Frequency histograms of vegetation cover revealed that most of the study area has greater than 70 per cent forest cover and less than 30 per cent wetland habitat (Figure 1.2).

Table 1.1: Correlation matrix of anthropogenic factors for 106 10 x 10 km blocks. * denotes significance ($p<0.05$).

	Human population	Hard-top roads	Loose-top roads	Trails	Total roads	Buildings
Human population	1	-	-	-	-	
Hard-top roads	0.525*	1	-	-	-	
Loose-top roads	0.407*	0.572*	1	-	-	
Trails	-0.028	0.030	0.084	1	-	
Total roads	0.419*	0.732*	0.802*	0.552*	1	
Buildings	0.470*	0.563*	0.622*	0.262*	0.692*	1
Forest cover	-0.254	-0.216	-0.279	-0.411*	-0.416*	-0.297*

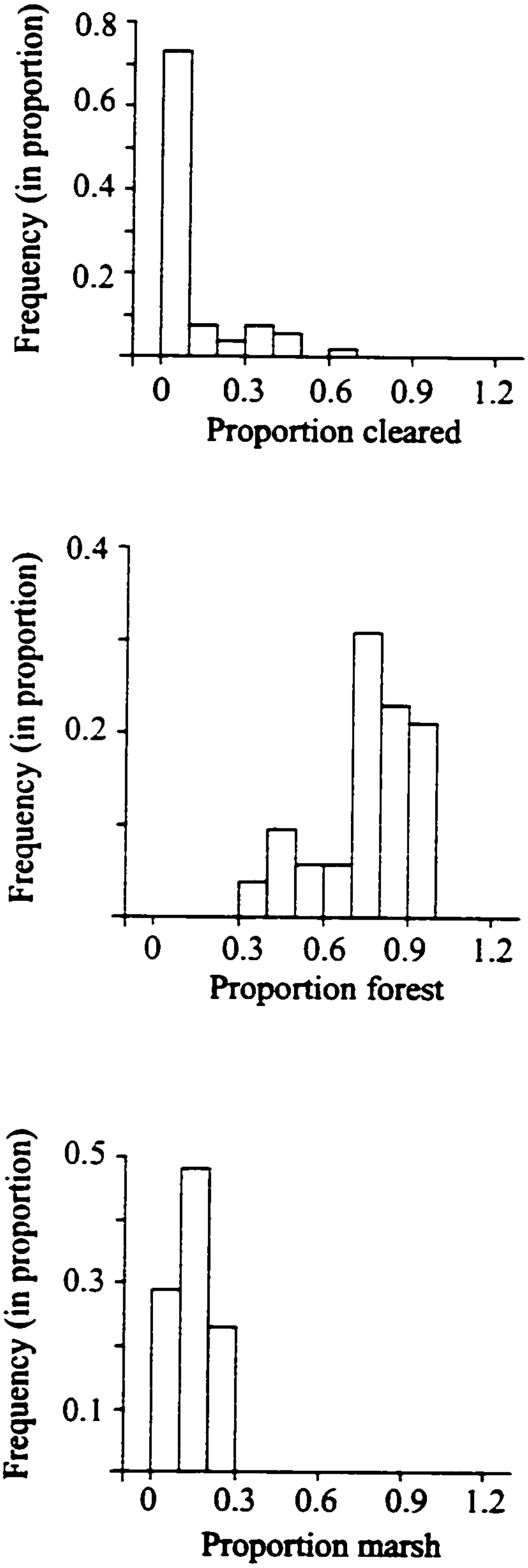

Figure 1.2: Histograms of the forest and marsh cover for the Frontenac Axis (Universal Transverse Mercator TE, UE, VE).

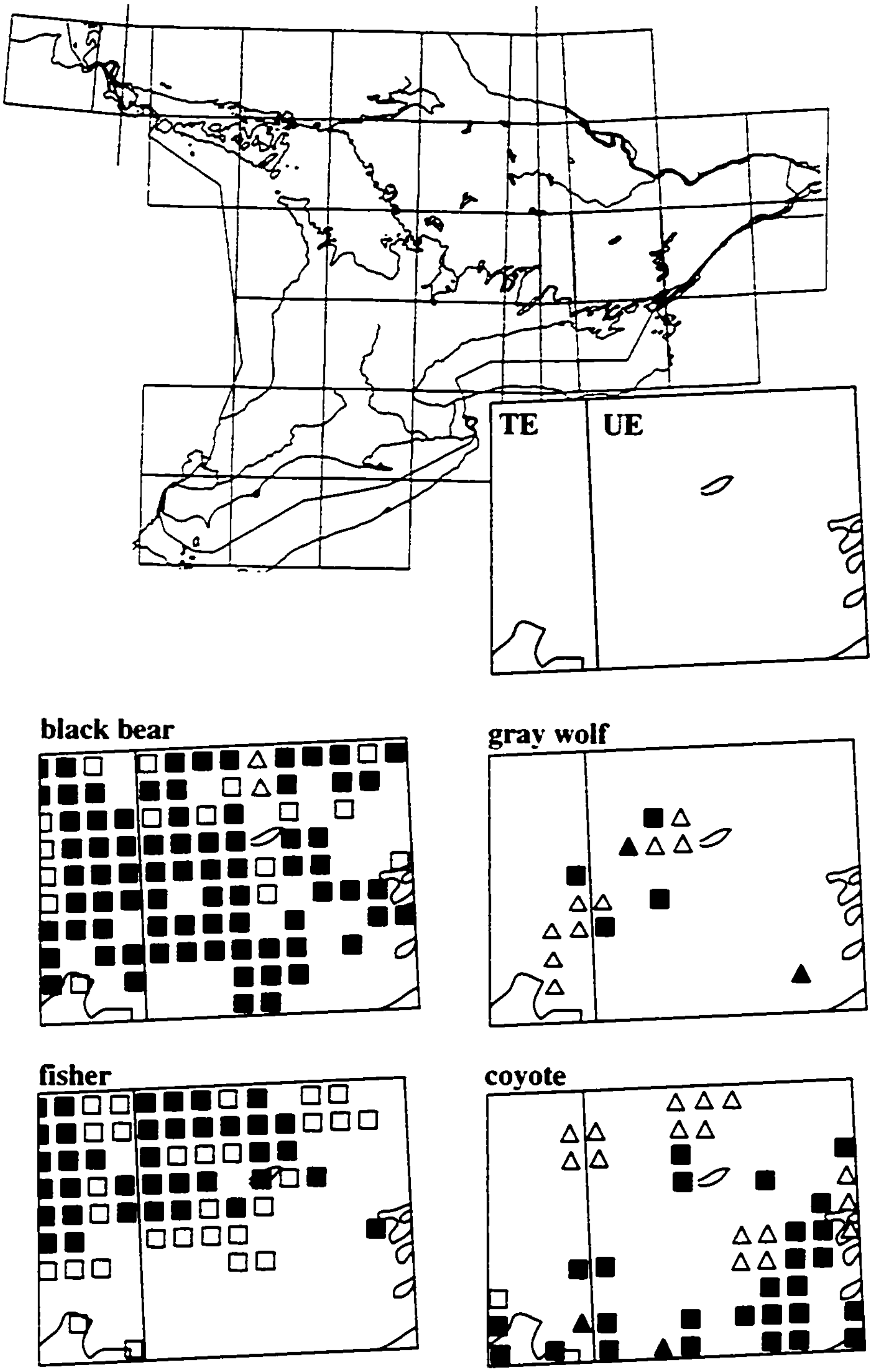

Figure 1.3: Distribution maps for 4 carnivore species in Universal Transverse Mercator blocks UE and TE (data from Dobbyn, 1994). Triangles denote records from 1900-1969, squares denote records from 1970-1993, and open symbols indicate that a record can not be assigned to a single square. All data points were used in the statistical analysis.

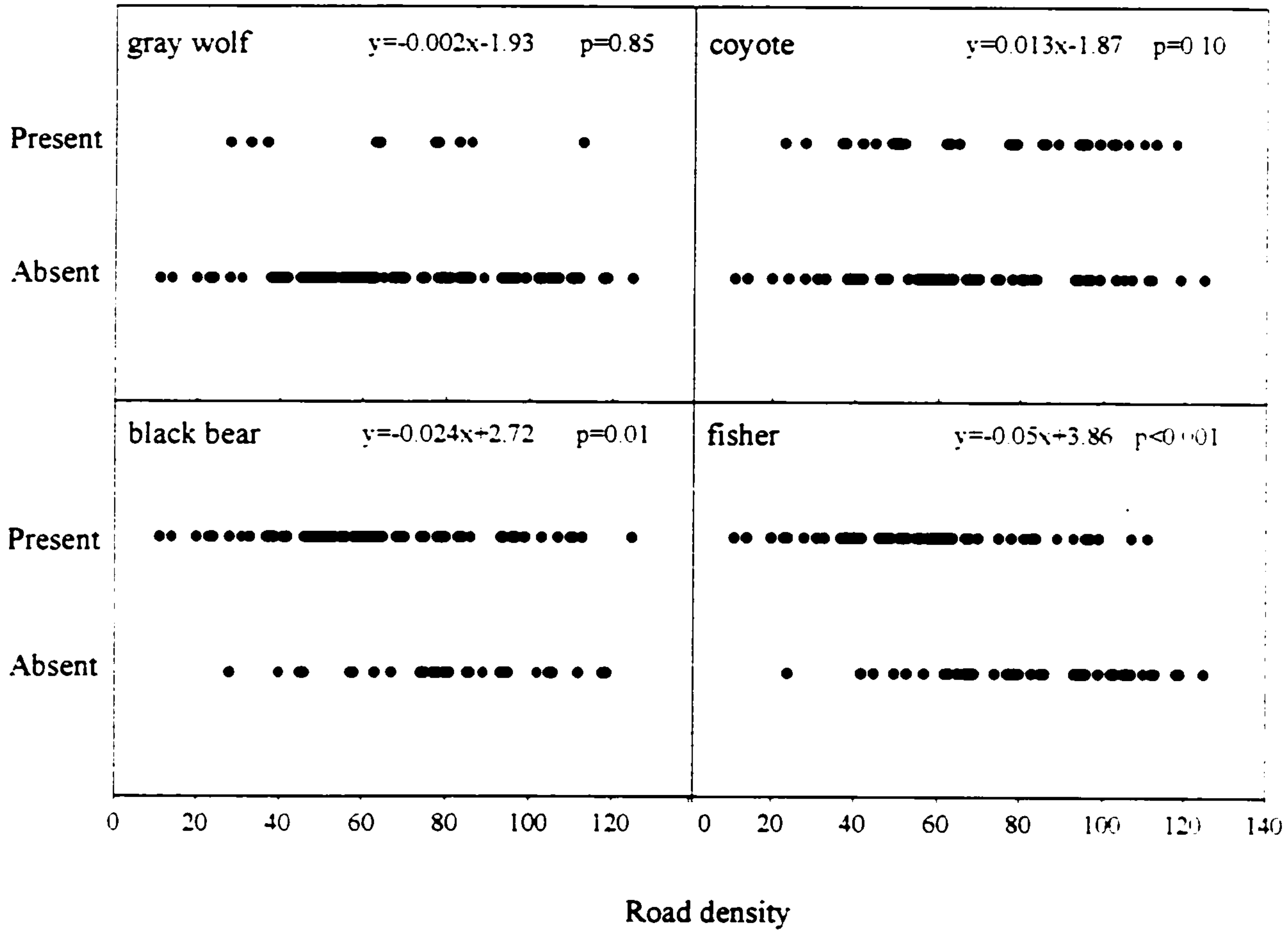

Figure 1.4: The presence of four large carnivore species as a function of road density (100 km^2). Using logistic regression analysis, the line that joins the road density logit-weighted means for presence/absence categories was defined (n=107). Black bear and fisher occurred more often in areas of lower road density. The occurrence of grey wolf and coyote did not seem to be related to road density.

Large carnivores

The distributions of the four large carnivores considered in this study are shown in Figure 1.3. Black bear and fisher were recorded more often in areas of low road density, while gray wolf and coyote distribution did not change with road stress (Figure 1.4). To circumvent the possible problem of observers not recording wolves in highly stressed areas because the effort to record them is low (one might not look for them where they are not likely to be), I considered UTM squares with coyote present and wolf absent. These areas were stressed enough for wolves to avoid, but studied enough that people have recorded coyote there. A logistic regression showed that UTM squares with coyote and without wolf had lower forest cover ($p=0.029$). Black bear was the only large carnivore that occurred mostly in areas of high forest cover.

Birds

The regressions between the number of bird species in each functional group and the stressor variables, roads, buildings, and human population, did not reveal negative trends (Table 1.3). Seven to 18 per cent of the variation in species richness of all avian functional groups was significantly ($p<0.05$) explained by observer effort (square-root of number of observer hours) (Figure 1.5). As observer effort increased, the number of species increased. There was no significant relationship between the number of bird species in each functional group and the amount of forest cover. Observer effort was positively correlated with stress variables (Table 1.5), which indicates that records were made in areas that were easily accessible and more highly stressed. Because observer effort significantly explains some of the variation in species richness and is also

Table 1.2: Results for linear regressions between the number of bird species in functional groups and four anthropogenic factors without observer effort accounted for (r^2=0, n=106 for all regressions). FI = forest interior.

Functional group	Road density		Building density		Human population		Forest cover	
	coeff.	p	coeff.	p	coeff.	p	coeff.	p
FI ground-nesters	-0.009	0.27	0	0.89	0	0.49	-3.947	0.20
FI snag-nesters	-0.009	0.31	-0.001	0.56	0	0.31	-0.137	0.96
Carnivores	0.012	0.06	0.002	0.03	0	0.94	-3.101	0.27
Migrants	0.041	0.14	0.006	0.03	0	0.54	-13.22	0.24
Total FI	-0.033	0.38	0.001	0.76	0	0.41	-5.17	0.71

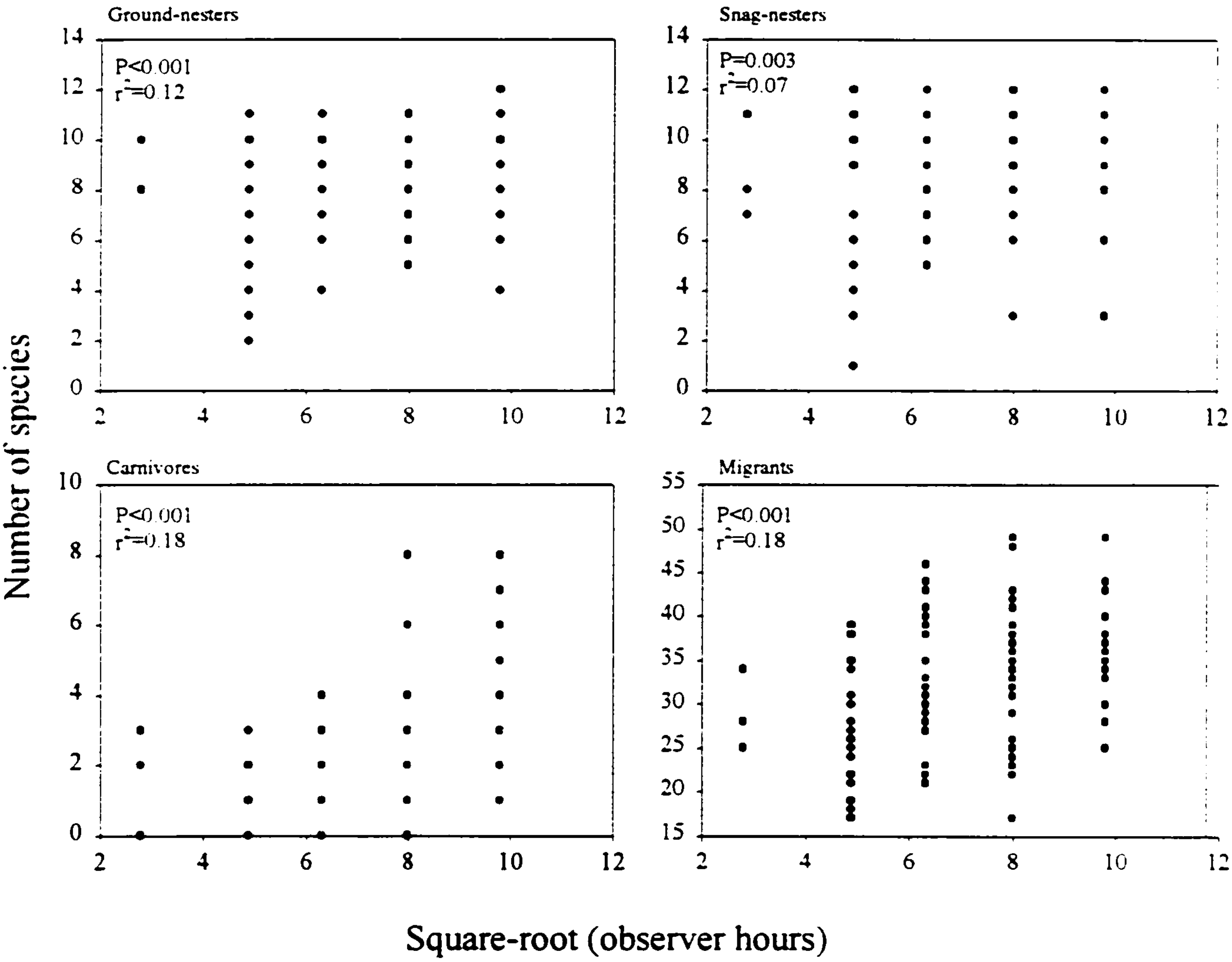

Figure 1.5: Number of bird species increased with number of hours spent collecting records.

Table 1.3: Observer effort and number of quadrats included in statistical analyses of bird and herptile data sets. Observer effort for the bird data set was square root number of hours, and for the herptile data set, the number of collections by different collectors on separate days (episodes). There is a greater proportion of quadrats included in the data sets in forested areas than the proportion of forested quadrats for both measures of observer effort.

	Forest cover		Proportion of quadrats >50% forested
	>50%	<50%	
Bird data set	697	18	0.975
Herptile data set	331	14	0.959
Quadrats in study area	45	6	0.882

Table 1.4: Correlations between stress variables and observer effort for the bird data set (observer effort is hours spent per quadrat) and herptiles data set (observer effort is records per quadrat and episodes per quadrat). All stress variables (except human population) are positively correlated with observer effort. * denotes significance ($p<0.05$).

	Bird (hours)	Herptile (records)	Herptile (episodes)
Road density	0.29*	0.27*	0.26*
Human population	0.16	0.02	0.02
Building density	0.23*	0.30*	0.27*

positively correlated with stress variables, removing the effect of observer effort may also remove the effect, if any, of the stress variables.

Herptiles

Linear regressions between species richness and stress showed that as building density increased, so did species richness (Table 1.6). The logarithm of the number of records per block (observer effort) significantly explained 92 per cent of the variation in the square root of herptile species richness, and suggests a strong observer effort effect on species richness (Figure 1.6).

For the purpose of this study, let us further define an episode as a collector or group of collectors making one or more recordings on one day. When the number of episodes replaced the number of records, the relationship of herptile species richness against observer effort resembled a saturating curve; as effort increased, more species were added to the list, until a point at which the rate of adding new species leveled off (Figure 1.7). Because records did not show this pattern, number of episodes may be a better measure of observer effort for this data set than number of records. The number of episodes was significantly positively correlated with the number of roads (r=0.258, p=0.012) and buildings (r= 0.267, p=0.01) which indicates that collectors predominantly recorded species in areas easily accessible and close to towns.

In order to detect a stress-response relationship, observer effort must be removed. A multiple regression with roads, number of episodes and available forest habitat as independent variables was used to try to explain the variation in herptile species richness (Table 1.7). The number of episodes had a significantly positive coefficient, that is, species richness increased with observer effort. The other variables were not significant. This indicated that observer effort explained most of the variation in herptile species richness, and because observer effort was correlated with stress, attempts to remove observer effort would also remove the effects of stress.

As with birds, sampling of the quadrats was again biased towards forested areas. Of the quadrats in UTM TE and UE, 88.2% had greater than half forest cover, however 95.9 per cent of the records were taken from quadrats with greater than half forest cover (Table 1.4). Therefore, more effort was made to collect records from forested areas than would be expected based on the number of forested quadrats.

Table 1.5: Results for linear regressions between herptile species richness and stress variables without observer effort accounted for. Number of species increases slightly with building density.

Independent variable	coefficient	n	r	p
Road density	0.025	101	0	0.265
Building density	0.009	93	0.11	0.001
Human population	0.01	93	0.02	0.104
Proportion forest	8.792	51	0.04	0.089
Proportion marsh	-4.457	51	0	0.716
Proportion cleared	-9.407	51	0.02	0.141

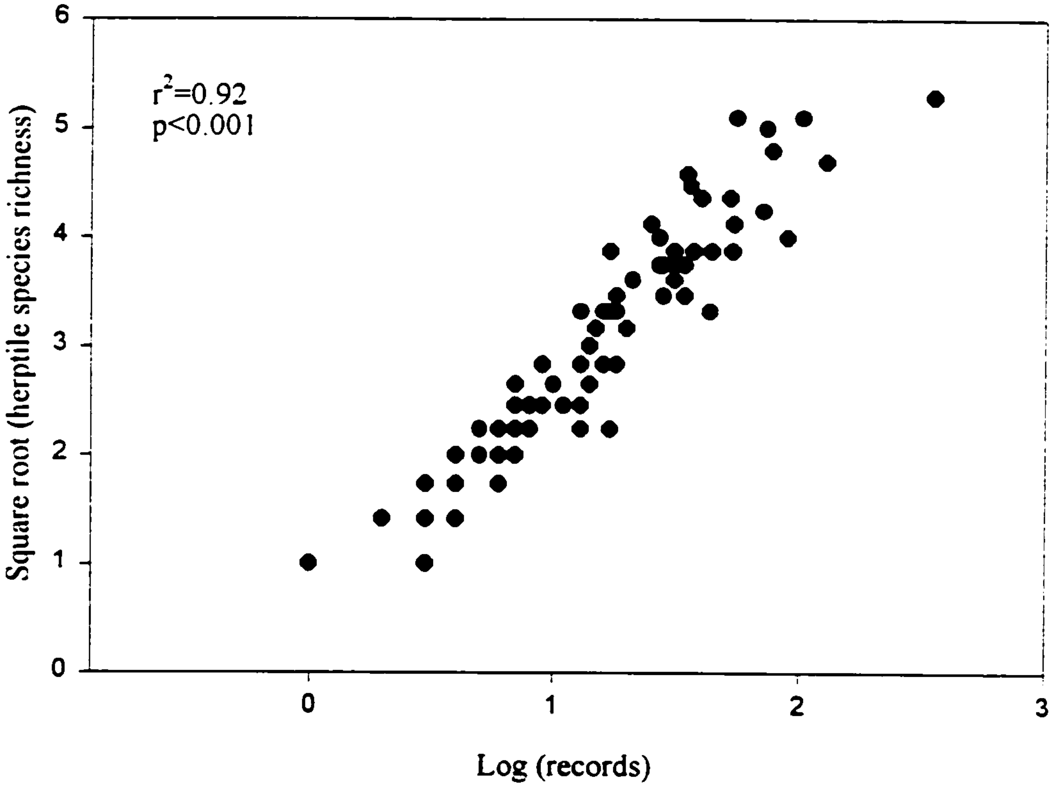

Figure 1.6: The number of herptile species increases with increased observer effort as measured by the logarithum$_{10}$ of the number of records per UTM square.

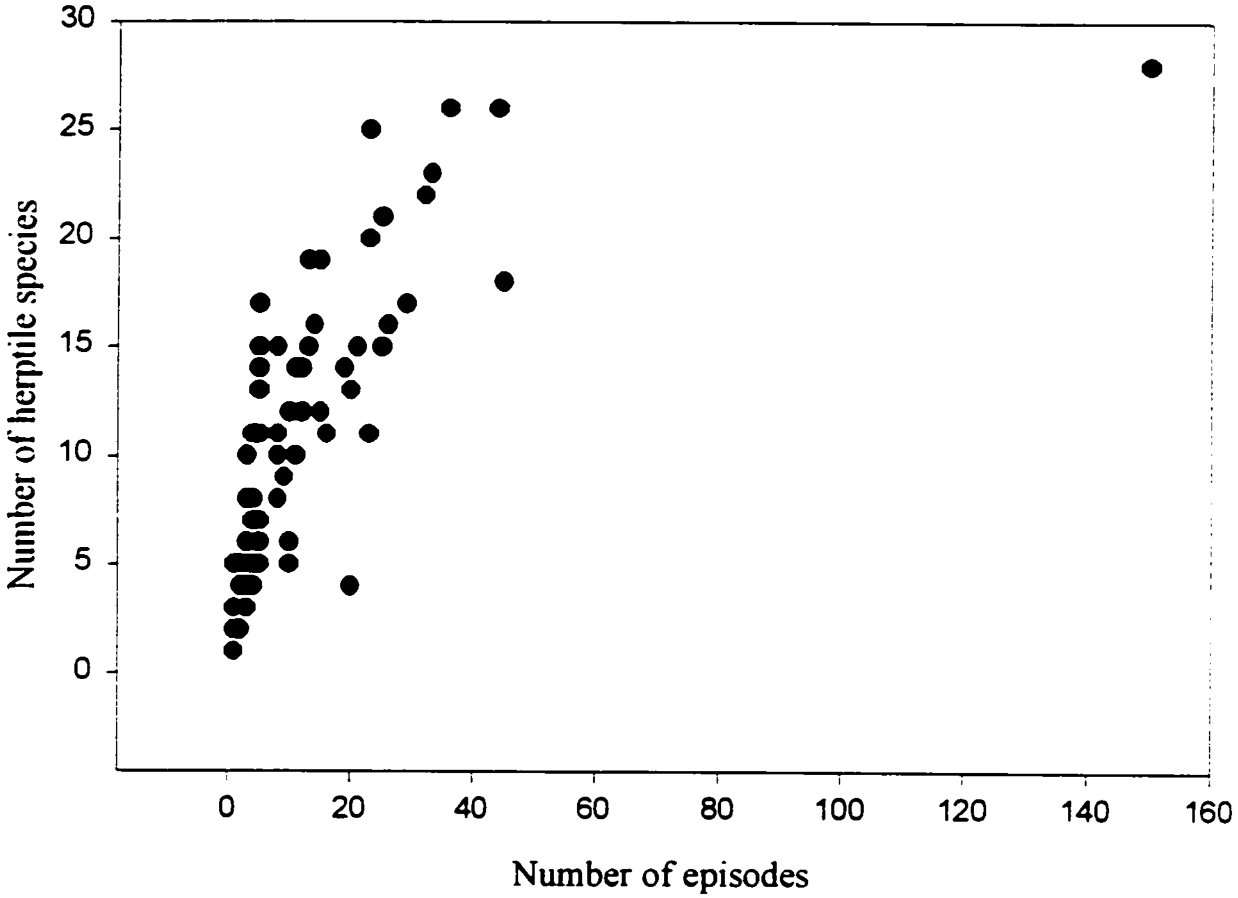

Figure 1.7: The number of herptile species plotted against the number of collection episodes. Number of episodes may be a better measurement of observer effort than the number of records because the number of species found starts to saturate with increasing episodes.

Table 1.6: A multiple regression between the number of herptile species and road density, observer effort and forest cover (n=44). The overall P value was <0.0001 and the adjusted r^2 was 0.65. Observer effort significantly accounted for most of the variation.

	coefficient	t	p
Constant	2.38	0.49	0.63
Episodes	0.56	8.83	<0.01
Road density	0.02	0.80	0.43
Proportion forest	0.14	0.03	0.98

DISCUSSION

The hypothesis of the study in this chapter was that measures of biodiversity at three levels (taxonomic, functional groupings, and individual species) would respond negatively to anthropogenic stress factors (roads, buildings, human population, and habitat loss).

Individual species

Individual species such as black bear and fisher were found to be negatively related to road density. This supports the current thinking that roads are detrimental to wildlife. There are detailed studies ongoing to determine specifically the response of large carnivore population and density to road stress (J. Theberge, Personal communication). Let us consider each species in turn.

Gray wolf: The Atlas of the Mammals of Ontario is not an entirely reliable source of information on wolf presence on the Axis mainly because of wolf/coyote hybridization. The wolf populations of Algonquin Park are the purest genetically even though these have coyote genes, however, the genetic purity of the wolves occurring south of the park is unknown (J. Theberge, Personal communication). Trapping records, which make up part of the Atlas's records, cannot be relied upon to have accurately identified wolves, hybrids, and even coyotes. The records sometimes accidentally confuse wolves with coyotes (coyotes are often referred to as brush wolves), and sometimes intentionally for profit (J. Theberge, Personal communication). Neither gray wolf or coyote distribution was negatively affected by anthropogenic stress or lack of forest cover, but because of the confusion between the two species, this result may not be meaningful.

Black bear: Black bears have large home ranges, inhabit forest, and were sensitive to high road density and forest loss, so they are potentially an indicator species. Areas of land clearing and development become sinks draining individuals from surrounding regions because they are more likely to be shot in clearings or hit by cars (Samson, 1996). On the other hand, species such as the black bear may adjust more easily to changes in landscape by shifting their use of resources within their home range, integrating adverse and beneficial effects, and thus are poor indicators (Landres *et al.*, 1988). Black bears require dense deciduous and mixed forest for shelter, and as this habitat is being replaced by agricultural and residential uses, they are forced to venture into settled areas and will seek garbage dumps, agricultural fields and campsites for food. Although I found they were sensitive to roads and habitat loss, there is a danger in incorrectly assuming that other species are receiving protection if black bear habitat is intact, and therefore I suggest that black bear does not make the ideal indicator species for the Frontenac Axis.

Fisher: Fisher is a true predator and its presence was negatively affected by high road density. Unlike black bear, fisher does not seem to switch habitat type when land use changes cause an abundance of food. For example, Arthur *et al.* (1989) found that fishers did not switch to deciduous from coniferous stands when apples were abundant in second growth mixed forest around abandoned farms. For this reason, fisher may be a better choice of an indicator species than black bear. Fishers did not respond to a loss of forest cover and that may be because they can tolerate a high degree of fragmentation. For example in Maine, fishers tolerated low intensity housing, roads, and trapping because forest diversity was maintained through farmland reverting back to forest (Arthur *et al.*, 1989). Fishers have recovered from a recent population decline due to over-exploitation and I suggest that they are a promising indicator species for the Frontenac Axis because their presence is negatively correlated with road density.

Taxonomic and functional groups

My results did not support the hypothesis that herptiles and bird functional groups would respond to stress for two possible reasons: 1) I did not detect an effect due to low statistical and experimental power, time scale or lags, and/or poor data quality, or 2) there was no effect.

Experimental and statistical power: This project was intentionally carried out on a regional scale because although there is evidence that anthropogenic stress elicits a response on a global scale, little research has been done at a regional level. By choosing a narrow range in stress, as found on the Frontenac Axis, (maximum road density is 99 km/100km^2) I may have limited my ability to detect a significant response due to low experimental power. As the range of stress is reduced, the range of responses may narrow (Figure 1.8). As range on the x-axis declines, the standard error of the regression coefficient increases, so for a fixed n, an increasingly large slope is required to achieve significance. For example, there is a large difference in stress between a heavily

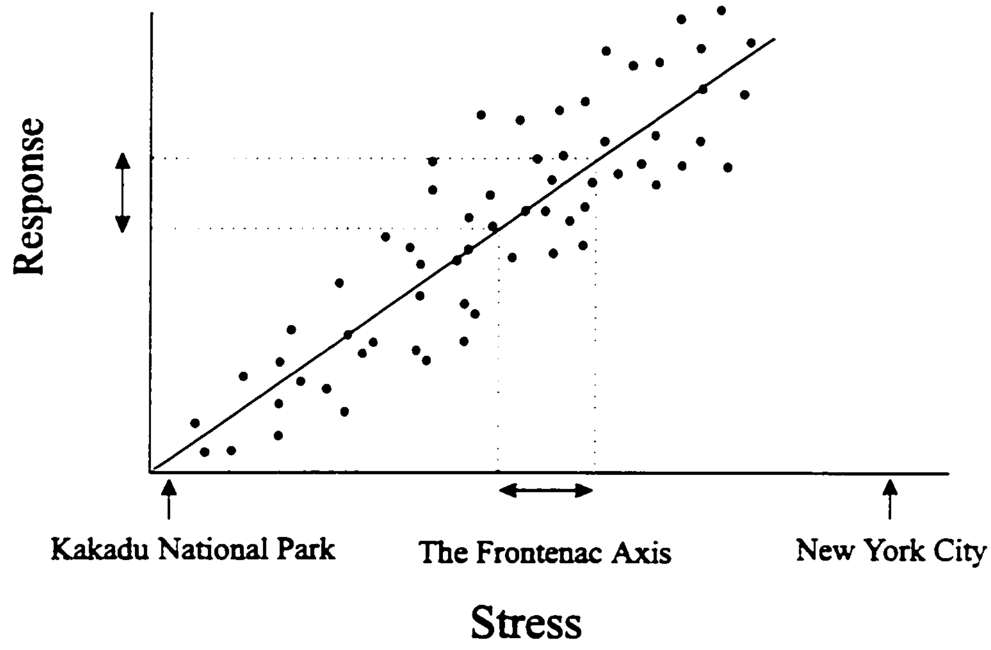

Figure 1.8: Stress-response relationship and the issue of scale. As the spatial scale is reduces, the range of stress and response narrows, thereby reducing the likelihood of detecting a significant relationship between the two.

populated capital city, such as New York, and Kakadu National Park, a pristine world heritage site. It is not hard to imagine, therefore, that there would also be a significant difference in the ecosystem functions of these two places. On a regional scale, by comparing the Madawaska Highlands to a settled portion of southern Ontario, the stress gradient is less pronounced, and thus, the response may be less pronounced. A future study might increase the range of potential stress to include more highly stressed areas and large pristine areas, keeping in mind the regional scale goal, to determine if the range of response also increases.

Statistical power ($1-\beta$) is the probability of rejecting the null hypothesis when it is false and ideally it should be high (>0.9). For the linear regressions between herptiles and anthropogenic stress (Table 1.6) the sample sizes were 101, 93 and 51. Low sample sizes yield low power and therefore we can't be certain that we have accepted a true null hypothesis (that the slope of the regression between herptile richness and stress is zero). By increasing the sample size, power improves (while α remains constant).

Thresholds and time lags: There are two possible explanations for non-significant stress-response relationships, and they have very different interpretations and implications for management: (1) there may be a threshold of stress below which a response will not be elicited: (2) it is also possible that a response will occur but not be detected. These two scenarios are inseparable with the data available, so both must be considered. In the first case, it is possible that there is a tolerable amount of anthropogenic stress and that the stress levels are low enough that the number of species is not affected (Figure 1). Alternatively, the stress may have caused a response (i.e. some species have disappeared from some squares), but the response could not be detected below a certain level due to the coarseness of the data. All the while it remains undetected, effects may be accumulating. The location and steepness of the threshold depends on population parameters and habitat availability, and therefore it is impossible to determine the exact location of the threshold. Knowledge of these thresholds is valuable, because finding no response to anthropogenic stress could be interpreted in two ways: either the ecosystem was not being affected by the stress, or the response could not be detected. Neither interpretation can be validated, however, until more accurate data are available on species presence or absence.

Changes in species richness or populations may not be detected until after critical levels of habitat degradation even when monitoring data are excellent (Lamberson *et al.*, 1992; Doak, 1995; Means *et al.*, 1996; Findlay and Bourdages, *in review*). In less than 200 years, the human residents of southern Ontario have transformed a predominantly forested landscape into one dominated by agriculture, industry and settlement. In the past 30 years, agriculture and farming have been steadily declining and these areas are either being developed or left to regenerate naturally (Riley and Mohr, 1994). As development increases, the network of roads becomes more dense. If time lags occur, it is possible that some effects of present day development will not be detected for another 20 years (Findlay and Bourdages, *in review*).

Data quality: The quality and completeness of the species richness data are crucial for making assertions about stress-response relationships. The data sets used were collected on a volunteer basis and were most likely not complete. Observer effort accounted for some if not most of the variation in species richness for the two data sets for which observer effort was estimated. The remaining variation could not be explained by any other variable because there was more error (uncertainty due to inaccuracy of data) associated with individual data points than there was variation among the data points. Observer effort was highly correlated with stress measures (roads, buildings, population), and therefore any attempt to remove the effects of effort would also remove the effects of stress. A negative relationship between number of species and stressors would be more likely detected if observer effort was not variable. To reduce the variability, collection of atlas data by volunteers must be standardized and data collection programs well-designed *a priori* so that blocks that are not easily accessible are as intensively sampled as those that are accessible, or that this is controlled for. Volunteer data collection programs are an important community educational tool, and at the same time, valuable information is collected and compiled, however, these atlases would be more useful to researchers and for biological indicator programs if the data were accurate, complete, and standardized.

Species richness as an indicator: The indicators of biodiversity chosen for this study represented three different levels of taxonomic organization -- a complete taxonomic group, functional groups, and individual species. The most informative approach was that of individual indicator species, large carnivorous mammals. The herptile taxonomic group and avian functional groups may have been too broad, that is, the species within a group were not redundant enough in their functional roles to respond to stress as a cohesive unit, and the variability in response obscured the relationships. If taxonomic groupings are of interest, a more enlightening measure may be something similar to the Floristic Quality Assessment System (Wilhelm and Ladd, 1988; Oldham *et* *al.*, 1995). In this system, each native plant species is assigned a numerical value according to its degree of fidelity to a specific habitat and is termed the 'coefficient of conservatism'. The natural quality of an area is reflected by its richness of conservative species, and it is reasonable to expect that a decrease in quality due to anthropogenic stress will be reflected in this measure.

The number of species alone may not reveal changes to an ecosystem over time in response to stress because composition changes while numbers remain the same. For example, after the Exxon Valdez oil spill off the coast of Alaska, bird diversity was not affected one year after the spill, but species that feed on or close to shore and either breed on the beach or are winter or full-year residents did not show clear evidence of recovery (Wiens *et al.*, 1996). In a limnological study by Schindler (1987), phytoplankton species richness did not respond to signs of early anthropogenic stress, however, the pre-perturbation species list was very different from the post-perturbation list -- chrysophyceans and diatoms were replaced by chlorophyceans and cyanophyceans in acidified and eutrophied lakes. In a study of avian diversity along an urban stress gradient, the composition shifted from predominantly native species to invasive and exotic species, yet total species richness peaked at moderately disturbed sites (Blair, 1996). Ranges of species may shrink or expand over time and may indicate response to land-use changes (Saunders, 1993), and individual species may go extinct or be introduced, but the number of species may be constant. Thus, comparing species lists in space and time may be a more useful and sensitive indicator of ecosystem response.

CONCLUSIONS AND RECOMMENDATIONS

The number of herptile and bird species did not respond negatively to road density or to forest clearing. This was probably because the data sets used were not complete, the power of the regressions was low, the range of stress narrow, and therefore, no conclusions can be made about the actual presence of a stress-response relationship. Perhaps, then species richness within taxonomic or functional groups may not be an appropriate indicator for the Canadian Council of Forest Minister's criterion 'maintenance of biodiversity'.

The usefulness of present atlas data may be limited. Collection methods must be consistent and standardized to ensure that observer effort does not explain the most of the variation and obscure the stress-response relationship. Until the atlases are complete, using individual key species may be a better approach than using the number of species in taxonomic groups. A better approach may be to examine changes in the distributions of key species, such as large carnivores. In southern Ontario, the fisher is a potential indicator of ecosystem change because it is associated with forests and was not found in areas of high anthropogenic stress. Black bear is not a good indicator species because it can adapt to human land use. This knowledge may be useful for other regional studies that rely on published species data.

CHAPTER TWO: DIVERSITY OF FERNS AND ITS RELATIONSHIP TO COARSE WOODY DEBRIS

INTRODUCTION

The first chapter focused on stress-response relationships between indicators of biodiversity and anthropogenic stressors. Biodiversity indicators have been developed for many taxonomic groups, however, understory plants have been rarely used. We have a fairly good understanding of how forestry related stress directly affects coarse woody debris (CWD) (Bormann and Likens, 1979; Lambert *et al.*, 1980; Tritton, 1980; Lang, 1985; Spies *et al.*, 1988; Harmon and Hua, 1991; McCarthy and Bailey, 1994). It is thought that CWD provides habitat for ferns (Harmon *et al.*, 1986) and this chapter examines that relationship. If ferns truly are dependent on CWD, then general conclusions can be drawn about the effect that forestry has on CWD's ability to provide habitat and therefore, maintain biodiversity.

CWD is the term applied to decaying fallen logs and stumps on the forest floor, standing dead trees (Harmon *et al.*, 1986). It is an important component of the forest ecosystem and contributes to processes such as carbon and nutrient cycling and provides habitat for many types of organisms.

The three most common, measurable properties to quantify and describe CWD are amount, size and decay class. Let us consider them in turn:

(1) **Amount**: Coarse woody debris is added to a system through tree death (caused by fire, wind-throw, disease and insect infestations) by breaking branches, and by physical transportation from adjacent ecosystems (Harmon *et al.*, 1986). Aside from being involved in forest processes and providing habitat, large quantities of CWD give ecosystems greater ability to resist disturbance because it provides a longer lived and

more stable humus (Kimmins, 1997). The amount of CWD found on the forest floor is the result of the balance between input and removal. Low levels are caused by a) wood decay, b) harvesting mature trees before they can die naturally, and c) preventing disease, insect infestation, and fire from killing trees.

(2) **Size**: Larger logs (>7.7 cm in diameter) have the greatest probability of persisting on the forest floor before they decay or are consumed by fire. Large pieces are more useful to wildlife because they have more heartwood so can hold moisture for longer periods and do not decay as quickly (Maser *et al.*, 1979; Kimmins, 1997). There is a positive relationship between the amount of organic matter on the forest floor and ectomycorrhizae (Graham *et al.*, 1994).

(3) **Decay class**: Rates of decomposition of CWD influence CO_2 production and interact with the global carbon cycle (Marra and Edmonds, 1994). When a tree falls to the forest floor, the sapwood is invaded by wood-boring insects, the phloem is channeled by phloem-boring bark beetles, and other invertebrates invade the galleries left behind, creating a decomposer community of increasing complexity (Marra and Edmonds, 1994). Mammals looking for the invertebrates under bark and in wood will burrow through a soft log, which then allows access by herptiles. The fragmentation increases the surface area and encourages transport of fungal decomposers. Five groups of micro-organisms colonize and decay wood: basidomycetes, ascomycetes, fungi imperfecti, phycomycetes and bacteria. The respiration rate increases as the complexity of microorganisms invading a log increase (Marra and Edmonds, 1994). Establishment and subsequent spread of fungal infection are controlled by factors such as temperature, moisture, aeration, and absence of inhibiting substances (Kaarik,

1974). Respiration rates are highest in freshly fallen logs and logs in the latest stages of decay (Marra and Edmonds, 1994).

It takes 60 to 500 years for a log to reach late stages of decay (Harmon *et al.*, 1986), however, decay is much slower when there is no contact with the soil (e.g. a standing dead tree) (Kaarik, 1974). The amount of decay is related to stand age simply because it takes time for wood to decay. Spies *et al.* (1988) found that CWD in the later stages of decay occurs more frequently in mature (65 to 90 years) forests while the debris of young forests will be in the early stages of decay.

Coarse woody debris as habitat for ferns

Ferns are common on old, decaying logs (W. Wagner and P. Keddy, Personal communication), but there have been no studies to determine whether ferns require a certain size or amount of CWD. Nutrient-rich rotting logs could be suitable habitat for ferns because they provide elevation above litter and moisture throughout the summer. Disruption to fern communities may be detrimental to forest processes because some species of ferns are mycorrhizal and may represent important nutrient sinks.

Two fern species, *Dryopteris carthusiana* (Vill.) H.P. Fuchs and *D. intermedia* (Muhl.) A. Gray, similar in form and habitat preference, are commonly known as 'woodferns' and were examined separately because they appear to grow on CWD more often than other species (P. Keddy, Personal communication). For this chapter, I collected data on true ferns and related them to levels of CWD. I predicted that fern diversity and abundance would be greater in stands with a large amount of CWD and with CWD in late stages of decay.

Bedrock, CWD and ferns

Soil is formed partly by the weathering of the underlying bedrock and therefore the bedrock influences soil properties. Bedrock has been found to determine the presence or absence of a few species of trees and shrubs (Braun, 1950). Marble is a metamorphic carbonate-based rock which has the ability to buffer soil water and causes the overlying soil to be alkaline (D. Fortin, Personal communication). Most soil fungi prefer slightly acidic soil and most bacteria prefer neutral soil (Killham, 1994), therefore the rate of wood decomposition may be affected by soil pH. I postulated that CWD would last longer in an undecayed state, contributing longer to the CWD found on the forest floor in an area with marble bedrock. It follows then, that alkaline soil may affect plant composition, particularly that of ferns which may rely on CWD. A number of herbaceous species might be considered indicators of calcareous or noncalcareous rock (Braun, 1950). Presence of marble bedrock was noted and I predicted that CWD characteristics and fern species richness would be different in areas with marble bedrock than in areas without.

DATA COLLECTION

Between May and August 1996, field data on quantity and quality of CWD were collected along the Frontenac Axis, south-eastern Ontario. Sampling was done only in mesic hardwood forest, but otherwise, there were no controls for site conditions, stand age, or stand history.

To determine the best length of transect to use, two forests with different land use histories were sampled using 5 replicates of 25, 50, and 100 m long transects. Amount, size and decay class of the CWD were measured (Figure 2.1). I concluded from these preliminary results that 50 m transects were most suitable because there was enough information to give a difference in the amount (total and large size) and decay class. For the extra work involved in 100 m transects, there was no difference detected in the stage of decay.

Within each 9 km^2 square, I used five straight line transects 50 m in length. Twenty seven squares were chosen based upon forest type. The beginning of each transect was a random distance greater than 50 m from the road into the forest. A plastic disk marked with an arrow was spun to determine a random direction for the transect. I positioned the five transects as far away from each other as possible within each 3 x 3 km block.

The number of pieces, size and decay class of CWD was recorded along each transect. Debris was included only if the transect line crossed the piece of CWD, and if fallen logs and stumps were greater than 10 cm in diameter. Aerial CWD (not directly touching the ground) and stumps were also included. A hard plastic template with a 10 cm cut and a 20 cm cut was used to quickly classify the CWD into two size categories. The stage of decay of each piece was ranked on a scale of 1 to 4: value 1 being freshly fallen, bark intact; value 2 having no bark; value 3 being crumbling on the outer surfaces, but the core remaining hard; and value 4 being crumbly to the core. Decay median was calculated by assigning each piece of CWD the value of its decay class (1 to 4). All field data are provided in Appendix 7.

For one half of a meter on either side of the transect line, every fern species encountered was recorded. Abundance for each species was estimated using a scale of 0 to 5; ranging from value 0 being not present to value 5 being very abundant. In addition, two wood ferns, *Dryopteris carthusiana* (Vill.) H.P. Fuchs and *D. intermedia* (Muhl.) A. Gray, were tallied separately.

Geological survey maps were used to determine if transects in each block lay on marble bedrock. These transects were ground-truthed when possible, but it was difficult to determine the nature of the bedrock unless the rock was exposed.

Statistical analyses on ferns and the CWD measures were done using Systat 5.0 software (Systat, 1990-1992). t-tests were used to determine if CWD varied with bedrock type.

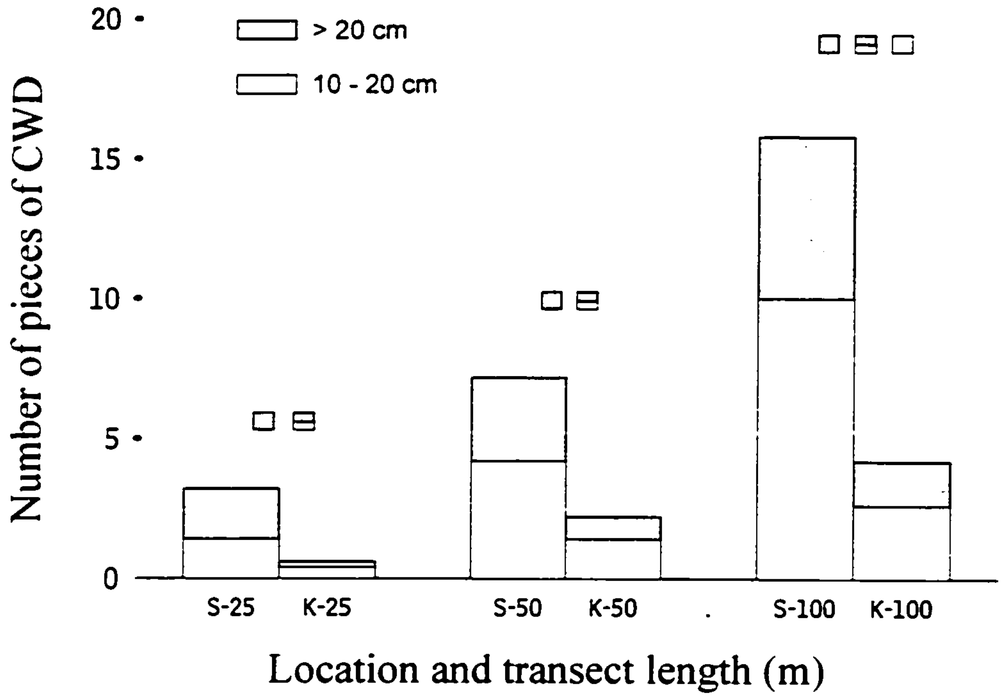

Figure 2.1: The amount of coarse woody debris in each size class (averaged over 5 transects) in ShawWoods (S), a 150 year old undisturbed preserve, and Keddy Woods (K), which is recovering from cutting and grazing, at three transect lengths (25, 50, 100m). Appearance of small boxes above bars indicates which of the three classes (small, large, total) of CWD are significantly different within pairs.

Table 2.1: Spearman Rank correlation for abundance of ferns and amount of CWD. N=27, r_s=0.329. No correlations are significant.

	Number of fern species	Fern abundance	*Dryopteris intermedia* abundance	*Dryopteris carthusiana* abundance
CWD (10-20 cm)	-0.165	0.166	-0.036	0.288
CWD (>20 cm)	0.004	0.148	0.293	0.010
Total CWD	-0.184	0.110	-0.042	0.217
Decay median	-0.207	-0.207	-0.058	-0.142

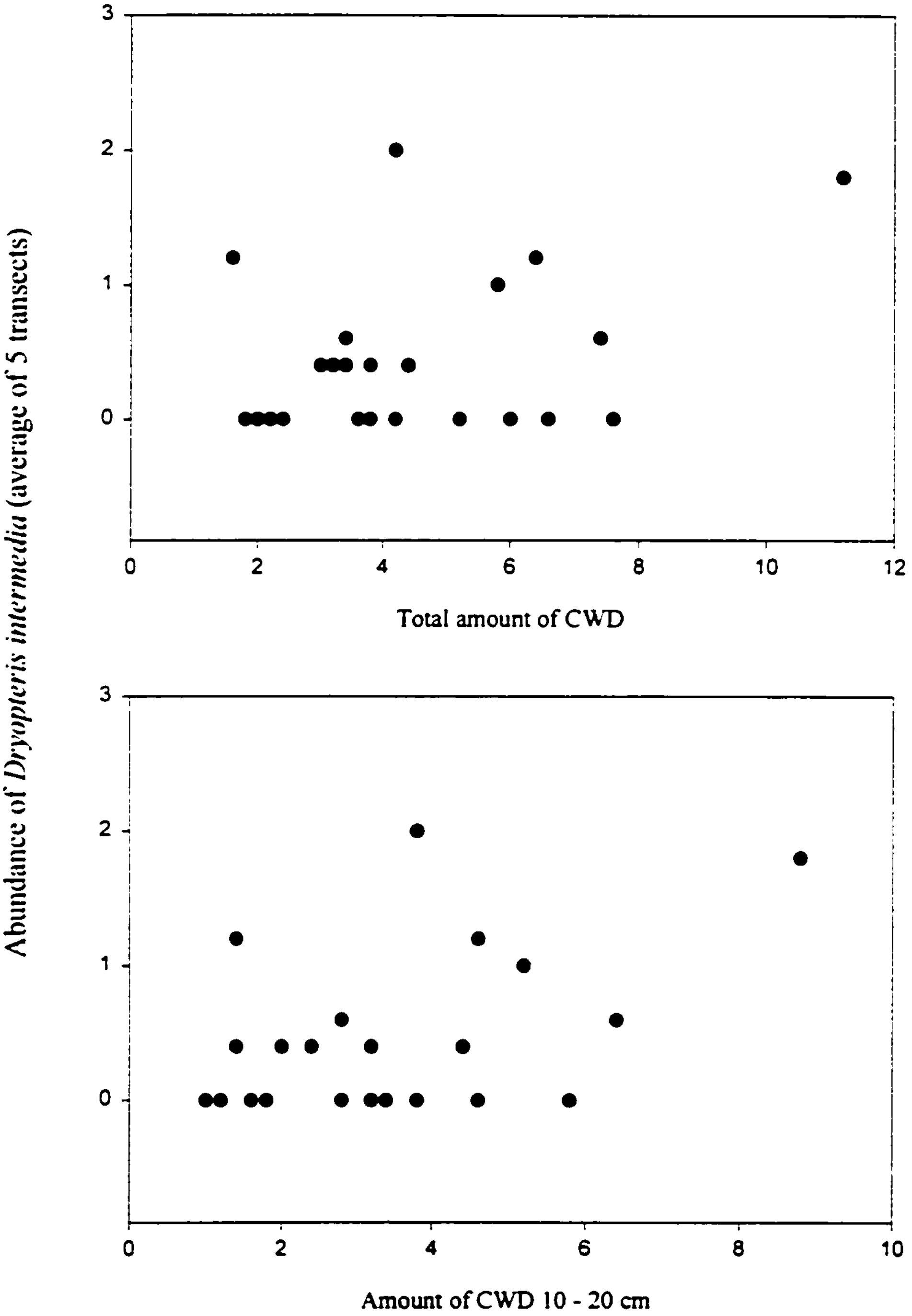

Figure 2.2: Abundance of *Dryopteris intermedia* Muhl. averaged over 5 transects plotted against amount of CWD. N=23, 22.

Table 2.2: t-tests for coarse woody debris and fern richness between transects with marble bedrock and those without. Amount of CWD in both size classes was significantly different between marble and non-marble sites.

Dependent variable	Marble (n=30)		Non-marble (n=105)		p
	Mean	SD	Mean	SD	
Total CWD	6.4	5.2	3.7	3.0	<0.001
>20 CWD	1.6	1.9	0.7	1.1	0.004
>10 CWD	4.8	3.9	2.9	2.5	0.002
Median decay	2.3	1.0	2.5	1.3	0.243
Fern richness	2.0	2.0	2.0	1.5	0.889

RESULTS

Twenty-three species of true ferns were encountered on the Frontenac Axis (Appendix 8). Species richness and abundance were not correlated with the amount or decay stage of CWD (Table 2.1). The abundance of *Dryopteris carthusiana* (Vill.) H.P. Fuchs and *D. intermedia* (Muhl.) A. Gray were examined separately. The plot of abundance of *D. intermedia* shows a trend that abundance increases with increasing amounts of CWD (Figure 2.2), but this could not be statistically analysed with regression. Overall, the number of pieces of CWD ranged from 1-8 per transect, with a median of 3. Total amount of CWD and amount of CWD in each size class were significantly higher in transects that had marble bedrock, although the average state of decay of the CWD was not affected by bedrock (Table 2.2). The number of fern species was not significantly different on marble and non-marble sites (Table 2.2). The walking fern (*Camptosorus rhizophyllus* (L.) Link) is a species thought to be associated with marble, and the only patch of it that I observed was in an area with marble bedrock, however, no obvious differences in fern composition appeared in the transect data.

DISCUSSION

The primary hypothesis of this chapter was that fern richness and abundance were related to CWD. The results of this study did not support this hypothesis. Ferns may not rely on CWD for habitat and therefore may not be good indicators for the contribution of CWD to understory biodiversity. However, the absence of a relationship between ferns and quantity or quality of CWD may be the result of 1) forest characteristics in the study area, and 2) the collection methods of the fern species richness data.

1) Nurse logs provide both elevation and water for tree seedlings to establish. In west-coast forests, nurse logs are strikingly abundant, and play a seemingly more significant role in the forest ecosystem than in Ontario forests. One explanation for this may be that Ontario forests are less productive than west coast forests (up to 1500 m^3/ha in British Columbia vs. 600 m^3/ha in Ontario, D. Burgess, Personal communication). Less initial biomass combined with the fact that Ontario forests are younger and have been harvested more results in less potential CWD. There may also be a soil nutrient difference. In nutrient poor soil, CWD will be nutrient poor and seedlings will grow slowly (Kimmins, 1997). There may be a threshold concentration of nutrients required for gametophyte establishment which may not be reached in all pieces of CWD in Ontario forests. Alternatively, the difference may be related to the amount of moisture in the CWD. The west coast gets more precipitation than Ontario (1167 mm/ann. in Vancouver, 911 mm/ann. in Ontario) and the CWD may be saturated which allows seedlings and ferns to establish with a higher success rate. Different weather conditions also affect wood decomposition rates.

2) I decided to use 50 m transects based on the amount of information on CWD, but five transects 50 m in length may not cover enough area to accurately sample a forest stand for ferns. A longer transect (100 m) may give a more accurate representation of both the CWD and the fern species present. A longer transect would encompass subtle habitat changes, such as slope, moisture, and light gradients. These habitat variables likely affect fern species composition. It is not possible to completely control habitat

variables, but by including them in every sample, thereby reducing the variation in species richness due to habitat, the likelihood of detecting a correlation between CWD and fern species richness may increase. Increasing the sample size with more repetitions would have increased the statistical power of the analysis.

The question of how CWD contributes to biodiversity could be investigated with many other species. This study could be repeated for fern allies, byrophytes and mosses, because they are also often found growing on CWD. Another interesting study would be to quantify amphibian dependence on CWD. It is a relatively well-known fact that amphibians require moist, rotting logs as habitat, but the size and amount required have not been studied in detail.

Given the importance of CWD to ecosystem processes attempts should be made to determine the optimum level of CWD on the forest floor in deciduous forests. In order to recommend a healthy level of CWD for a region, we must understand how abiotic (climate and site conditions) and historical factors (age, management and fire history) affect CWD in forests. Management should strive to retain critical types and ranges of natural variation in resource systems in order to maintain their resiliency (Holling and Meffe, 1996). It takes time and long term planning to ensure a range of amount, decay stage and size of CWD.

More CWD occurred in sites that contained marble in the bedrock. There are two possible explanations for this -- abiotic and historical. Alkaline soil may decrease decomposition rates of wood which allows more CWD present at any given time. Second, historical land-use may be affected by soil pH. Low pH reduces phosphorus and manganese availability, and restricts mycorrhizal development (Killham, 1994) which may have decreased agricultural and grazing quality enough to reduce human impacts upon these forests.

GENERAL CONCLUSIONS

I examined the relationship between road density and other stressors and several biodiversity indicators: number of species in a taxon (herptiles); number of species in avian functional groups (ground- and snag-nesters, migrants, and carnivores); and the distribution of individual large carnivore mammal species (gray wolf, black bear, and fisher). The only significant responses were that of fisher and black bear to road density and forest area. For the other indicators, either there was no effect, or else I did not detect an effect due to low statistical and experimental power, time scale or lags, and/or poor data quality. I provisionally recommend that until accurate and complete species richness data are available, distribution of key species, such as the fisher, should be used as indicators of anthropogenic stress on biodiversity. This has risks: if individual species alone are used as indicators there is a danger of incorrectly assuming that if these indicator species are not responding to stress, then the ecosystem as a whole is not responding. This would lead to policy decisions that are detrimental to ecosystem health. None-the-less, large carnivores do appear to provide the important first step in forest monitoring.

I also recommend that a comprehensive data base on species distributions with low variation in observer effort is needed if species distribution data is to used for monitoring forest ecosystems. Volunteer-collected data are important and should be encouraged, with the understanding that, in order for them to be useful as a monitoring tool, they must be collected in a standardized manner. The goal should be that observer effort doesn't vary between sampling areas so much that it obscures a possible stress-response relationship. This requires *a priori* planning for how the data will be collected.

Coarse woody debris appears to play a limited role in providing suitable fern habitat in this region. I expect the same experiment done on the west coast would reveal a significant relationship between fern species richness and CWD due to differences in climate and soil nutrient levels and the greater importance of nurse logs there. Arthropods, fungi, plants, amphibians and small mammals, may all be negatively affected by the reduction in CWD by forestry. By retaining large snags to support birds and mammals, and providing sustained recruitment of large CWD by allowing some trees to grow large, managers may counter this tendancy and ensure the role of CWD in contributing to biodiversity.

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APPENDICES

Appendix 1: The Montreal Process Criteria and Indicators (Canadian Forest Service, 1997).

Criterion 1: Conservation of biological diversity

Indicators:

1.1 *Ecosystem diversity*

- a. Extent of area by forest type relative to total forest area
- b. Extent of area by forest type by age or successional stage
- c. Extent of area by forest type in protected area categories as defined by IUCN or other classification systems
- d. Extent of area by forest type in protected areas defined by age class or successional stage
- e. Fragmentation of forest types

1.2 *Species diversity*

- a. The number of forest dependent species
- b. The status (threatened, rare, vulnerable, endangered or extinct) of forest dependent species at risk of not maintaining viable breeding populations, as determined by legislation or scientific assessment

1.3 *Genetic diversity*

- a. Number of forest dependent species that occupy a small portion of their former range
- b. Population levels of representative species from diverse habitats monitored across their range

Criterion 2: Maintenance of productive capacity of forest ecosystems

Indicators:

- a. Area of forest land and net area of forest land available for timber production
- b. Total growing stock of both merchantable and non-merchantable tree species on forest land available for timber production
- c. The area and growing stock of plantations of native and exotic species
- d. Annual removal of wood products compared to the volume determined to be sustainable
- e. Annual removal of non-timber forest products (e.g. fur bearers, berries, mushrooms, game), compared to the level determined to be sustainable

Criterion 3: Maintenance of forest ecosystem health and vitality

Indicators:

- a. Area and percent of forest affected by processes or agents beyond the range of historic variation, e.g. by insects, disease, competition from exotic species, fire, storm, land clearance, permanent flooding, salinisation, and domestic animals

b. Area and percent of forest land subjected to levels of specific air pollutants (e.g. sulfates, nitrates, ozone) or UVB that may cause negative impacts on the forest ecosystem
c. Area and percent of forest land with diminished biological processes (e.g. soil nutrient cycling, seed dispersion, pollination) and/or ecological continuity (monitoring of functionally important species such as fungi, aboreal epiphytes, nematodes, beetles, wasps, etc.)

Criterion 4: Conservation and maintenance of soil and water resources

Indicators:

a. Area and percent of forest land with significant soil erosion
b. Area and percent of forest land managed primarily for protective functions, e.g. watershed, flood protection, avalanche protection, riparian zones
c. Percent of stream kilometers in forested catchments in which stream flow and timing has significantly deviated from the historic range of variation
d. Area and percent of forest land with significantly diminished soil organic matter and/or changes in other soil chemical properties
e. Area and percent of forest land with significant compaction or change in soil physical properties resulting from human activities
f. Percent of water bodies in forest areas (e.g. stream kilometers, lake hectares) with significant variance of biological diversity from the historic range of variability
g. Percent of water bodies in forest areas (e.g. stream kilometers, lake hectares) with significant variation from the historic range of variability in pH, dissolved oxygen, levels of chemicals (electrical conductivity), sedimentation or temperature change
h. Area and percent of forest land experiencing an accumulation of persistent toxic substances

Criterion 5: Maintenance of forest contribution to global carbon cycles

Indicators:

a. Total forest ecosystem biomass and carbon pool, and if appropriate, by forest type, age class, and successional stages
b. Contribution of forest ecosystems to the total global carbon budget, including absorption and release of carbon (standing biomass, coarse woody debris, peat and soil carbon)
c. Contribution of forest products to the global carbon budget

Criterion 6: Maintenance and enhancement of long-term multiple socio-economic benefits to meet the needs of societies

Indicators:

6.1 *Production and consumption*
a. Value and volume of wood and wood products production, including value added through downstream processing
b. Value and quantities of production of non-wood forest products
c. Supply and consumption of wood and wood products, including consumption per capita
d. Value of wood and non-wood products production as percentage of GDP
e. Degree of recycling of forest products

f. Supply and consumption/use of non-wood products

6.2 *Recreation and tourism*

a. Area and percent of forest land managed for general recreation and tourism, in relation to the total area of forest land
b. Number and type of facilities available for general recreation and tourism, in relation to population and forest area

6.3 *Investment in the forest sector*

a. Value of investment, including investment in forest growing, forest health and management, planted forests, wood processing, recreation and tourism
b. Level of expenditure on research and development, and education
c. Extension and use of new and improved technologies
d. Rates of return on investment

6.4 *Cultural, social and spiritual needs and values*

a. Area and percent of forest land managed in relation to the total area of forest land to protect the range of cultural, social and spiritual needs and values
b. Non-consumptive use of forest values

6.5 *Employment and community needs*

a. Direct and indirect employment in the forest sector and forest sector employment as a proportion of total employment
b. Average wage rates and injury rates in major employment categories within the forest sector
c. Viability and adaptability to changing economic conditions, of forest dependent communities, including indigenous communities
d. Area and percent of forest land used for subsistence purposes

Criterion 7: Legal, institutional and economic framework for forest conservation and sustainable management

Indicators:

7.1 *Extent to which the legal framework (laws, regulations, guidelines) supports the conservation and sustainable management of forests, including the extent to which it:*

a. Clarifies property rights, provides for appropriate land tenure arrangements, recognizes customary and traditional rights of indigenous people, and provides means of resolving property disputes by due process;
b. Provides for periodic forest-related planning, assessment, and policy review that recognizes the range of forest values, including coordination with relevant sectors;
c. Provides opportunities for public participation in public policy and decision-making related to forests and public access to information;
d. Encourages best practice codes for forest management;
e. Provides for the management of forests to conserve special environmental, cultural, social and/or scientific values.

7.2 *Extent to which the institutional framework supports the conservation and sustainable management of forests, including the capacity to:*

a. Provide for public involvement activities and public education, awareness and extension programs, and make available forest-related information;
b. Undertake and implement periodic forest-related planning, assessment, and policy review including cross-sectoral planning and coordination;
c. Develop and maintain human resource skills across relevant disciplines;
d. Develop and maintain efficient physical infrastructure to facilitate the supply of forest products and services and support forest management;
e. Enforce laws, regulations and guidelines.

7.3 *Extent to which the economic framework (economic policies and measures) supports the conservation and sustainable management of forests through:*
a. Investment and taxation policies and a regulatory environment which recognize the long-term nature of investments and permit the flow of capital in and out of the forest sector in response to market signals, non-market economic valuations, and public policy decisions in order to meet long-term demands for forest products and services;
b. Non-discriminatory trade polices for forest products.

7.4 *Capacity to measure and monitor changes in the conservation and sustainable management of forests, including:*
a. Availability and extent of up-to-date data, statistics and other information important to measuring or describing indicators associated with criteria 1-7;
b. Scope, frequency and statistical reliability of forest inventories, assessments, monitoring and other relevant information;
c. Compatibility with other countries in measuring, monitoring and reporting on indicators.

7.5 *Capacity to conduct and apply research and development aimed at improving forest management and delivery of forest goods and services, including:*
a. Development of scientific understanding of forest ecosystem characteristics and functions;
b. Development of methodologies to measure and integrate environmental and social costs and benefits into markets and public policies, and to reflect forest-related resource depletion or replenishment in national accounting system;
c. New technologies and the capacity to assess the socio-economic consequences associated with the introduction of new technologies;
d. Enhancement of ability to predict impacts of human intervention on forests;
e. Ability to predict impacts on forests of possible climate change.

Appendix 2: The 38 herptile (amphibian and reptile) species found on the Frontenac Axis. Source: Oldham, unpublished data for the Herptile Atlas of Ontario. Nomenclature follows Collins, 1990.

Common name	Scientific name and author
Black rat snake	*Elaphe o. obsoleta* (Say, 1823)
Brown snake	*Storeria dekayi* (Holbrook, 1836)
Eastern fox snake	*Elaphe vulpina gloydi* Conant, 1940
Eastern garter snake	*Thamnophis s. sirtalis* (Linnaeus, 1758)
Eastern hognose snake	*Heterodon platyrhinos* Latreille 1801
Eastern milk snake	*Lampropeltis t. triangulum* (Lacépède, 1788)
Eastern smooth green snake	*Opheodrys v. vernalis* (Harlan, 1827)
Northern ribbon snake	*Thamnophis sauritus septentrionalis* Rossman, 1963
Northern ringneck snake	*Diadophis punctatus edwardsi* (Marrem, 1820)
Northern water snake	*Nerodia s. sipedon* (Linneaus, 1758)
Redbelly snake	*Storeria o. occipitomaculata* (Storer, 1839)
Red-spotted newt	*Notophthalmus v. viridescens* (Rafinesque, 1820)
Mudpuppy	*Necturus m. maculosus* (Rafinesque, 1818)
Five-lined skink	*Eumeces fasciatus* (Linneaus, 1758)
Blue-spotted salamander	*Ambystoma laterale* (Hallowell, 1856)
Eastern redback salamander	*Plethodon cinereus* (Green, 1818)
Four-toed salamander	*Hemidactylium scutatum* (Temminck and Schlegel, 1838)
Jefferson salamander	*Ambystoma jeffersonianum* (Green, 1827)
Jefferson-Blue-spotted salamander hybrid	*Ambystoma laterale* - jeffersonianum complex
Two-lined salamander	*Eurycea bislineata* (Green, 1818)
Yellow-spotted salamander	*Ambystoma maculatum* (Shaw, 1802)
American toad	*Bufo a. americanus* Holbrook, 1836
Bullfrog	*Rana catesbeiana* (Shaw, 1802)
Green frog	*Rana clamitans melanota* (Rafinesque, 1820)
Mink frog	*Rana septentrionalis* Baird, 1854
Northern leopard frog	*Rana pipiens* Schreber 1782
Pickeral frog	*Rana palustris* LeCompte 1825
Spring peeper	*Pseudacris c. crucifer* (Wied-Meuwied, 1838)
Tetraploid gray treefrog	*Hyla versicolo* LeCompte 1825
Western chorus frog	*Pseudacris t. triseriata* (Wied-Meuwied, 1838)
Wood frog	*Rana sylvatica* LeCompte 1825
Blanding's turtle	*Emydoidea blandingi* Holbrook 1838
Eastern Box turtle	*Terrapene c. carolina* (Linnaeus 1758)
Common musk turtle	*Sternotherus odoratus* (Latreille 1802)
Common snapping turtle	*Chelydra s. serpentina* (Linnaeus 1758)
Map turtle	*Graptemys geographica* (LeSueur 1817)
Midland painted turtle	*Chrysemys picta marginata* Agassiz 1857
Spotted turtle	*Clemmys guttata* (Schneider 1792)

Appendix 3: The 130 bird species found on the Frontenac Axis that can be classified into snag-nesting, ground-nesting, migrants and carnivores. * denotes forest species. Data from Cadman *et al.* 1987.

Common name	Scientific name	Snag nester	Ground nester	Migrant	Carnivore
Acadian flycatcher*	*Empidonax virescens*			1	
Alder flycatcher*	*Empidonax alnorum*			1	
American redstart*	*Setophaga ruticilla*			1	
American woodcock*	*Scolopax minor*		1		
Bank swallow	*Riparia riparia*			1	
Barred owl*	*Strix varia*	1			1
Belted kingfisher	*Ceryle alcyon*			1	
Black-and-white warbler*	*Mniotilta varia*		1		
Black-backed woodpecker*	*Picoides arcticus*				
Blackburnian warbler*	*Dendroica fusca*			1	
Black-capped chickadee*	*Parus atricapillus*	1			
Black-throated blue warbler*	Dendroica caerulescens				
Black-throated green warbler*	*Dendroica virens*			1	
Blue jay*	*Cyanocitta cristata*				
Blue-grey gnatcatcher*	*Polioptila caerulea*			1	
Blue-winged teal	*Anas discors*			1	
Blue-winged warbler	*Vermivora pinus*			1	
Bobolink	*Dolichonyx oryzivorus*			1	
Brewer's blackbird	*Euphagus cyanocephalus*			1	
Brewster's warbler*	*Vermivora chrysoptera x V. pinus*			1	
Broad-winged hawk*	*Buteo platypterus*				
Brown creeper*	*Certhia americana*		1		
Brown-headed cowbird	*Molothrus ater*			1	
Canada warbler*	*Wilsonia canadensis*		1		
Cape may warbler*	*Dendroica tigrina*			1	
Caspian tern	*Sterna caspia*			1	
Cerulean warbler*	*Dendroica cerulea*			1	
Chestnut-sided warbler*	*Dendroica penslyvanica*			1	
Chimney swift*	*Chaetura pelagica*			1	
Chipping sparrow	*Spizella passerina*			1	
Chuck-will's-widow*	*Caprimulgus carolinensis*			1	
Cinnamon teal	*Anas cyanoptera*			1	
Cliff swallow	*Hirundo pyrrhonota*			1	
Common moorhen	*Gallinula chloropus*			1	
Common nighthawk*	*Chordeiles minor*		1	1	
Common raven*	*Corvus corax*				
Common tern	*Sterna hirundo*			1	
Common yellowthroat	*Geothlypis trichas*			1	
Connecticut warbler	*Oporornis agilis*			1	
Cooper's hawk*	*Accipiter cooperii*			1	1
Dark-eyed junco*	*Junco hyemalis*		1	1	
Dickcissel	*Spiza americana*			1	
Downy woodpecker*	*Picoides pubescens*	1			
Eastern kingbird	*Tyrannus tyrannus*			1	
Eastern wood pewee*	*Contopus virens*			1	
Evening grosbeak*	*Coccothraustes vespertinus*				
Golden-crowned kinglet*	*Regulus satrapa*				
Golden-winged warbler	*Vermivora chrysoptera*			1	
Northern Goshawk*	*Accipiter gentilis*				1
Grasshopper sparrow	*Ammodramus savannarum*			1	
Gray catbird	*Dumetella carolinensis*			1	
Gray jay*	*Perisoreus canadensis*				

Common name	Scientific name	Snag nester	Ground nester	Migrant	Carnivore
Great blue heron*	*Ardea herodias*	1			
Great horned owl*	*Bubo virginianus*				1
Great-crested flycatcher*	*Myiarchus crinitus*	1		1	
Green-backed heron	*Butorides striatus*			1	
Green-winged teal*	*Anas crecca*		1		
Hairy woodpecker*	*Picoides villosus*	1			
Hermit thrush*	*Catharus guttatus*		1		
Hooded warbler	*Wilsonia citrina*			1	
Kirtland's warbler	*Dendroica kirtlandii*			1	
Lawrence's warbler*	*Vermivora chyrosptera x V. pinus*			1	
Lesser yellowlegs	*Tringa flavipes*			1	
Lincoln's sparrow	*Melospiza lincolnii*			1	
Loggerhead shrike	*Lanius ludovicianus*			1	
Long-eared owl*	*Asio otus*				1
Louisiana waterthrush*	*Sieurus motacilla*		1	1	
Magnolia warbler*	*Dendroica magnolia*			1	
Merlin	*Falco columbarius*			1	
Mourning warbler	*Oporornis philadelphia*			1	
Nashville warbler*	*Vermivora ruficapilla*		1	1	
Northern flicker*	*Colaptes auratus*	1			
Northern goshawk*	*Accipiter gentilis*				
Northern harrier	*Circus cyaneus*				1
Northern oriole*	*Icterus galbula*			1	
Northern parula*	*Parula americana*			1	
Northern waterthrush	*Seiurus noveboracensis*			1	
Olive-sided flycatcher*	*Contopus borealis*			1	
Orchard oriole	*Icterus spurius*			1	
Osprey	*Pandion haliaetus*			1	
Ovenbird*	*Seiurus aurocapillus*		1	1	
Palm warbler	*Dendroica palmarum*			1	
Peregrine falcon	*Falco peregrinus*			1	
Philadelphia vireo	*Vireo philadelphicus*			1	
Pileated woodpecker*	*Dryocopus pileatus*	1		1	
Pine siskin*	*Carduelis pinus*				
Pine warbler*	*Dendroica pinus*				
Prothonotary warbler	*Protonotaria citrea*			1	
Purple gallinule	*Porphyrula martinica*			1	
Purple martin	*Progne subis*			1	
Red crossbill*	*Loxia curvirostra*				
Red-breasted nuthatch*	*Sitta canadensis*	1			
Red-eyed vireo*	*Vireo olivaceus*			1	
Red-shouldered hawk*	*Buteo lineatus*				1
Red-tailed hawk*	*Buteo jamaicensis*				1
Rose-beasted grosbeak*	*Pheucticus ludovicianus*			1	
Northern Rough-winged swallow	*Stelgidopteryx serripennis*			1	
Ruby-crowned kinglet*	*Regulus calendula*			1	
Ruby-throated hummingbird*	*Archilochus colubris*			1	
Ruffed grouse*	*Bonasa umbellus*		1		
Savannah sparrow	*Passerculus sandwichensis*			1	
Northern Saw-whet owl*	*Aegolius acadicus*	1			1
Scarlet tanager*	*Piranga olivacea*			1	
Sharp-shinned hawk*	*Accipiter striatus*			1	1
Short-eared owl	*Asio flammeus*				1
Solitary vireo*	*Vireo solitarius*				
Spotted sandpiper	*Actitis macularia*			1	
Spruce grouse*	*Dendragapus canadensis*			1	

Common name	Scientific name	Snag nester	Ground nester	Migrant	Carnivore
Swainson's thrush*	*Catharus ustulatus*		1		
Tennessee warbler*	*Vermivora peregrina*		1		
Tufted titmouse	*Parus bicolor*			1	
Turkey vulture*	*Cathartes aura*		1		1
Veery*	*Catharus fuscescens*		1		
Warbling vireo*	*Vireo gilvus*				
Whip-poor-will	*Caprimulgus vociferus*			1	
White-breasted nuthatch*	*Sitta carolinensis*	1			
White-throated sparrow*	*Zonotrichia albicollis*				
White-winged crossbill*	*Loxia leucoptera*			1	
Willow flycatcher	*Empidonax trailli*			1	
Wilson's phalarope	*Phalaropus tricolor*			1	
Wilson's warbler*	*Wilsonia pusilla*		1		
Winter wren*	*Troglodytes troglodytes*			1	
Wood duck	*Aix sponsa*			1	
Wood thrush*	*Hylocichla mustelina*				
Yellow rail	*Coturnicops noveboracensis*			1	
Yellow-bellied flycatcher*	*Empidonax flaviventris*		1		
Yellow-bellied sapsucker*	*Sphyrapicus varius*	1		1	
Yellow-rumped warbler*	*Dendroica coronata*			1	
Yellow-throated vireo*	*Vireo flavifrons*				
Yellow warbler	*Dendroica petechia*			1	

Appendix 4: Herptile data set, (Oldham, unpublished data from Natural Heritage Information Centre). The study area includes parts of UTM squares UE, TE and VE. * indicates that the number of collectors was not precisely determinable. Habitat availability was measured for a sample of squares.

UTM	Herptile species	Records	Collectors	Episodes	Total roads	Buildings	Human population	Proportion forest	Proportion marsh	Proportion cleared
UE3	15	53	10	13	113	511	627	0.939	0.029	0.032
UE4	10	15	5	3	83	334	380	0.924	0.057	0.019
UE5	6	11	2	5	11	10	136	0.811	0.181	0.008
UE6	3	4	1	1	38	4	142	0.833	0.087	0
UE7	4	4	3	3	23	48	123	0.83	0.17	0
UE8	2	3	1	1	38	68	145			
UE9	3	3	1	1	38	380	124			
UE13	16	89	17	26	83	384	130			
UE14	11	13	4	4	28	68	128			
UE15	8	13	4	3	14	7	159	0.954	0.029	0.016
UE17	7	10	5	5	20	3	204	0.776	0.224	0
UE18	4	4	5	3	28	39	156	0.801	0.199	0
UE19	2	2	3	2	41	134	86	0.904	0.082	0.013
UE22	4	4	5	20	69	84	719	0.906	0.094	0
UE23	11	43	12	23	68	188	297			
UE24	14	34	10	19	64	84	207	0.752	0.248	0
UE25	12	28	14	12	60	127	212			
UE26	19	52	9	13	63	588	233	0.679	0.086	0.196
UE27	26	103	23	44	33	356	176	0.871	0.109	0.019
UE28	7	10	9	5	46	127	98	0.809	0.141	0.05
UE29	10	20	9	8	61	147	93			
UE33	10	20	12	11	55	58	297	0.744	0.25	0.005
UE34	23	77	23	33	48	116	208			
UE35	4	6	4	4	28	49	250			
UE36	15	31	9	8	88	800	288	0.768	0.112	0.12
UE37	4	4	5	3	37	179	200	0.92	0.044	0.036
UE38	19	40	6	15	49	198	87			
UE39	3	5	2	3	52	78	92	0.866	0.134	0
UE42	2	2	2	2	94	425	515	0.743	0.241	0.015
UE43	1	1	1	1	58	79	223			
UE44	12	18	11	10	53	207	228			
UE45	28	352	4	150	111	708	216			
UE46	18	71	9	45	40	280	144			
UE47	5	9	6	5	75	470	94			
UE48	13	21	5	5	51	208	99			
UE49	4	1	3	4	28	57	67			
UE52	4	5	3	3	74	499	1534	0.938	0.028	0.033
UE53	5	8	4	3	42	163	375	0.717	0.222	0.061
UE54	1	1	1	1	45	183	293	0.71	0.233	0.057
UE55	17	54	13	29	103	283	252			
UE56	17	25	7	5	24	148	162			
UE57	6	13	11	10	31	165	80			
UE58	6	18	5	8	62	232	71			
UE59	6	11	2	3	50	24	70			
UE62	21	35	6	25	86	762	1178			
UE63	5	9	4	5	95	388	365	0.63	0.151	0.219
UE64	14	28	1	12	103	691	316	0.73	0.176	0.094
UE65	15	44	22	25	99	854	436	0.926	0.046	0.028
UE66	26	55	16	38	98	288	415			
UE67	16	27	10	14	57	149	88			
UE68	5	5	3	3	67	108	165			
UE72	22	129	15	32	79	912	1841			
UE73	25	73	18	23	85	629	302	0.786	0.138	0.076
UE74	6	7	3	3	89	778	288	0.773	0.121	0.106
UE75	11	19	6	8	67	633	330			
UE76	9	14	14	9	83	388	436	0.756	0.244	0
UE81	14	31	5	11	119	875	2046			
UE82	13	31	21	20	80	673	1571			
UE83	12	34	11	15	62	542	273	0.787	0.185	0.028
UE84	5	5	4	5	110	483	1100	0.478	0.18	0.342
UE85	1	1	1	1	89	382	487			
UE86	2	2	2	1	105	532	976			
UE91	15	17		5	118	768	8247			
UE92	5	13	6	10	74	438	1204	0.691	0.14	0.169
UE93	15	37	19	21	86	684	888	0.742	0.16	0.098
UE94	1	1	1	1	108	779	832	0.414	0.108	0.048
UE95	1	1	1	1	83	558	452			
UE99	2	4	1	1	107			0.807	0.112	0.081
TE64	1	1	1	1	47	730	372			
TE65	5	8	2	1	48	29	287			
TE66	1	1	1	1	75	587	183			
TE67	5	6	2	2	42	68	288			
TE68	1	1	1	1	58	374	385	0.956	0.041	0.003
TE69	4	8	3	4	56	348	383			
TE73	1	1	1	1	59	686	425			
TE75	3	3	1	1	14	74	388			
TE76	5	5	2	2	58	182	280			
TE77	14	27	4	5	70	324	404			
TE78	8	9	5	3	107	282	568			
TE79	20	38	17	23	89	875	2868			
TE83	4	4	2	2	78	402	443	0.874	0.072	0.054
TE84	1	1	2	1	47	80	338			
TE85	1	3	1	1	24	16	279	0.939	0.028	0.033
TE86	11	16	4	5	58	482	181	0.834	0.15	0.016
TE87	8	16	5	4	68	176	217	0.747	0.232	0.021
TE88	7	7	4	4	84	207	588	0.827	0.158	0.015
TE89	8	9	4	3	53	137	481	0.798	0.129	0.073
TE93	11	17	10	16	77	330	536			
TE94	7	14	8	4	63	290	351	0.841	0.138	0.021
TE95	5	17	5	4	64	108	134			
TE96	5	7	4	3	60	70	135	0.728	0.247	0.025
TE97	5	5	3	3	85	418	144	0.848	0.131	0.02
TE98	5	5	3	4	78	10	274			
TE99	2	2	1	2	81	182	202			
VE02	3	3			144			0.442	0.131	0.427
VE03	2	2			110			0.501	0.123	0.376
VE05	1	1			100			0.567	0.221	0.212
VE06	3	3			117			0.445	0.234	0.321
VE13	1	1			139			0.535	0.114	0.351
VE14	4	4			143			0.412	0.086	0.502
VE15	2	2			107			0.324	0.276	0.4

Appendix 5: Bird data set. Data from Cadman *et al.*, 1987. Snag- and ground-nesting species are forest interior only, and 'total forest' refers to forest interior only.

UTM	Human population	Total roads	Buildings	Observer hours	Migrants	Carnivores	Snag-nesters	Ground-nesters	Total forest	Forest	Marsh	Cleared
UE3	627	113	511	39.75	38	2	9	8	35	0.839	0.129	0.032
UE4	380	63	334	23.75	34	0	10	9	39	0.924	0.057	0.019
UE5	135	11	10	63.75	25	2	9	7	31	0.811	0.181	0.008
UE6	147	38	4	23.75	25	1	10	9	35	0.933	0.067	0
UE7	123	23	48	7.75	25	2	7	10	33	0.83	0.17	0
UE8	145	38	68	39.75	43	2	11	10	47			
UE9	124	39	380	39.75	35	1	5	10	37			
UE12	2338	125	794	23.75	34	2	7	8	32			
UE13	130	93	384	39.75	39	2	7	8	37			
UE14	128	28	88	23.75	34	3	10	9	42			
UE15	159	14	7	63.75	23	2	9	8	32	0.954	0.029	0.016
UE16	177	28	22	23.75	28	2	6	8	31			
UE17	204	20	3	39.75	32	1	10	11	42	0.776	0.224	0
UE18	156	28	39	39.75	38	1	12	11	50	0.801	0.199	0
UE19	95	41	134	23.75	30	1	11	9	39	0.904	0.082	0.013
UE22	719	69	84	63.75	39	1	10	9	37	0.906	0.094	0
UE23	297	68	188	23.75	39	0	10	10	41			
UE24	207	64	84	39.75	41	3	11	10	50	0.752	0.248	0
UE25	212	60	127	86.75	34	2	11	11	46			
UE26	233	83	588	86.75	40	4	11	12	50	0.679	0.088	0.198
UE27	176	33	356	86.75	43	1	10	10	49	0.871	0.109	0.019
UE28	96	48	127	39.75	31	3	10	9	39	0.809	0.141	0.05
UE29	93	61	147	63.75	34	2	12	9	48			
UE33	297	55	58	63.75	29	1	9	11	38	0.744	0.25	0.005
UE34	208	48	116	86.75	44	8	12	12	56			
UE35	250	28	49	7.75	34	3	11	10	47			
UE36	298	88	800	95.75	35	3	11	11	46	0.758	0.112	0.13
UE37	200	37	179	23.75	28	1	7	8	34	0.92	0.044	0.036
UE38	67	49	198	63.75	42	1	12	11	53			
UE39	92	52	78	39.75	40	0	12	9	51	0.866	0.134	0
UE42	515	94	425	63.75	37	0	9	9	34	0.743	0.241	0.015
UE43	223	58	79	63.75	35	1	10	9	38			
UE44	228	53	207	63.75	43	4	11	10	48			
UE45	216	111	708	95.75	40	1	11	11	51			
UE46	144	40	200	23.75	38	0	11	10	44			
UE47	94	75	470	23.75	27	0	9	9	35			
UE48	99	51	208	23.75	39	2	12	11	49			
UE49	67	28	57	39.75	46	1	12	11	49			
UE52	1534	74	499	95.75	38	3	9	9	38	0.938	0.028	0.033
UE53	375	42	163	86.75	43	2	10	10	45	0.717	0.222	0.061
UE54	293	45	183	63.75	31	0	8	9	34	0.71	0.233	0.057
UE55	252	103	283	63.75	33	0	11	9	38			
UE56	162	24	148	23.75	35	0	10	10	42			
UE57	80	31	165	39.75	27	1	9	9	33			
UE58	71	62	232	39.75	32	2	11	8	38			
UE59	70	50	24	39.75	31	2	10	8	43			
UE62	1178	88	762	63.75	38	1	10	8	38			
UE63	355	95	388	86.75	40	6	9	10	38	0.63	0.151	0.219
UE64	318	103	691	63.75	38	2	9	10	39	0.73	0.176	0.094
UE65	438	99	854	86.75	33	5	11	11	47	0.926	0.046	0.028
UE66	415	98	288	63.75	38	1	11	9	42			
UE67	88	57	149	39.75	33	2	9	8	38			
UE68	165	67	108	63.75	35	3	10	9	41			
UE69	233	75	82	39.75	32	1	8	7	37			
UE72	1841	79	912	63.75	49	6	12	10	53			
UE73	302	85	629	63.75	48	8	11	10	52	0.788	0.136	0.076
UE74	298	99	778	39.75	44	4	10	10	48	0.773	0.121	0.106
UE75	330	67	633	23.75	24	1	6	5	22			
UE76	438	93	388	39.75	21	0	8	8	25	0.756	0.244	0
UE77	285	78	332	23.75	18	0	3	4	14			
UE78	283	93	171	23.75	22	1	6	4	22			
UE79	208	58	138	23.75	21	0	1	4	16			
UE81	2048	119	875	39.75	30	3	8	6	33			
UE82	1571	80	673	63.75	41	3	11	9	45			
UE83	273	62	542	63.75	38	8	11	8	43	0.787	0.185	0.028
UE84	1100	110	483	86.75	37	3	11	11	44	0.478	0.18	0.342
UE85	487	89	392	63.75	28	2	9	6	30			
UE86	876	106	532	63.75	32	0	3	5	23			
UE87	748	83	327	86.75	30	3	6	6	28			
UE88	388	97	233	86.75	28	1	8	7	29			
UE89	408	80	242	23.75	25	0	5	6	23			
UE91	8247	118	788	86.75	38	2	8	8	35			
UE92	1204	74	438	63.75	33	1	7	8	34	0.691	0.14	0.169
UE93	996	98	664	63.75	43	8	11	9	47	0.742	0.16	0.098
UE94	832	108	779	63.75	39	1	8	10	40	0.414	0.108	0.048
UE95	452	63	368	39.75	28	1	8	7	32			
UE96	870	102	588	86.75	25	1	3	4	21			
UE97	6833	84	711	39.75	23	0	7	6	24			
UE98	1573	112	603	39.75	29	2	6	7	26			
UE99		107		23.75	28	1	7	4	22	0.807	0.112	0.081
TE64	372	47	730	7.75	28	0	8	6	33			
TE65	297	48	28	23.75	36	0	10	8	37			
TE66	183	75	587	23.75	27	0	7	6	30			
TE67	288	42	68	39.75	29	0	9	9	38			
TE68	385	56	374	86.75	48	1	11	11	54	0.956	0.041	0.003
TE69	383	55	349	86.75	37	1	9	11	48			
TE73	425	59	686	23.75	28	0	5	5	20			
TE74	401	48	322	23.75	22	1	6	5	23			
TE75	388	14	74	23.75	18	2	7	5	21			
TE76	280	59	182	23.75	24	0	7	4	21			
TE77	404	70	324	63.75	24	0	8	7	27			
TE78	588	107	282	39.75	36	1	11	8	44			
TE79	2868	90	875	39.75	38	2	8	11	43			
TE83	443	78	402	23.75	27	1	9	4	24	0.874	0.072	0.054
TE84	338	47	80	39.75	22	0	5	4	22			
TE85	279	24	16	63.75	25	0	6	7	38	0.939	0.028	0.033
TE86	191	56	482	23.75	17	0	3	3	17	0.834	0.15	0.016
TE87	217	68	178	23.75	18	0	3	7	21	0.747	0.232	0.021
TE88	588	84	207	39.75	39	0	7	10	42	0.827	0.158	0.015
TE89	491	53	137	39.75	30	0	8	8	27	0.798	0.129	0.073
TE92	535	77	330	23.75	21	0	4	4	17			
TE94	351	63	250	63.75	22	0	6	5	20	0.841	0.138	0.021
TE95	134	84	108	63.75	17	1	8	6	24			
TE96	135	80	73	23.75	18	0	5	2	13	0.728	0.247	0.025
TE97	144	85	416	23.75	19	0	9	5	24	0.849	0.131	0.02
TE98	274	78	10	23.75	31	1	12	10	39			
TE99	222	81	182	63.75	32	1	6	9	35			

Appendix 6: Large carnivore data set. Data from Dobbyn, 1994.

UTM	Human population	Hardtop roads	Loosetop roads	Trails	Total roads	Buildings	Wolf	coyote	bear	fisher	coyote no wolf	Forest	Marsh	Cleared
UE3	627	46	39	28	113	511	1	1	1	0	0	0.939	0.029	0.032
UE4	360	18	12	33	63	334	1	0	1	1	0	0.924	0.057	0.019
UE5	136	0	0	11	11	13	0	0	1	1	0	0.811	0.181	0.008
UE6	142	0	12	26	38	4	0	0	1	1	0	0.933	0.067	0
UE7	123	0	3	20	23	48	0	1	1	1	1	0.83	0.17	0
UE8	145	9	14	15	38	68	0	1	1	1	1			
UE9	134	0	15	24	39	380	0	0	1	1	0			
UE12	2338	32	70	23	125	796	0	0	1	0	0			
UE13	130	25	42	26	93	386	0	0	1	0	0			
UE14	128	1	13	14	28	88	0	0	0	1	0			
UE15	189	0	0	14	14	7	0	0	1	1	0	0.954	0.029	0.016
UE16	177	0	14	14	28	22	1	0	1	1	0			
UE17	204	0	0	20	20	3	0	0	1	1	0	0.776	0.224	0
UE18	156	0	9	19	28	39	0	0	1	1	0	0.801	0.199	0
UE19	96	1	3	37	41	136	0	0	1	1	0	0.904	0.082	0.013
UE22	719	12	41	16	69	86	0	0	1	0	0	0.906	0.094	0
UE23	297	12	25	31	68	186	0	0	1	0	0			
UE24	207	11	31	22	64	86	1	0	1	1	0	0.752	0.248	0
UE25	212	18	11	31	60	127	0	0	1	1	0			
UE26	233	14	36	33	83	666	1	0	1	1	0	0.679	0.088	0.199
UE27	176	11	12	10	33	386	1	0	1	1	0	0.871	0.109	0.019
UE28	96	12	22	12	46	127	0	0	0	1	0	0.809	0.141	0.05
UE29	93	17	14	30	61	147	0	0	1	1	0			
UE33	297	12	13	30	55	58	0	0	1	1	0	0.744	0.25	0.006
UE34	206	21	0	27	48	116	0	0	1	1	0			
UE35	250	2	12	15	29	49	0	0	1	1	0			
UE36	296	8	33	45	86	800	1	1	1	0	0	0.768	0.112	0.12
UE37	200	6	6	25	37	179	1	1	1	1	0	0.92	0.044	0.036
UE38	87	0	22	27	49	198	0	1	1	1	1			
UE39	92	0	17	36	53	78	0	1	1	1	1	0.866	0.134	0
UE42	515	30	58	9	96	425	0	0	1	0	0	0.743	0.241	0.015
UE43	223	22	8	28	58	79	0	0	0	1	0			
UE44	228	3	12	38	53	207	0	0	1	0	0			
UE45	216	22	22	67	111	708	0	0	1	1	0			
UE46	144	3	14	23	40	260	0	0	0	1	0			
UE47	96	18	24	33	75	470	0	0	0	1	0			
UE48	99	11	16	24	51	206	0	1	1	1	1			
UE49	87	0	12	16	28	57	0	1	1	1	1			
UE52	1534	29	39	6	74	498	0	0	1	0	0	0.938	0.029	0.033
UE53	375	2	19	21	42	163	0	1	1	0	1	0.717	0.222	0.061
UE54	293	7	23	15	45	183	0	1	0	0	1	0.71	0.233	0.057
UE55	252	25	35	43	103	283	0	0	1	0	0			
UE56	162	9	5	9	24	148	0	0	1	1	0			
UE57	80	8	8	15	31	168	0	0	1	1	0			
UE58	71	12	17	33	62	232	0	0	1	1	0			
UE59	70	0	0	50	50	36	0	1	1	0	1			
UE62	1178	32	24	30	86	762	0	1	0	0	1			
UE63	368	22	33	40	95	386	0	1	0	0	1	0.63	0.151	0.219
UE64	316	24	32	47	103	681	0	1	1	0	1	0.73	0.176	0.094
UE65	436	17	40	42	99	864	0	0	1	0	0	0.926	0.044	0.029
UE66	415	25	29	42	96	288	0	1	1	1	1			
UE67	88	15	12	30	57	149	0	0	0	0	0			
UE68	166	11	20	36	67	106	0	0	0	1	0			
UE69	233	0	15	60	75	82	0	0	1	1	0			
UE72	1861	22	26	31	79	912	0	1	1	0	1			
UE73	302	13	27	45	85	629	0	1	0	0	1	0.788	0.136	0.076
UE74	298	11	43	45	99	778	0	1	1	0	1	0.773	0.121	0.106
UE75	330	13	19	35	67	633	0	0	0	0	0			
UE76	436	25	33	35	93	366	0	0	0	0	0	0.756	0.244	0
UE77	286	17	24	37	78	332	0	0	0	0	0			
UE78	283	3	25	65	93	171	0	0	1	1	0			
UE79	206	0	39	19	58	136	0	0	1	1	0			
UE81	2046	38	50	31	119	975	0	0	0	0	0			
UE82	1671	14	36	31	81	673	0	0	0	0	0			
UE83	273	8	8	46	62	542	0	1	1	0	1	0.787	0.185	0.028
UE84	1100	25	42	43	110	483	0	1	1	0	1	0.478	0.18	0.342
UE85	487	30	11	48	89	382	0	1	0	1	1			
UE86	976	26	39	41	106	632	0	0	0	0	0			
UE87	748	23	35	25	83	327	0	0	1	0	0			
UE88	398	17	49	31	97	233	0	0	1	1	0			
UE89	406	32	25	23	80	342	0	0	1	0	0			
UE91	8347	33	45	40	118	780	0	1	0	0	1			
UE92	1206	13	31	30	74	436	0	0	0	0	0	0.691	0.14	0.169
UE93	698	6	36	56	98	686	0	0	1	0	0	0.742	0.16	0.098
UE94	832	17	30	59	106	779	0	1	0	0	1	0.846	0.106	0.048
UE95	482	17	29	17	63	568	0	1	0	0	1			
UE96	670	38	45	19	102	886	0	1	0	0	1			
UE97	6633	48	37	12	97	711	0	1	0	0	1			
UE98	1573	39	44	29	112	683	0	0	0	0	0			
UE99	719	23	63	21	107	380	0	0	1	0	0	0.807	0.112	0.081
TE64	372	0	27	20	47	730	0	0	1	1	0			
TE65	297	12	10	26	48	29	0	0	1	1	0			
TE66	193	8	37	30	75	887	0	0	1	1	0			
TE67	286	2	11	29	42	66	0	0	1	1	0			
TE68	398	3	22	31	56	374	0	0	1	1	0	0.956	0.041	0.003
TE69	383	13	15	27	55	389	0	0	1	1	0			
TE73	428	8	18	33	59	888	0	0	1	1	0			
TE74	401	17	8	21	46	322	0	0	1	1	0			
TE75	386	0	4	11	14	74	0	0	1	1	0			
TE76	280	2	27	30	59	182	0	0	1	1	0			
TE77	406	9	28	33	70	326	0	0	1	1	0			
TE78	666	6	18	83	107	282	0	0	1	1	0			
TE79	2968	38	36	28	98	879	0	0	1	1	0			
TE83	443	14	32	32	78	482	1	0	1	1	0	0.874	0.072	0.054
TE84	339	0	1	46	47	88	0	0	1	1	0			
TE85	279	0	4	22	26	16	0	0	1	0	0	0.939	0.028	0.033
TE86	191	1	21	34	56	482	0	0	1	1	0	0.834	0.15	0.016
TE87	217	19	9	49	80	176	0	0	1	1	0	0.747	0.232	0.021
TE88	566	15	24	48	87	387	0	0	1	1	0	0.827	0.158	0.015
TE89	491	18	18	25	63	137	0	0	1	1	0	0.798	0.129	0.073
TE93	836	20	25	32	77	338	1	1	0	0	1			
TE94	381	10	25	28	63	280	1	0	1	0	0	0.841	0.138	0.021
TE95	134	11	22	31	64	168	1	0	1	1	0			
TE96	136	15	15	38	68	70	0	0	1	1	0	0.728	0.247	0.025
TE97	144	5	20	40	65	416	0	1	1	0	1	0.849	0.131	0.02
TE98	274	0	43	35	78	10	0	1	0	1	1			
TE99	282	14	25	42	81	182	0	0	0	1	0			
VE01							0	1	0	0	1	0.324	0.075	0.601
VE02							0	0	0	0	0	0.442	0.131	0.427
VE03							0	0	1	0	0	0.501	0.123	0.376
VE05							0	1	0	1	1	0.567	0.221	0.212
VE06							0	1	0	1	1	0.445	0.234	0.321
VE13							0	0	0	0	0	0.535	0.114	0.351
VE14							0	0	0	0	0	0.412	0.095	0.493
VE15							0	0	0	1	0	0.346	0.254	0.4

Appendix 7: Fern diversity and abundance and coarse woody debris data set.

UTM	30m	1km	replicate	marble	CWD>10	CWD>20	Total CWD	decay median	mean CWD>10	mean CWD>20	mean total	mean decay	species no	mean species	mean abund	D carthu	D intermedia
4	06/4	05/4	1	0	4	1	5	4	1.6	0.4	2	1.8	4	2.4	0.6	0.6	0
		06/4	2	0	3	0	3	2					1				
		07/4	3	0	0	0	0	0					0				
		08/4	4	0	0	0	0	0					5				
		08/4	5	0	1	1	2	3					2				
23	20/3	21/3	1	0	2	0	0	3	2.4	1	3	2.6	1	3.6	2	1.6	0.4
		21/3	2	0	3	3	6	3					6				
		20/3	3	0	0	0	0	0					5				
		21/3	4	0	6	2	8	4					2				
		22/3	5	0	1	0	1	3					4				
25	21/6	23/6	1	0	0	1	1	3	1.4	0.2	1.6	1.7	5	3.4	3.2	2	1.2
		23/6	2	0	5	0	5	4					7				
		22/6	3	0	0	0	0	0					1				
		22/6	4	0	2	0	2	1.5					2				
		22/6	5	0	0	0	0	0					2				
37	37/7	38/7	1	0	5	1	6	1.5	5.8	0.8	6.6	2.2	2	0.6	0	0	0
		38/7	2	0	7	0	7	3					0				
		39/7	3	0	5	1	6	2					0				
		37/7	4	0	5	1	6	3					1				
		37/7	5	1	7	1	8	1.5					0				
44	45/4	47/4	1	0	2	0	2	3.5	3.2	1	4.2	3.5	2	2	0.4	0.4	0
		47/4	2	0	3	0	3	3					3				
		46/4	3	0	3	2	5	4					1				
		46/4	4	0	6	3	9	4					2				
		45/4	5	0	2	0	2	3					2				
46	41/6	43/6	1	0	1	0	1	4	4.4	0	4.4	3.5	1	1.4	0.4	0	0.4
		43/6	2	0	2	0	2	3.5					0				
		43/6	3	0	5	0	5	4					3				
		43/6	4	0	7	0	7	3					2				
		43/6	5	0	7	0	7	3					1				
49	43/9	44/9	1	0	2	2	4	3.5	1.4	1.8	3.2	2.7	1	1.4	0.4	0	0.4
		44/9	2	0	1	1	2	2.5					1				
		44/9	3	0	1	1	2	3.5					1				
		45/9	4	0	0	0	0	0					1				
		43/9	5	0	3	5	8	4					3				
53	54/3	56/3	1	0	2	0	2	3.5	3.8	0	3.8	3.5	3	2.4	0	0	0
		56/3	2	0	3	0	3	4					3				
		56/3	3	0	3	0	3	3					2				
		56/3	4	0	3	0	3	4					3				
		56/3	5	0	8	0	8	3					1				
56	56/6	56/6	1	0	2	0	2	1.5	3.2	0.6	3.8	2.5	5	2	0.4	0	0.4
		56/6	2	0	1	0	1	1					1				
		56/6	3	0	3	0	3	4					1				
		56/6	4	0	5	0	5	4					1				
		56/6	5	0	5	3	8	2					2				
67	66/7	66/7	1	0	2	0	2	2	3.4	0.8	4.2	3.1	0	2.6	0.4	0.4	0
		68/7	2	0	2	0	2	2.5					3				
		66/7	3	0	3	0	3	3					0				
		67/7	4	0	7	2	9	4					4				
		68/7	5	0	3	2	5	4					6				
73	70/3	70/3	1	0	4	2	6	4	1.6	0.6	2.2	2	1	2.2	0.6	0.6	0
		70/3	2	0	2	0	2	3					2				
		71/3	3	0	2	1	3	3					5				
		72/3	4	0	0	0	0	0					1				
		72/3	5	0	0	0	0	0					2				
75	77/6	79/6	1	0	1	0	1	2	1.8	0.2	2	2.5	2	2.8	0.8	0.8	0
		78/6	2	0	1	1	2	2.5					2				
		79/6	3	0	3	0	3	3					3				
		78/6	4	1	1	0	1	2					2				
		78/6	5	1	3	0	3	3					5				
79	73/9	74/9	1	0	4	5	9	2	4.6	1.8	6.4	3	5	2.8	2.8	1.6	1.2
		73/9	2	0	6	1	7	3					2				
		75/9	3	0	2	2	4	3					3				
		74/9	4	0	5	0	5	4					2				
		75/9	5	0	6	1	7	3					2				
83	82/3	83/3	1	0	2	0	2	3	1.8	1.8	3.6	2.7	2	3	0	0	0
		83/3	2	0	0	2	2	3.5					0				
		83/3	3	0	2	1	3	3					2				
		84/3	4	1	0	0	0	0					4				
		84/3	5	1	5	6	11	4					7				
86	81/6	83/6	1	0	5	1	6	2.5	1.8	0.6	2.4	2	5	2.6	0	0	0
		83/6	2	0	0	1	1	4					3				
		83/6	3	1	4	0	4	2.5					1				
		82/6	4	0	0	1	1	1					2				
		81/6	5	0	0	0	0	0					2				
87	83/7	84/7	1	1	13	6	19	2	5.8	1.8	7.6	2.4	2	1.8	1.2	1.2	0
		84/7	2	1	3	0	3	2					0				
		85/7	3	1	2	1	3	3					0				
		86/7	4	1	5	1	6	2					3				
		83/7	5	1	6	1	7	3					4				
88	86/8	87/8	1	1	2	1	3	3	3.8	1.4	5.2	2.4	4	2.6	1	1	0
		87/8	2	1	1	0	1	2					4				
		88/8	3	1	3	1	4	1.5					0				
		88/8	4	1	1	1	2	2.5					4				
		88/8	5	1	12	4	16	3					1				
96	98/6	96/6	1	0	0	0	0	0	1	0.8	1.8	2.9	1	1.6	0.8	0.8	0
		96/6	2	0	2	3	5	3					1				
		96/6	3	0	0	1	1	4					0				
		96/6	4	0	1	0	1	4					2				
		97/6	5	0	2	0	2	3.5					4				
97	96/7	98/7	1	0	2	1	3	3	2.8	0.6	3.4	2.6	3	1	0.6	0	0.6
		98/7	2	0	3	0	3	1					1				
		98/7	3	0	8	1	9	3					1				
		96/7	4	0	0	1	1	2					0				
		96/7	5	0	1	0	1	4					0				
99	92/9	93/9	1	1	3	1	4	2.5	2	1.4	3.4	1.7	1	1.2	1.6	1.2	0.4
		93/9	2	1	1	0	1	1					1				
		92/9	3	1	3	6	9	4					3				
		92/9	4	1	3	0	3	1					1				
		94/9	5	1	0	0	0	0					0				
T66	63/6	63/6	1	1	1	1	2	2	6.4	1	7.4	2.4	2	1	1.2	0.6	0.6
		63/6	2	1	7	1	8	2					0				
		63/6	3	1	8	1	9	4					1				
		66/6	4	0	9	0	9	2					1				
		66/6	5	1	7	2	9	2					1				
T67	66/7	67/7	1	1	5	0	5	3	8.8	2.4	11.2	2.8	2	1.8	2.8	1	1.8
		67/7	2	1	8	4	12	3					6				
		66/7	3	1	5	3	8	2.5					1				
		66/7	4	1	13	4	17	3					0				
		66/7	5	1	13	1	14	1					0				
T69	68/9	68/9	1	0	9	0	9	4	3.8	0.4	4.2	2	2	1.8	2	0	2
		68/9	2	0	8	2	10	4					1				
		66/9	3	0	1	0	1	1					0				
		68/9	4	0	0	0	0	0					1				
		68/9	5	0	1	0	1	1					5				
T75	79/8	71/9	1	2	3	1	4	2.5	4.4	1.4	6	2.3	1	1	0	0	0

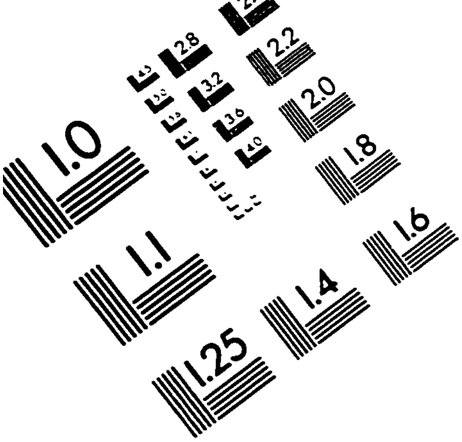
Appendix 7 continued.

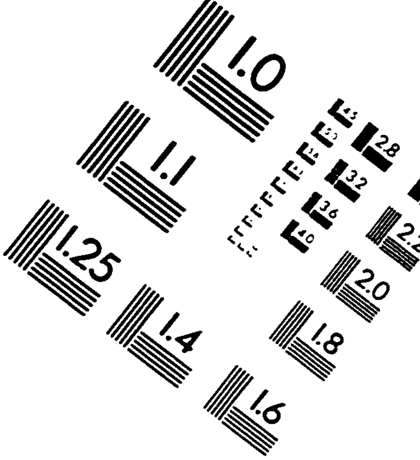
		71/8	2	0	2	1	3	3					1				
		70/8	3	0	8	3	11	2					1				
		70/8	4	0	5	2	7	2					1				
		71/8	5	0	5	0	5	2					1				
T78	71/8	73/8	1	0	3	2	5	3	2 8	1 4	4 2	2 9	2	1 2	0 4	0 4	0
		72/8	2	0	1	0	1	2					2				
		71/8	3	0	4	4	8	3					0				
		72/8	4	0	5	1	6	2 5					1				
		72/8	5	0	1	0	1	4					1				
T79	77/9	78/9	1	0	2	3	5	3	5 2	0 6	5 8	1 5	1	1 8	1	0	1
		79/9	2	0	7	0	7	1					3				
		77/9	3	0	6	0	6	1 5					1				
		77/9	4	0	11	0	11	2					2				
		79/9	5	0	0	0	0	0					2				
T93	97/3	97/3	1	0	0	0	0	0	1 2	0 6	1 8	1 9	1	1	[illegible]	0	0
		98/3	2	0	2	0	2	4					2				
		97/3	3	0	0	0	0	0					0				
		99/3	4	0	1	1	2	2 5					1				
		99/3	5	0	3	2	5	3					1				

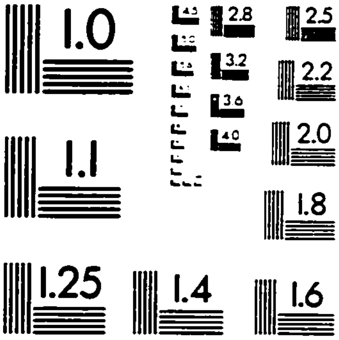
Appendix 8: Twenty-three fern species that were found on the Frontenac Axis. Nomenclature follows Cody and Britton (1989).

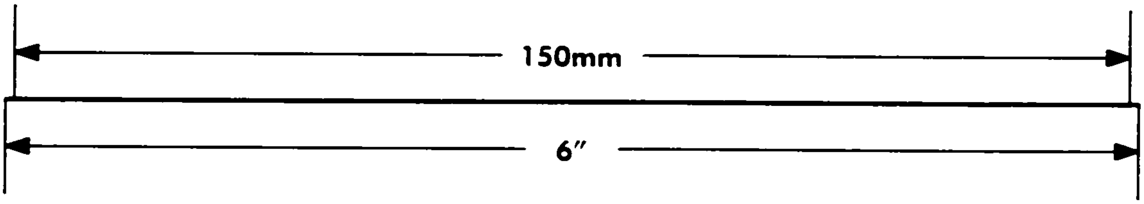
Common name	Scientific name
Bracken	*Pteridium aquilinum* (L.) Kuhn var. *latiusculum* (Desv.) Underw.
Bulblet fern	*Cystopteris bulbifera* Bernh.
Christmas fern	*Polystichum acrostichoides* (Michx.) Schott
Cinnamon fern	*Osmunda cinnamomea* L.
Common polypody	*Polypodium virginianum* L.
Crested wood fern	*Dryopteris cristata* (L.) Gray
Evergreen wood fern	*Dryopteris intermedia* (Muhl.) A. Gray
Fragile fern	*Cystopteris fragilis* (L.) Bernh. var. *fragilis*
Hay-scented fern	*Dennstaedtia punctilobula* (Michx.) Moore
Interrupted fern	*Osmunda claytoniana* L.
Lady fern	*Athyrium filix-femina* (L.) Roth var. *michauxii*
Long beech fern	*Phegopteris connectilis* (Michx.) Watt
Maidenhair fern	*Adiantum pedatum* L. ssp. *pedatum*
Marginal shield fern	*Dryopteris marginalis* (L.) Gray
Marsh fern	*Thelypteris palustris Schott* var. *pubescens* (Lawson) Fern.
Oak fern	*Gymnocarpium dryopteris* (L.) Newm. ssp. *dryopteris*
Ostrich fern	*Matteuccia struthiopteris* (L.) Todaro var. *pensylvanica* (Willd.) Morton
Rattlesnake fern	*Botrychium virginianum* (L.) Sw. var. *virginianum*
Royal fern	*Osmunda regalis* L. var. *spectabilis* (Willd.) Gray
Sensitive fern	*Onoclea sensibils* L.
Silvery spleenwort	*Athyrium thelypterioides* (Michx.) Desv.
Spinulose wood fern	*Dryopteris carthusiana* (Vill.) H.P. Fuchs
Walking fern	*Camptosorus rhizophyllus* (L.) Link

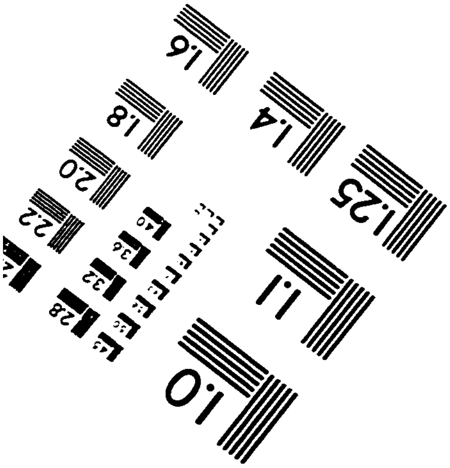
TEST TARGET (QA-3)

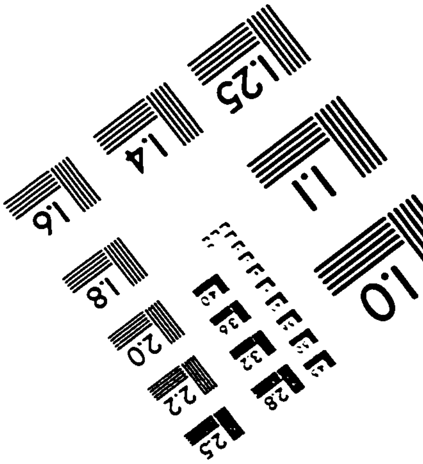












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