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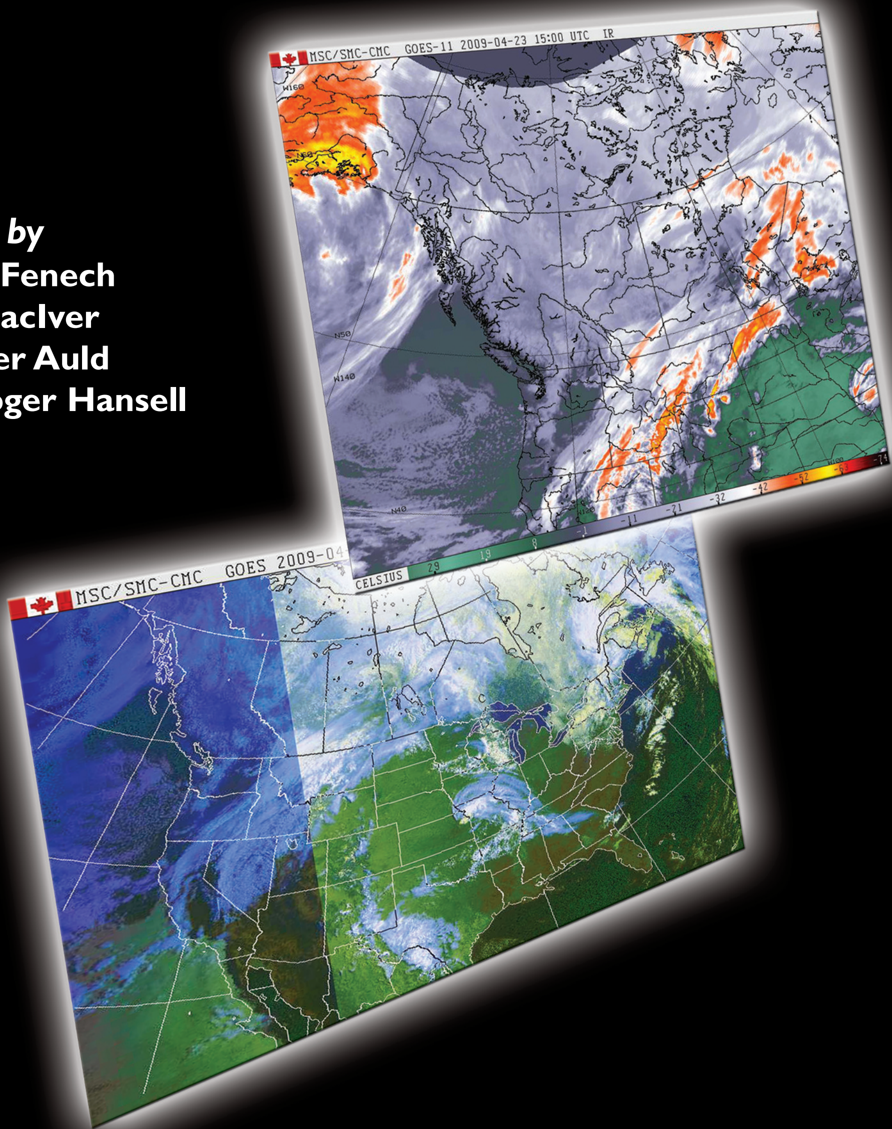
Integrated Mapping Assessment



Edited by
Adam Fenech
Don MacIver
Heather Auld
and Roger Hansell

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To obtain additional copies, please contact:
Adaptation and Impacts Research Division
Environment Canada
4905 Dufferin Street
Toronto, Ontario, Canada M3H 5T4
Contact: Don MacIver

Design: BTT Communications

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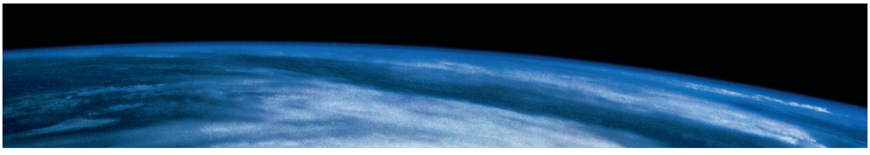

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Executive Summary

In 2000, the Institute for Environmental Studies (IES) at the University of Toronto and Environment Canada established an Integrated Mapping Assessment Project (IMAP) Lab at the University of Toronto (UofT). IMAP has been engaged in collecting published maps on topics such as climate, severe weather, air quality, human health, woodlots, wetlands, wildlife, land-use, roads and many other themes, and then functionally linking and integrating these map surfaces together on specific issues such as atmospheric change and biodiversity.

All papers in this volume have two things in common – each emerges from a research study conducted at the IMAP Lab at the University of Toronto; and each looks at change. Change can be defined as making something different from what it would be if left alone. This volume examines environmental changes, both natural and human-induced, with its papers organized around three major themes of change – climate change; landscape change; and social change.

Climate Change

The first theme of climate change begins with a paper by Fenech and Chiotti (2005) examining the effects of climate change on the West Nile virus. As of 2002, the West Nile virus has spread to and throughout Ontario leading to one human death in the late summer. It is not known how the virus entered Ontario – whether it was an infected bird (imported, migratory or overwintering), mosquito, human or other vertebrate host. The West Nile virus is spread when infected birds that have high levels of West Nile virus in their blood are bitten by mosquitoes. The infected mosquitoes can then transmit the West Nile virus to humans or other animals. In North America, the West Nile virus cycles through 3 species of mosquitoes described as initiator, amplifier and bridger with the *Culex restuans*, *Culex pipiens* and *Culex salinararius* playing each role respectively. Wild birds are the principal hosts of the West Nile virus, especially the American crow which also plays an important role in signaling the epi-centre of the virus outbreak two weeks prior to peak exposures, and the onset of severe symptoms in humans. The West Nile virus fever in humans usually is an influenza-like illness, but occasionally, the more severe symptoms of meningitis or encephalitis occur. Studies have shown that only 20 percent of all humans (1 in 5) infected with the West Nile virus exhibit adverse effects. Temperature and other climate factors can be implicated in the spread and severity of the West Nile virus across North America, yet the range of influence that climatic factors play is not entirely known. Fenech and Chiotti show that under future climate change scenarios, climatic conditions conducive to the spread and severity of the West Nile virus will increase. The authors recommend management options including monitoring the spread of infection; reducing human exposure to infected vectors; preventing initiation and magnification of the virus; screening blood supplies and other products capable of spreading the virus; and conducting public information campaigns.

Liu *et al.* (2005) examine the impact of excessive rainfall on waterborne diseases in southern Ontario by examining the Walkerton case study example. The occurrence of excessive rainfall over a five day period in Walkerton, Ontario resulted in one of Canada's most severe waterborne disease outbreaks, killing 7 people with thousands becoming ill. Many factors are associated with the transportation of contaminated water, including rainfall, runoff, soil moisture status, temperature and evapotranspiration. The unique synoptic situation leading to this excessive rainfall event was characterized by two slowly moving deep low-pressure systems, which passed through southern Ontario consecutively, with both of the low-pressure centers crossing the Walkerton area. The five-day cumulative rainfall, beginning with four days of 15-20 mm each day, followed on the fifth day by a 70 mm rainfall, exceeds both the 90th percentile and the two standard deviation of the 30-year rainfall mean for Walkerton. Further analysis of soil moisture budgets showed saturated soil conditions were present during this rainfall event, resulting in surface runoff, an effective mechanism for the transport of contamination into drinking-water systems. Liu *et al.* present radar images providing an assessment of the spatial extent of this rainfall event plus the timing of the rain events over the five-day period. Interestingly, most of the rain occurred during the late evening or nighttime hours, raising the question whether residents fully understood the amounts and the impact of accumulated rain, runoff and contamination. Theauthors explore the meteorological forecast potential to develop a WellHead Protection Alert System (WELLPASS) for either municipal or private drinking-water systems. It is proposed that advisories, based on the Quantitative Precipitation Forecast and 90% thresholds, would be issued to warn residents, days in advance, of the risk of excessive rainfall and hence the potential for surface runoff. Drinking-water wells, under the influence of surface water, would be particularly vulnerable during these rainfall alert events, requiring adaptive management actions.

Fenech *et al.* (2005) present the results of a study examining the impact of climate on changes in the seasonal timing of life cycle events of eastern Canada from 1901 to 1924. During this time, an influential inspector of schools in Nova Scotia, Dr. A.H. MacKay, recruited a number of knowledgeable teachers around the province to use their students to observe 100 natural occurrences each year, and report them in a standardized way. This is the science of phenology - the study of the seasonal timing of life cycle events. These observations included the appearance of blooming wildflowers, cultivated plants, migratory birds, mammals, amphibians plus the freezing of lakes and rivers, appearance of frost and snow, number and severity of thunderstorms, hurricanes, etc. In addition, the timing of human agricultural practices was also recorded, including calving, seeding, potato planting, and haying. Tracking the timing of naturally occurring events helps show trends in the effects on biota and human activities as a result of climate change and weather variability. Analysis has shown that earlier Springs can be linked to El Niño events, and a trend has been observed towards earlier plant development over the last 40 years in the Edmonton, Alberta area - a trend that matches trends in warmer January to June temperatures in Western Canada. Some plant and animal life cycle events integrate the effects of various climate factors and can be used to detect subtle trends against the noisy background of normal weather variability. Many centuries of plant phenology records from Europe show us that plants and animals are sensitive weather instruments: they can be used for recording climate variables (heat, precipitation, wind) and for forecasting the best time for planting, harvesting, treating for pests, avoiding pollen or planning your holidays. Knowing valuable seasonality information such as the timing of spring flowering helps decision making for farmers and foresters, that is, to correctly time operations such as planting, fertilizing, crop protection (integrated pest management) and to predict harvest timing. It also is useful in wildlife management (the survival of deer fawns is greater in years with early spring arrival); human health (pollen warnings for allergy sufferers), and tourism (best times to photograph flowers or animals, or to go fly fishing). MacKay was an acclaimed botanist whose lichen collection and publications are part of the Nova Scotia Museum resources. The records from his environmental observation project are also part of the Nova Scotia Museum collection, and are a valuable source of data. With over 1500 Nova Scotian schools participating, MacKay filled 20 thick volumes with meticulous records of the natural environment (6 are summary volumes). In 1998, these records were digitized, put into a database, and are now available for study. Fenech *et al.* examine the 20 years of MacKay data identifying trends in phenology and human activity, and its possible messages for climate change in eastern Canada.

The final paper under the climate change theme is presented by Karsh (2005) on biodiversity research and plant hardiness zones across a southern Ontario transect. The paper compares expected species lists for the new plant hardiness zones with species lists collected by volunteers in SI/MAB plots along a longitudinal gradient in the Niagara Escarpment from Long Point to Wiarton.

Scientists have currently documented 12 tree families at Long Point and nine tree families at Wiarton. The expected loss in the number of tree families in Long Point, as predicted by the new plant hardiness zones, could result in a potential biodiversity crisis for Ontario. Our native species diversity could be threatened, especially species growing in the Carolinian Region of Ontario, one of the most diverse areas in Canada. Karsh says that native species that have been naturally adapted to our Canadian climates may potentially be lost. Detailed examples of biodiversity data are discussed using a Southern Ontario case study. In addition, Karsh presents recommendations for future paired SI/MAB plots. The author concludes that ongoing monitoring on these paired 1 ha SI/MAB sites by the volunteer sector and ACER (Association for Canadian Education Resources) can provide scientists with an early detection of changes in the landscape, especially in high impact areas.

Landscape Change

The second theme of the book - landscape change - begins with a paper by Butt *et al.* (2005) who examine the impacts of European colonization since 1750 on the landscape of southern Ontario, Canada. As European settlement in southern Ontario began in the 18th Century, land was prepared for agriculture by draining wetlands and removing trees, leading to altered and continually stressed ecosystems. To illustrate the changing landscape, the authors use a Geographic Information System (GIS) to create a first approximation map of the pre-European land cover of southern Ontario. This was derived from survey notes of the original land surveys of European settlement completed from 1798-1850. When compared to a modern day map of landscape coverage, results show a decrease in forested land from more than 80 percent to less than 20 percent. The implications are decreasing forest diversity and loss of forest cores to support sensitive wildlife species resulting in significant changes in the overall forest ecology.

Fenech *et al.* (2005) present the implications of changes in the major roads of southern Ontario, Canada 1935-1995 for protected areas. Roads are important indicators of environmental change as forested lands are cleared and wetlands are drained to make the roads. Roads also open up areas to further human development leading to declining wildlife habitat and increased introduction of invasive species. Fenech *et al.* examine changes in the major roads of southern Ontario every decade from 1935 to 1995. The authors began with a digitized 1995 road map of Ontario and hard copy road maps from the Ontario archives for 1985, 1975, 1965, 1955, 1945 and 1935. Using a geographic information system, roads not present on the 1985 map were removed from the 1995 digitized map. This was repeated for every ten year interval map. Maps are presented to illustrate the dramatic changes in roads around three areas of southern Ontario with varying levels of environmental protection: the Oak Ridges Moraine, the Niagara Escarpment and Algonquin Park.

The final paper under the landscape change theme is presented by Fenech *et al.* on the landscape changes at Canada's Biosphere Reserves. The results of landscape change studies at six of Canada's Biosphere Reserves show that resource development and human settlement are the major drivers of landscape changes at Biosphere Reserves since European settlement of Canada. Most of the major landscape changes occurred in the early days of European settlement of Canada, yet significant changes are occurring today. Resource development and human settlement is common across all the studies resulting in landscape changes including: the removal of forests, conversion of grasslands and draining of wetlands in order to convert land for agricultural purposes; and the building of houses, roads and other infrastructure to support an ever-increasing human population. Landscape changes at Biosphere Reserves have significantly fragmented wildlife habitats threatening wildlife species such as the grizzly bear (Waterton), caribou (Charlevoix) and scarlet tanager (Niagara Escarpment). These species are reflecting the impacts of land use change as indicators of overall wildlife habitat decline. The protected areas at Biosphere Reserves provide an opportunity to support wildlife species, but when species require more undisturbed area than the protected areas can provide, then certain wildlife become threatened. The authors demonstrate the significant insights about changes that humans have brought on the landscapes around Biosphere Reserves since European settlement of Canada that can be gathered from existing landscape data and information around protected areas.

Social Change

The third and final theme of the book – social change – begins with Timmerman *et al.'s* (2005) paper on exploring emerging environmental issues. 'Emerging issues' has emerged as an important theme in recent years, partly as an element in a diverse mix of 'strategic thinking' approaches. Emerging issues can be defined as those issues (both positive and negative) that are not generally or immediately recognized but which will have significant impact on human and/or ecosystem health in the 21st century. The authors detail the results of two studies attempting to identify emerging environmental issues in Canada, as well as internationally in the field of atmospheric and climate sciences. Emerging issues of climate change and biodiversity in Canada - and severe weather and climate change detection in the atmospheric and climate sciences - are identified using both written surveys and key actor interviews. The authors identify the next steps in the future study of emerging environmental issues.

The final paper in the book authored by Fenech (2005) is on social learning in the management of global atmospheric risks. Social learning is how humans, as individuals and groups, adopt and spread new concepts, knowledge and skills. There was a clear recognition during the late 1980s of the need for a better understanding of how human societies perceive and respond to global environmental change. Applying this "social learning" framework to the identification of global atmospheric risks, this paper traces the evolution of efforts of individuals and agencies in Canada to address the issues of stratospheric ozone depletion and climate change focusing on how an issue became an issue, how it was framed and how it received attention. Fenech draws four conclusions from his study. One obvious observation is that scientists "learned" from other scientists, although Canadian scientists usually "learned" from scientists from countries other than Canada. Another obvious observation is that media attention to a scientific issue acted as a "teacher" of the Canadian public (the "learner") creating a controversy that sparked scientific investigation and government action, although the surprise here is that the media attention was American in origin. A third conclusion was that the common stable of atmospheric scientists in Canada (the Meteorological Service) allowed for cross-issue learning in the areas of atmospheric monitoring, research and modelling. And finally, the authors conclude that the time period for an idea of global change growing into an accepted issue can be quite long, even decades.

The short history of the Integrated Mapping Assessment Project at the University of Toronto is an active and successful one. This volume details some of that success from the IMAP research projects; the IMAP symposia, conferences, workshops and events; the IMAP publications; and the partnerships made by IMAP with other organizations, students and professors. The co-location of Environment Canada scientists at universities has proved successful in the case of the IMAP Lab at the University of Toronto. The editors of this volume support continuing partnerships in this area.

Adam Fenech
Don MacIver
Heather Auld
Roger Hansell

Résumé

En 2000, l'Institut pour l'étude de l'environnement de l'Université de Toronto et Environnement Canada ont mis sur pied un laboratoire de projet d'évaluation de la cartographie intégrée à l'Université de Toronto. Dans le cadre du projet d'évaluation de la cartographie intégrée, des cartes déjà publiées qui traitent de sujets comme le climat, le temps violent, la qualité de l'air, la santé humaine, les terrains boisés, les terres humides, les espèces sauvages, l'utilisation des terres, les routes ainsi que de nombreux autres thèmes sont collectées, puis elles sont fonctionnellement intégrées et reliées entre elles en fonction d'enjeux bien précis comme les changements atmosphériques et la biodiversité.

Tous les articles de ce volume ont deux choses en commun – chacun est issu d'une étude de recherche menée au laboratoire de projet d'évaluation de la cartographie intégrée de l'Université de Toronto et chacun examine le changement. Le changement peut être défini comme le fait de rendre quelque chose différent de ce qu'il aurait été si rien n'avait été fait. Ce volume examine les changements environnementaux, qu'ils soient naturels ou anthropiques, à l'aide d'articles qui s'articulent autour de trois thèmes principaux du changement – les changements climatiques, les changements à l'échelle du paysage et les changements sociaux.

Changements climatiques

Le premier thème des changements climatiques commence par un article de Fenech et Chiotti (2005) dans lequel les auteurs examinent les effets des changements climatiques sur le virus du Nil occidental. Dès 2002, le virus du Nil occidental s'était propagé à tout l'Ontario, causant la mort d'une personne à la fin de l'été. On ignore de quelle façon le virus est entré en Ontario – par un oiseau contaminé (importé, migrateur ou hivernant), un moustique, un être humain ou un autre hôte vertébré. Le virus du Nil occidental se propage lorsque des oiseaux contaminés qui ont de fortes concentrations du virus dans le sang sont piqués par des moustiques. Les moustiques contaminés peuvent alors transmettre le virus du Nil occidental à l'homme ou à d'autres animaux. En Amérique du Nord, le virus du Nil occidental opère son cycle par 3 espèces de moustiques décrites comme l'amorceur, l'amplificateur et le dérivateur, le *Culex restuans*, le *Culex pipiens* et le *Culex salinararius* qui assument respectivement chaque rôle. Les oiseaux sauvages sont les hôtes principaux du virus du Nil occidental, en particulier la Corneille d'Amérique qui joue également un rôle important puisqu'elle signale l'épicentre de l'épidémie virale 2 semaines avant l'exposition maximale et le début de l'apparition des symptômes graves chez

l'homme. La fièvre causée par le virus du Nil occidental chez l'homme évoque généralement les symptômes d'une grippe, mais à l'occasion, des symptômes plus graves de méningite ou d'encéphalite peuvent apparaître. Les études montrent qu'à peine 20 % de tous les êtres humains (un sur cinq) contaminés par le virus du Nil occidental présentent des symptômes sérieux. La température et d'autres facteurs climatiques peuvent entrer en jeu dans la propagation et la gravité du virus du Nil occidental en Amérique du Nord, même si l'on ne connaît pas parfaitement l'ampleur de l'influence des facteurs climatiques. Fenech et Chiotti montrent qu'en vertu des scénarios de changements climatiques futurs, les conditions climatiques propices à la propagation et à la gravité du virus du Nil occidental se multiplieront. Les auteurs recommandent des options de gestion, par exemple suivre de près la propagation de l'infection, réduire l'exposition humaine aux vecteurs contaminés, prévenir les cycles amorceur et amplificateur du virus, procéder à un dépistage des réserves de sang et des autres produits propagateurs du virus, et mener des campagnes d'information publiques.

Liu *et al.* (2005) ont étudié l'effet de pluies excessives sur les maladies d'origine hydrique dans le sud de l'Ontario en se penchant sur l'exemple de l'étude de cas de Walkerton. Les pluies excessives qui sont tombées sur Walkerton (Ontario) pendant une période de 5 jours ont entraîné une des plus graves poussées de maladies hydriques au Canada, tuant 7 personnes et rendant malades des milliers d'autres. De nombreux facteurs sont liés au transport de l'eau contaminée, y compris la pluie, le ruissellement, l'humidité du sol, la température et l'évapotranspiration. La situation synoptique unique ayant mené à ces chutes de pluie excessives était caractérisée par 2 systèmes dépressionnaires en basse altitude, se déplaçant lentement, qui sont passés l'un après l'autre sur le sud de l'Ontario, le centre des 2 dépressions traversant la région de Walkerton. L'accumulation de pluie pendant les 5 jours, à commencer par de 15 à 20 mm chaque jour pendant les 4 premiers jours, suivis de 70 mm le cinquième jour, dépasse le 90e centile et les 2 écarts types de la moyenne sur 30 ans des chutes de pluie pour Walkerton. Une analyse plus approfondie des bilans d'humidité du sol a montré que les sols étaient saturés pendant cet événement de pluie, ce qui a entraîné un écoulement de surface, un mécanisme efficace pour le transport de la contamination dans les systèmes d'eau potable. Liu *et al.* présentent des images radars qui montrent l'étendue spatiale de cet événement de pluie ainsi que le rythme des événements de pluie au cours de la période de 5 jours. Fait intéressant, la majeure partie de la pluie est tombée en fin de soirée ou au cours de la nuit, ce qui soulève la question de savoir si les résidants ont eu pleinement conscience des accumulations de pluie et des répercussions de ces accumulations, du ruissellement et de la contamination. Les auteurs étudient le potentiel des prévisions météorologiques afin de mettre au point un système d'alerte pour la protection des têtes de puits (WELLPASS), tant pour les réseaux municipaux d'eau potable que pour les installations individuelles d'alimentation en eau potable. Ils proposent que des avis qui sont fondés sur les prévisions quantitatives de précipitation et un seuil de 90 % soient émis pour avertir les résidants, plusieurs jours à l'avance, des risques de chutes de pluie excessives et donc de la possibilité de ruissellement de surface. Au cours de ces événements de chutes de pluie excessive, les puits d'eau potable, qui sont influencés par les eaux de surface, sont particulièrement vulnérables et nécessitent des mesures de gestion adaptées.

Fenech *et al.* (2005) présentent les résultats d'une étude qui examine l'effet des changements climatiques sur le rythme saisonnier d'événements liés au cycle de vie de l'est du Canada de 1901 à 1924. Au cours de cette période, un inspecteur d'école influent de la Nouvelle-Écosse, A.H. MacKay (Ph. D.), a recruté un certain nombre d'enseignants d'expérience de la province pour qu'ils demandent à leurs élèves d'observer une centaine de phénomènes naturels chaque année, puis d'en rendre compte selon une méthode normalisée. Il s'agit de la science de la phénologie – l'étude des variations des phénomènes périodiques de la vie végétale et animale. Les élèves devaient observer, entre autres, l'apparence des fleurs sauvages en floraison, des plantes cultivées, des oiseaux migrateurs, des mammifères et des amphibiens, ainsi que le phénomène des lacs et des rivières qui gèlent, l'apparence de la gelée et de la neige, le nombre d'orages, d'ouragans, etc., et leur importance. De plus, le calendrier des pratiques agricoles humaines devait être consigné, y compris la mise bas, l'ensemencement, la plantation des pommes de terre et la fenaison. En faisant le suivi de la chronologie des phénomènes naturellement présents, il est plus facile de dégager les tendances des effets des changements climatiques et des conditions météorologiques variables sur le biote et les activités humaines. Les analyses ont montré que les printemps précoces sont peut-être liés aux épisodes El Niño et une tendance selon laquelle les plantes se développeraient plus tôt a été observée au cours des 40 dernières années dans la région d'Edmonton, en Alberta – une tendance qui correspond à la tendance de températures plus chaudes entre janvier et juin observées dans l'ouest du Canada. Certains événements du cycle de vie végétal et animal intègrent les effets de divers facteurs climatiques et peuvent être utilisés pour dégager des tendances subtiles dans le brouhaha de la variabilité normale des conditions météorologiques. De nombreux siècles d'observations phénologiques des plantes en Europe nous montrent que les plantes et les animaux sont des instruments météorologiques sensibles qui peuvent nous aider à consigner les variables climatiques (chaleur, précipitations, vent) et à faire des prévisions quant au meilleur moment pour planter, récolter, appliquer des traitements contre les organismes nuisibles, éviter le pollen ou planifier nos vacances. Le fait d'avoir des renseignements précieux sur la saisonnalité, comme le moment de la floraison printanière, aide les cultivateurs et les forestiers à prendre des décisions pour coordonner adéquatement les activités comme la plantation, la fertilisation et la protection des cultures (lutte antiparasitaire intégrée) et pour prédire le calendrier des récoltes. De tels renseignements sont également utiles pour la gestion des espèces sauvages (la survie des faons du chevreuil est meilleure les années où le printemps est précoce), la santé humaine (avis de pollen à l'intention des personnes souffrant d'allergies) et le tourisme (quel est le meilleur temps pour photographier les fleurs ou les animaux ou encore pour aller à la pêche à la mouche). Mackay était un botaniste de renommée dont la collection de lichen et les publications sont conservées au Musée de la Nouvelle-Écosse. Les notes prises dans le cadre de son projet d'observation de l'environnement font également partie de la collection du Musée de la Nouvelle-Écosse et constituent une précieuse source de données. Avec plus de 1 500 écoles de la Nouvelle-Écosse qui participaient, Mackay a rempli 20 gros volumes d'observations méticuleuses du milieu naturel (6 sont des volumes sommaires). En 1998, ces observations ont été numérisées et mises dans une base de données, et elles peuvent maintenant faire l'objet d'études. Fenech *et al.* examinent les données que Mackay a recueillies sur 20 ans et dégagent des tendances relatives à la phénologie et à l'activité humaine, ainsi que les messages possibles que ces tendances véhiculent au sujet des changements climatiques dans l'est du Canada.

Le dernier article sur le thème des changements climatiques est présenté par Karsh (2005) et traite des recherches portant sur la biodiversité et les zones de rusticité le long d'un transect dans le sud de l'Ontario. Une comparaison est établie entre les espèces que l'on s'attend à observer dans les nouvelles zones de rusticité et les espèces récoltées par des bénévoles dans des parcelles d'étude de la biodiversité de la Smithsonian Institution, le long d'un gradient longitudinal au sein de l'escarpement du Niagara, entre Long Point et Wiarton. À l'heure actuelle, les scientifiques ont dénombré 12 familles d'arbres à Long Point et 9 à Wiarton. La perte prévue de familles d'arbres à Long Point, telle qu'on la prédit d'après les nouvelles zones de rusticité, pourrait provoquer une éventuelle crise sur le plan de la biodiversité en Ontario. La diversité des espèces indigènes telle qu'on la connaît pourrait être menacée et ce sont tout particulièrement les espèces qui poussent dans la région carolinienne de l'Ontario, l'une des zones les plus diversifiées au Canada, qui sont menacées. Karsh affirme que les espèces indigènes qui se sont naturellement adaptées au climat canadien pourraient éventuellement disparaître. Des exemples détaillés de données sur la biodiversité font l'objet de discussions dans le cadre d'une étude de cas menée dans le sud de l'Ontario. En outre, Karsh fait des recommandations pour les futures parcelles d'étude appariées de la Smithsonian Institution. L'auteur conclut qu'une surveillance continue des sites d'étude appariés de la Smithsonian Institution, dont la superficie est de 1 ha, assurée par des bénévoles et l'ACER (Association for Canadian Educational Resources), peut fournir aux scientifiques des indices précoces des changements à l'échelle du paysage, en particulier dans les zones très touchées.

Changements à l'échelle du paysage

Le deuxième thème du livre – changements à l'échelle du paysage – commence par un article de Butt *et al.* (2005) qui examinent les répercussions de la colonisation européenne depuis les années 1750 sur le paysage du sud de l'Ontario, au Canada. Lors de la colonisation européenne dans le sud de l'Ontario, qui a débuté au XVIIIe siècle, les terres ont été préparées pour l'agriculture en procédant au drainage des terres humides et à l'élimination des arbres, transformant ainsi les écosystèmes et créant des écosystèmes perturbés en permanence. Pour illustrer le paysage changeant, les auteurs utilisent un système d'information géographique (SIG) afin de créer une première carte approximative de la couverture terrestre préeuropéenne du sud de l'Ontario. Cette carte a pu être tracée à l'aide des notes des premiers travaux d'arpentage de la colonisation européenne réalisés entre 1798 et 1850. Lorsqu'ils sont comparés à une carte contemporaine de la couverture du paysage, les résultats indiquent une diminution de la superficie des terres forestières, qui est passée de plus de 80 % à moins de 20 %. Les implications de cette réduction des terres forestières sont une diminution de la diversité forestière et une disparition des centres forestiers qui assurent la subsistance des espèces sauvages sensibles, entraînant d'importants changements dans l'ensemble de l'écologie de la forêt.

Fenech *et al.* (2005) présentent les implications pour les aires protégées attribuables aux modifications apportées aux routes principales du sud de l'Ontario entre 1935 et 1995. Les routes sont des indicateurs importants des changements environnementaux parce que des terres forestières sont déboisées et des terres humides sont asséchées pour construire ces routes. Les routes permettent également l'aménagement éventuel du territoire, lequel mène à un déclin de l'habitat faunique et à une augmentation des espèces envahissantes introduites. Fenech *et al.* examinent les modifications apportées aux routes principales du sud de l'Ontario, tous les dix ans, de 1935 à 1995. Les auteurs ont commencé par une carte routière numérisée de l'Ontario datant de 1995 et de cartes routières papier de 1985, 1975, 1965, 1955, 1945 et 1935, obtenues dans les archives de l'Ontario. À l'aide d'un système d'information géographique, les routes qui n'étaient pas représentées sur la carte de 1985 ont pu être supprimées de la carte numérisée de 1995. Ce processus a été répété pour toutes les cartes à intervalle de dix ans. Les cartes sont présentées pour illustrer les modifications spectaculaires apportées aux routes dans les environs de trois régions du sud de l'Ontario qui bénéficient de différents niveaux de protection environnementale : la moraine d'Oak Ridges, l'escarpement du Niagara et le parc Algonquin.

Le dernier article du thème changements à l'échelle du paysage est présenté par Fenech *et al.* et porte sur les changements observés à l'échelle du paysage des réserves de la biosphère canadienne. Les résultats d'études sur les changements à l'échelle du paysage de six réserves de la biosphère du Canada révèlent que l'exploitation des ressources et les établissements humains sont les principaux catalyseurs des changements à l'échelle du paysage des réserves de la biosphère depuis la colonisation européenne du Canada. La plupart des changements majeurs à l'échelle du paysage ont eu lieu au début de la colonisation européenne du Canada, mais des changements importants se produisent encore aujourd'hui. L'exploitation des ressources et les établissements humains sont des facteurs communs dans toutes les études qui concluent à des changements à l'échelle du paysage, y compris : la destruction des forêts, la conversion des prairies et le drainage des terres humides dans le but de transformer les terres à des fins agricoles, et la construction de maisons, de routes et autres infrastructures pour subvenir aux besoins d'une population humaine toujours croissante. Les changements à l'échelle du paysage des réserves de la biosphère ont fragmenté de façon importante les habitats fauniques, menaçant des espèces sauvages comme le grizzli (Waterton), le caribou (Charlevoix) et le Piranga écarlate (escarpement du Niagara). Ces espèces sont le reflet des effets des changements dans l'utilisation des terres, car elles sont des indicateurs du déclin global de l'habitat faunique. Les aires protégées au sein des réserves de la biosphère sont un moyen d'assurer la subsistance des espèces sauvages, mais lorsque les espèces ont besoin de zones non perturbées plus importantes que ce qu'offrent les aires protégées, certaines espèces sauvages deviennent alors menacées. Les auteurs expliquent les importantes réflexions émises concernant les changements apportés à l'échelle du paysage par l'homme dans les réserves de la biosphère depuis la colonisation européenne au Canada qui peuvent être déduites des données actuelles sur le paysage et des renseignements au sujet des aires protégées.

Changements sociaux

Le troisième et dernier thème du livre – changements sociaux – commence par l'article de Timmerman *et al.* (2005) sur l'étude des enjeux environnementaux émergents. Les « enjeux émergents » sont devenus un important thème au cours des dernières années, partiellement en tant qu'élément d'un ensemble d'approches de « réflexion stratégique ». Les enjeux émergents sont définis comme des enjeux (tant positifs que négatifs) qui ne sont pas généralement ni immédiatement reconnus, mais qui auront des conséquences importantes sur la santé humaine et sur la santé des écosystèmes au XXIe siècle. Les auteurs exposent en détail les résultats de deux études qui tentent de cerner les enjeux environnementaux émergents, au Canada ainsi que partout ailleurs dans le monde, dans le domaine des sciences du climat et de l'atmosphère. Les nouveaux enjeux en matière de changements climatiques et de biodiversité au Canada – et la détection des changements climatiques et des phénomènes de temps violent dans le cadre des sciences de l'atmosphère et du climat – sont mis en lumière à l'aide de sondages et d'entrevues auprès des intervenants clés. Les auteurs définissent les prochaines étapes de la future étude des enjeux environnementaux émergents.

Le dernier ouvrage du livre, rédigé par Fenech (2005), porte sur l'apprentissage social dans le contexte de la gestion des risques atmosphériques à l'échelle mondiale. L'apprentissage social est la façon dont les humains, en tant qu'individus ou groupes, adoptent et propagent de nouveaux concepts et de nouvelles connaissances et compétences. Il est devenu clair à la fin des années 1980 qu'il était dorénavant nécessaire de mieux comprendre la façon dont les sociétés humaines perçoivent les changements environnementaux à l'échelle du globe et comment elles y réagissent. L'ouvrage, qui applique ce cadre d'« apprentissage social » pour définir les risques atmosphériques à l'échelle mondiale, trace l'évolution des efforts individuels et organisationnels déployés au Canada pour s'attaquer aux enjeux de l'appauvrissement de la couche d'ozone stratosphérique et des changements climatiques, en mettant l'accent sur la façon dont un enjeu est devenu un enjeu, la façon dont il a été formulé et la façon dont il a fait l'objet d'un examen. Fenech tire quatre conclusions de l'étude. Une observation évidente est que les scientifiques « ont acquis des connaissances » auprès d'autres scientifiques, même si les scientifiques canadiens ont le plus souvent « appris » de scientifiques étrangers. Une autre observation évidente est que l'attention médiatique à une question scientifique a joué un rôle d'« enseignant » auprès de la population canadienne (« apprenant »), créant une controverse qui a déclenché une étude scientifique et des mesures gouvernementales, quoique la surprise ici fût que l'attention médiatique était d'origine américaine. Une troisième conclusion est que l'équipe canadienne de scientifiques de l'atmosphère (le Service météorologique) a permis des apprentissages transversaux dans les domaines de la surveillance, de la recherche et de la modélisation de l'atmosphère. Enfin, les auteurs concluent qu'il pourrait s'écouler beaucoup de temps, voire même des décennies, avant que l'idée de l'augmentation des changements climatiques à l'échelle du globe soit acceptée.

L'histoire du projet d'évaluation de la cartographie intégrée à l'Université de Toronto est brève, mais elle est dynamique et couronnée de succès. Le présent volume expose en détail une partie du succès des projets de recherche liés au projet d'évaluation de la cartographie intégrée ainsi que les symposiums, les conférences, les ateliers et les événements sur le projet d'évaluation de la cartographie intégrée, les publications sur le sujet et les partenariats conclus entre le projet d'évaluation et d'autres organisations, étudiants et professeurs. Le regroupement des scientifiques d'Environnement Canada dans les universités s'est avéré une réussite dans le cas du laboratoire du projet d'évaluation de la cartographie intégrée, à l'Université de Toronto. Les rédacteurs du présent volume appuient les partenariats permanents dans ce domaine.

Adam Fenech
Don MacIver
Heather Auld
Roger Hansell

PAPER 1

INTEGRATED MAPPING ASSESSMENT PROJECT (IMAP): A SUMMARY OF ACTIVITIES AT THE IMAP LAB OF THE UNIVERSITY OF TORONTO

ADAM FENECH[1], ROGER HANSELL[2], DON MACIVER[1] and HEATHER AULD[1]

[1]Environment Canada, Toronto, Ontario, Canada
[2]University of Toronto, Toronto, Ontario, Canada

ABSTRACT: In 2000, the Institute for Environmental Studies (IES) at the University of Toronto and Environment Canada established an Integrated Mapping Assessment Project (IMAP) Lab at the University of Toronto (UofT). IMAP has been engaged in collecting published maps on topics such as climate, severe weather, air quality, human health, woodlots, wetlands, wildlife, land-use, roads and many other themes, and then functionally linking and integrating these map surfaces together on specific issues, such as atmospheric change and biodiversity. The final maps are then assessed spatially at various scales, from local to global, although the initial focus of the study has been on regions of Ontario, where a range of detailed, high-quality maps are already available. This paper details the history of IMAP; IMAP directors; IMAP research projects; IMAP symposia, conferences, workshops and events; IMAP publications; IMAP student support; and IMAP course support. The co-location of Environment Canada scientists at universities has proved successful in the case of the IMAP Lab at the University of Toronto. The authors support continuing partnerships in this area.

Keywords: integrated assessment, Canada, science partnerships

1. Introduction

In 2000, the Institute for Environmental Studies (IES) at the University of Toronto and Environment Canada established an Integrated Mapping Assessment Project (IMAP) Lab at the University of Toronto (UofT). IMAP has been engaged in collecting published maps on topics such as climate, severe weather, air quality, human health, woodlots, wetlands, wildlife, land-use, roads and many other themes, and then functionally linking and integrating these map surfaces together on specific issues, such as atmospheric change and biodiversity. The final maps are then assessed spatially at various scales, from local to global, although the initial focus of the study has been on regions of Ontario, where a range of detailed, high-quality maps are already available. This regional focus is an important part of the project's goal of bringing national issues, such as climate change, to a level that municipal decision-makers can understand and take action on.

The IMAP office is located at Room 1047A, Earth Sciences Centre, 5 Bancroft Avenue entrance at the University of Toronto's St. George Campus (main campus) in Toronto, Ontario, Canada. IMAP has been administered by four directors (presented alphabetically): Heather Auld, Adam Fenech, Roger Hansell and Don MacIver.

Heather Auld is a meteorologist and climatologist with the Meteorological Service of Canada. Ms. Auld joined Environment Canada in 1979 after obtaining a Bachelor of Science in physics and a Masters of Science in meteorology. She has served as a weather forecaster in the Canadian cities of Edmonton, Vancouver, Toronto, Canadian Forces Base Trenton and has taught weather forecasting to university graduates. She has worked as a climatologist since 1988. For eight of those years, she researched and developed climatic design values for the National Building Code of Canada, building energy codes and other national infrastructure standards. Her current position with Environment Canada is with the Science Assessment and Integration Branch of the Atmospheric and Climate Science Directorate of the Meteorological Service of Canada.

Adam Fenech is a science advisor at the Meteorological Service of Canada, Environment Canada. Mr. Fenech has worked many years in the areas of climate change, air quality and stratospheric ozone depletion. Adam was seconded for two years to Harvard University working on the international Social Learning Research Project. He spent six years establishing the Ecological Monitoring and Assessment Network (EMAN) of Environment Canada. He is currently working on his doctorate in the area of integrated assessment modeling through the Department of Geography and the Institute of Environmental Studies at the University of Toronto. Adam teaches at the University of Toronto in areas of Ecological Economics, Regional Ecology and International Environmental Agreements, as well as at the Smithsonian Institution in their course on Monitoring Biodiversity Change.

Roger Hansell is a professor of Botany at the University of Toronto. He is cross-appointed at the Institute for Environmental Studies where he once served as its Director. Roger has a variety of research interests including vertical gardens and green canopies for urban environments; evolution of complex systems; and the response of the Arctic and tree-line communities to environmental changes.

Don MacIver is the Director of the Adaptation and Impacts Research Group at the Meteorological Service of Canada, Environment Canada. He has worked at a number of agencies as a meteorologist, climatologist, forester, biometrician and (forest) mensurationist. Outside of work, he is a municipal politician (namely, deputy mayor for Amaranth Township), a farmer, an environmental activist, an amateur ham radio operator and a CANWARN volunteer. Don served as a professor at York University from 1972-1981 and as an adjunct professor at the University of Toronto from 1988-1993. He worked as a biometrician and mensurationist at the Ontario Ministry of Natural Resources from 1981-1986 before joining Environment Canada in 1986 as a forest meteorologist and a climatologist.

2. IMAP Research Projects

2.1 *Atmospheric Hazards in Ontario* Website: A New Tool for Planning for Risks and Hazards from Naturally Occurring Events in Ontario

A website was developed at **www.hazards.ca** presenting background material and map data about risks and hazards from naturally occurring events in Ontario. The user is presented with various related data sets from the IMAP project, Meteorological Service of Canada and other cited references (for example, the **INFRASTRUCTURE WEATHER IMPACTS** section selects data sets from wind energy; wind loads for design; and severe ice storm loads). The website displays a map of the region with the layers of hazards information selected by the user. The user can then click on the map to "zoom in" to an area and list the values of the parameters there. The purpose was to enable the evaluation of multiple risks and to assist in the preparation of Municipal Emergency Management Programs as required by Bill 148, amendments to the Canadian province of Ontario's *Emergency Management and Civil Protection Act.*

2.2 Climate and the West Nile Virus in Ontario

This study traced the spread of the West Nile virus over the summers of 2000 to 2002, applied a risk analysis framework to the virus, and associated climate variables to the spread and severity of the virus across Ontario, Canada. This virus is a member of the Japanese encephalitis virus that can be spread to humans from birds through mosquito transmission. There have been infrequent human outbreaks, but more recently including the first outbreak in North America in New York City in 1999. Using Health Canada maps and a Geographic Information System (GIS), Fenech and Chiotti (this volume) hypothesized that the virus would be exacerbated by warmer winters allowing infected mosquitoes to survive the winter or migrating birds to winter in Ontario; by spring or early summer warmth to support bird migrations from virus infected areas of North America; and by summer heat to allow for virus incubation and transmission. The study concludes that climate is one of many variables affecting the spread and severity of the virus. As the virus has been shown to propagate in temperatures above 30°C, a climate indicator such as a "West Nile Virus Infection Threshold Alert" is recommended to provide early warnings to the public.

2.3 Linking Excessive Rainfall to the Walkerton Tragedy

This IMAP study (Liu *et al.*, this volume) focused on the occurrence of excessive rainfall over a five-day period between May 8-12, 2000 that resulted in one of Canada's worst waterborne disease outbreaks killing seven people with thousands becoming ill in Walkerton, Ontario. The five-day cumulative rainfall was unusually high and would, on average, be expected only once every 60 years or more. Drinking water from groundwater wells that are under the influence of surface water can be particularly vulnerable during excessive rainfall events. A study across the United States by Curriero *et al.* (2001) identified that in more than 51 percent of cases, there was a direct relationship between the upper 10th percentile threshold for extreme precipitation events and waterborne diseases. Using a similar approach, the IMAP study revealed that the five-day cumulative rainfall exceeded the 90th percentile of the 30-year rainfall mean for Walkerton. In the future, it may be possible to develop a WellHead Protection Alert System that could provide advisories in advance of the risk of excessive rainfall.

2.4 Changing Landscape of Southern Ontario since European Settlement

As European settlement in southern Ontario occurred, land was prepared for agriculture by draining wetlands and removing trees, leading to altered and continually stressed ecosystems. To illustrate the changing landscape, Butt *et al.* (this volume) used a Geographic Information System (GIS) to create a first approximation map of the pre-European land cover of southern Ontario. These were derived from paper survey maps by Finlay (1978) using the notes of the original land surveys of European settlement completed from 1798-1850. When compared to a modern day map of landscape coverage, results show a decrease in forested land from more than 80 percent to less than 20 percent. The implications are decreasing forest diversity and loss of forest cores to support sensitive wildlife species resulting in significant changes in the overall forest ecology.

2.5 Toronto: The Climate Change Laboratory

The heart of Toronto, Ontario, Canada is home to two-and-a-half million people with one-third of Canada's human population located within a 160 kilometer radius. Located on the northwest shore of Lake Ontario, Toronto lies within a "battleground" of colliding global air masses; the moderating influence of Lake Ontario; and the self-generating effects of urban heating. These combined effects result in winter mean temperatures that are about 3.3 degrees Celsius higher than those recorded at similar latitudes without the lake effect. Summers in Toronto are also moderated, and thus average July temperatures are 1.7 degrees Celsius cooler than similar locations in continental zones. This IMAP study examined 123 years of climate data at the downtown Toronto Climate Observatory (43° 40′ N, 79° 24′W) as compared to the rural site of Beatrice (45° 8′ N, 79° 23′ W) from 1878 to 1998. Using the comparative approach illustrated by Munn *et al.* (1999), concurrent data was analyzed for annual maximum, mean and minimum temperatures. Today, the "Toronto warming effect" has resulted in a 4.0 degree Celsius increase in the annual minimum temperatures at the downtown Toronto site since 1878. In contrast, at the rural Beatrice site, the trend is practically non-existent, with an increase of only 0.1 degrees Celsius over the 123 years of record.

2.6 Economic Valuation of Landscape Changes at Canada's Biosphere Reserves

Canada's natural environment provides ecosystem services to humans such as pollination, climate regulation, water purification, etc. At present, these ecosystem services are not valued because there is no private, organized market for such services. These services, unlike ecosystem goods such as lumber, do not go into making up a nation's Gross Domestic product (GDP). Nevertheless, their value is very large, if not infinite, since they support life itself. Using historical land surveys, aerial photos or satellite imagery, landscape change studies have revealed significant changes in the land cover across Canada over the years. The economic value of the ecosystem services provided by these land covers can be estimated using contingent valuation methods as applied by Costanza *et al.* (1997). Although difficult and fraught with uncertainties, Fenech estimated the changes in economic value of the economic services provided by landscapes in the North Halton region of the Niagara Escarpment over time. The importance of various approaches to landscape change analysis with respect to economic valuation were studied, and recommendations were made for the best approaches.

2.7 Lifestyle Meteorology

This IMAP study developed an internet tool allowing the public to access information on the physical and chemical aspects of the natural environment when seeking a place to live. For example, if you are seeking lower atmospheric pollutant levels, or simply milder temperatures, then the Lifestyle Meteorology internet tool allows you to click on maps and find the place best suited for you in southern Ontario.

2.8 Impact of Roads on Natural Areas of Southern Ontario

In a continuing study of roads and their ecological implications, Fenech *et al.* (this volume) focused on areas of southern Ontario with ecological significance and under threat of human development - the Oak Ridges Moraine, the Niagara Escarpment and Algonquin Park. The major (paved) roads in the Oak Ridges Moraine increased from 126 kilometers in 1935 to 554 kilometers in 1965 to 1016 kilometers in 1995. Most roads, which by 1995 include four multi-lane highways, run north to south creating a series of paved barriers to wildlife movement. The road density on the Oak Ridges Moraine was 0.518 kilometers in 1995, which is about 90 percent of the road density in York County, a typical county in the region. The major roads in the Niagara Escarpment increased from 173 kilometers in 1935 to 567 kilometers in 1965 to 923 kilometers in 1995. What is obvious from the maps is the increasing number of intersections of the natural corridor that the Niagara Escarpment is intended to protect. By 1995, there were 9 points at which multi-lane highways cross the escarpment, presenting a significant barrier for wildlife movement. While no quantitative analysis has been possible for the roads in Algonquin Park, a series of access roads now branch out to reach the Park, creating a "ring of roads" for recreation use at various access points to the Park. The primary concern now is not so much the barrier effect to wildlife but the potential for increases in invasive species and traffic volume into the Park as the number of access roads has increased.

2.9 Economic Valuation of the Ecosystem Services Provided by the Landscapes on the Oak Ridges Moraine

This IMAP project by Morgan (2004) was undertaken to provide an economic valuation of the ecosystem services of the western portion of the Oak Ridges Moraine (where it abuts the Niagara Escarpment) using quantified estimates of landscape types in the region (using remote sensing data), and transferring those estimates into a dollar figure based on the ecosystem services these landscapes provide to humans.

2.10 Research on Biodiversity and Frost Hardiness Zones across a Southern Ontario Transect

This research project (Karsh, this volume) compared expected species lists for the new plant hardiness zones with species lists collected by volunteers in SI/MAB plots along a longitudinal gradient on the Niagara Escarpment from Long Point to Wiarton. Scientists have currently documented 12 families at Long Point and nine families at Wiarton. The expected loss in the number of families at Long Point, as predicted by the new plant hardiness zones, could result in a potential biodiversity crisis for Ontario. Native species diversity could be threatened, especially species growing in the Carolinian Region of Ontario, one of the most diverse areas in Canada. There is a potential to lose native species that have been naturally adapted to our Canadian climates.

2.11 Changes in Major Roads of Southern Ontario

Major roads in southern Ontario increased five fold from 1935 to 1995 according to results of a recent University of Toronto study. Roads are important indicators of environmental change as forested lands are cleared and wetlands are drained to make the roads. Roads also open up areas to further human development leading to declining wildlife habitat and increased introduction of invasive wildlife species. This study (Fenech *et al.,* this volume) examined changes in the major roads of southern Ontario every decade from 1935 to 1995. The authors began with a digitized 1995 road map of Ontario and hard copy road maps from the archives for 1985, 1975, 1965, 1955, 1945 and 1935. Using a geographic information system, roads not present on the 1985 map were removed from the 1995 digitized map. This was repeated for every ten year interval map. Further study will examine how these major road changes are related to changes in forested land, agricultural activity, human population and economic development. Additional studies are planned for looking at the impact of major roads on breeding birds, and the relationship between a declining railway network, increased road traffic and climate change.

2.12 Heat as a Powerful Trigger in the Natural World, and a Major Influence on Land Use Change in Southern Ontario

Using international biodiversity protocols, this study revealed a link between climate and the family diversity of forest species – a factor that could affect conservation practices in the future. The IMAP lab also explored the possibility that, although a warmer landscape can support greater biodiversity, increases in species will come primarily from exotic or non-native species, similar to the invasions of zebra mussels and purple loosestrife.

3. IMAP Symposia, Conferences, Workshops and Events

3.1 Leading Edge Conference 2004, St. Catharines, Ontario, *March 2004*

A special session titled *Understanding the Niagara Escarpment through Integrated Mapping Techniques* was held with papers on *Atmospheric Hazards in Ontario: A New Tool for Planning for Risks and Hazards from Naturally Occurring Events in Ontario*; *Impact of Excessive Rainfall on Waterborne Diseases in southern Ontario: The Walkerton Case*; *The Change in Major Roads Along the Niagara Escarpment 1935-1995: Implications for Wildlife*; *The Change in Landscapes Along the Niagara Escarpment Since 1750: Effects of European Colonization*; *The Change in the Economic Valuation of Ecosystems and Biodiversity Along the Niagara Escarpment 1972-1994: The North Halton Case Study*; *The Spread and Severity of the West Nile*

Virus Along the Niagara Escarpment 2000-2003: Implications of Climate; and *Emerging Environmental Issues for the Niagara Escarpment: The Future Challenges.*

3.2 International Society of Biometeorology, Kansas City, *November 2002*

Heather Auld presented a paper on excessive precipitation and waterborne diseases.

3.3 International Conference on Water and Health, Ottawa, *September 2002*

Anthony Liu presented on the research of excessive precipitation and the Walkerton waterborne disease outbreak.

3.4 WSSD Day (World Summit on Sustainable Development), University of Toronto, *June 1, 2002*

The IMAP Lab celebrated the ten years since the United Nations Conference on Environment and Development (UNCED) held at Rio de Janeiro, Brazil, by hosting a WSSD Day as part of the overall Congress of the Social Sciences and Humanities. The objective of the day was to arrive at a comprehensive, frank and useful review of the past ten years, with some thoughts on future paths to global sustainable development. All of this was in anticipation of the World Summit on Sustainable Development held 26 August to 4 September 2002 in Johannesburg, South Africa. The WSSD Day at U of T, sponsored by the Canadian International Development Agency, the Environmental Studies Association of Canada (ESAC), the Canadian WSSD Secretariat and the Institute for Environmental Studies (IES), consisted of a symposium of speakers, a poster exhibit, a video diary, a youth contest and a special session on faith and the environment. Over 90 registrants attended the symposium which included sessions on emerging environmental issues; youth perspectives on water, faith and interdisciplinary study; biodiversity; NGOs and development; and education, knowledge and history.

3.5 Annual Meeting of Canadian Association of Geographers *May 2002*

A special full-day session on the *Integrated Mapping Assessment Project (IMAP) at IES* was organized for the *51st Annual Meeting of the Canadian Association of Geographers (CAG)*. Jointly hosted by the Geography departments at Ryerson Polytechnic University, the University of Toronto and York University, the 2002 CAG meetings took place at the University of Toronto in conjunction with the Congress of the Social Science and Humanities Federation of Canada. The session was an opportunity to showcase to the larger academic community and the general public through the extensive media coverage that the Congress receives. The IMAP session included studies on heat as a powerful trigger in the natural world, and a major influence on land use change in southern Ontario; major road changes across Canada from the 1930s to the 1990s; changes in major roads in natural areas of southern Ontario from 1935-95; changes in the forested landscapes of southern Ontario since European settlement; Lifestyle Meteorology: the physical and chemical aspects of the natural environment that drive modern human settlement; and changes in the economic valuation of ecosystems changes along the Oak Ridges Moraine over the past 20 years.

3.6 Niagara Escarpment, Oak Ridges Moraine, and Algonquin to Adirondack Heritage (NOAH) Workshop, Toronto, *April 2002*

A workshop was held to generate a broader interest for the concept of a large-scale wildlife corridor for southern Ontario that includes the Niagara Escarpment, Oak Ridges Moraine, and Algonquin to Adirondack Heritage (NOAH) Area. This workshop was organized by Public Spaces, a not-for-profit environmental organization dedicated to promoting stewardship and fostering a sense of community through the protection, enhancement and celebration of Ontario's public spaces. The NOAH Project emerged from the research and testimony before the Ontario Municipal Board of internationally-renowned ecologist Dr. Reed F. Noss in his attempts to inform decision-makers and the public on the need to maintain linkages between the large-scale natural corridors of southern Ontario. The workshop was co-sponsored by the Integrated Mapping Assessment Project (IMAP) of the Institute for Environmental Studies, the Public Spaces Appreciation Association of Ontario, the City of Toronto, Environment Canada, and Ontario Power Generation.

3.7 Leading Edge 2001: Focus on the Biosphere Conference, Burlington, Ontario, *October 17-19, 2001*

Members of IMAP presented papers at the fifth in a series of biennial conferences on science and management of the Niagara Escarpment, the *Leading Edge 2001: Focus on the Biosphere Conference*. This conference brought together more than 200 landowners, scientists, environmental interest groups, researchers, corporations, artists, government agencies, and representatives from other World Biosphere Reserves in Canada, USA and Europe. Conference themes included sustainable communities, research, monitoring and conservation. Members of the IMAP Lab were prominently featured in the program with:

- Preeti Ramprasad presenting on the Changing Forest Landscapes of Southern Ontario since European Settlement;
- Adam Fenech presenting on Major Road Changes In and Around the Niagara Escarpment 1935-95: Implications for the Natural Environment;

- Alexis Morgan presenting on Economic Valuation of the Ecosystem Services Provided by the Landscapes on the Oak Ridges Moraine; and
- Researcher and M.Sc. Forestry graduate Marianne Karsh presenting on Research on Biodiversity and Frost Hardiness Zones across a Southern Ontario Transect.

3.8 International workshop on Poverty, Development and Natural Capital, Toronto, *September 2001*

Along with the World Bank, Environment Canada, the Canadian International Development Agency, the International Development Research Council, U of T's Munk Centre for International Studies, Faculty of Forestry, the Connaught Fund for Symposia/Colloquia, and the Institute for Environmental Studies, IMAP co-sponsored an international conference on Natural Capital, Poverty and Development. Many key questions have emerged during debates on natural capital, poverty and development, which the conference addressed. What are realistic measures of poverty and development? Are there market or non-market mechanisms that can assign a value to natural capital? Can these valuation mechanisms facilitate decision making for poverty alleviation of natural capital based communities? What is the role of institutions in the process of development through natural capital? What are appropriate institutions for sustainable development of natural capital based communities? What are the experiences of donor agencies in designing appropriate institutional arrangements? How can fragile lands be used for poverty alleviation in land resource scarce communities? What are the experiences of developing countries and donor agencies in management of fragile lands? How can eco-tourism and biodiversity conservation programs be used for economic development of local communities? What should be the role of donor agencies in these natural capital based poverty alleviation and economic development programs. The conference was organized around four main themes: 1. Measurement issues in natural capital, poverty and development; 2. Institutions, natural capital and development; 3. Poverty, fragile lands and development; and 4. Ecotourism, biodiversity and development.

3.9 Official Launch of the IMAP Lab at UofT, *May 17, 2001*

Over 30 interested researchers joined the Institute for Environmental Studies and Environment Canada in officially launching the Integrated Mapping Assessment Project (IMAP) Lab at UofT.

3.10 Special Session at EMAN National Science Meeting, *January 2000*

Over 350 delegates from universities, federal and provincial governments, community groups and the private sector from across Canada attended the 6th annual meeting of Canada's Ecological Monitoring and Assessment Network (EMAN), held in Toronto from January 18 to 22, 2000. EMAN consists of approximately 90 research and monitoring sites located across the country with the objective of understanding what changes are occurring in Canadian ecosystems and why. Environment Canada is the coordinating partner for the network, and co-sponsored the 6th *Annual EMAN Meeting* with the Institute for Environmental Studies, IES. Over 100 research papers, and keynote speeches were presented to illustrate and explain changes occurring in Canadian ecosystems. IMAP Director, Adam Fenech, chaired a special session on Natural Capital: Valuing Ecosystems and Biodiversity. Speakers such as Roger Hansell, Acting Director of IES; Bill Rees from the University of British Columbia; Orie Loucks from Miami University; Mohammed Dore from Brock University; and Ana Isla from the Ontario Institute for Studies in Education at U of T presented the latest views on valuing the earth's natural environment. IMAP Director Don MacIver chaired a special session on Integrated Mapping Assessment. Brent Taylor, M.Sc. Candidate in U of T's Department of Planning, presented the study of the Major Road Changes in Southern Ontario from 1935-95. The presentation has led to potential partnership work in examining road development and wildlife mortality (roadkill); road development and protected/conservation areas; and an expansion of the study of road development across Canada.

4. IMAP Publications

4.1 Integrated Mapping Assessment. Edited by Adam Fenech, Roger Hansell, Don MacIver and Heather Auld. 2005.

This volume includes papers on IMAP studies including: Emerging environmental issues: the future challenges for Canada and the world by Timmerman *et al.*; The spread and severity of the West Nile virus in Ontario, Canada 2000-2003: implications of climate by Fenech and Chiotti; Excessive precipitation and waterborne diseases in southern Ontario, Canada by Liu *et al.*; The impact of climate changes in the seasonal timing of life cycle events of eastern Canada 1900 to 1920; by Fenech *et al.*; Changes in the landscape of southern Ontario, Canada since 1750: effects of European colonization by Butt *et al.*; Change in the major roads of Southern Ontario, Canada 1935-1995 by Fenech *et al.*; Landscape changes at Canada's Biosphere Reserves: an overview of land change studies by Fenech *et al.*; Social learning in the management of global atmospheric risks: a Canadian example of issue identification by Fenech; and research on biodiversity and plant hardiness zones across a Southern Ontario transect.

4.2 Integrated Mapping Assessment Project (IMAP) Website: www.utoronto.ca/imap

The IMAP Lab launched its Web site where a large collection of published maps on topics such as climate, severe weather, air quality, human health, woodlots, wetlands, wildlife, land-use, roads and many other themes can be found. The site also includes the functional linking and integration of these map surfaces together on specific issues into assessments on atmospheric change and biodiversity; roads and severe weather; climate and land use development; and severe weather and human health. All of these maps are referenced and can be easily downloaded.

4.3 Natural Capital: Views from Many Perspectives. Adam Fenech, Roger Hansell, Ana Isla, Shirley Thompson.

This report of an April 23, 1999 workshop (Environmental Monograph EM-16, Institute for Environmental Studies, University of Toronto) sponsored by the IMAP Lab, the Ecological Monitoring Assessment Network (EMAN), and the World Bank, held at Toronto, Ontario, Canada included over 30 participants from Canadian universities, government and the World Bank. Ideas and views that emerged from the workshop were categorized by the authors into four main themes: 1. measuring the wealth of nations; 2. valuing biodiversity and ecosystems; 3. models for bringing economics and ecology together; and 4. issues of sustainability and risk.

5. IMAP Funding

Funding was received domestically and internationally to hire students and run the IMAP Lab through a variety of sources including:

- Environment Canada's Youth Employment Strategy – Science Horizon's Project
- Canada's Climate Change Action Fund (CCAF)
- Canadian International Development Agency (CIDA)
- Environment Canada's Ontario Region
- Environment Canada's Ecological Monitoring and Assessment Network (EMAN)
- The World Bank

Support for the IMAP Lab at UofT from 2000 to 2004 ranged from CAN$9K to CAN$50K per annum.

6. IMAP Student Support

The following students worked under the auspices of the IMAP Lab at UofT at some time during the period of 2000 to 2004.

- Brent Taylor, MSc, Department of Planning
- Preeti Ramprasad, PhD, Faculty of Forestry
- Ana Isla, PhD, Ontario Institute for Studies in Education
- Shirley Thompson, PhD, Ontario Institute for Studies in Education
- Zoe Meletis, MSc, Department of Geography
- Alexis Morgan, MSc, Department of Geography
- Amar Wahab, PhD, Ontario Institute for Studies in Education
- Erik Sparling, MSc, Department of Geography
- Anthony Liu, PhD, Department of Physics
- Sadia Butt, MSc, Faculty of Forestry
- Mathew Lieberman, BA, Department of Geography
- Kim Snarr, MSc, Department of Anthropology

7. IMAP Course Support

IMAP Directors provided teaching for four courses including:

7.1 IES1433S Regional Resource Ecology (2000)

This course examined the ecosystems along the Niagara Escarpment including farms, recreation areas, cliffs, streams, wetlands, wildlife habitats, and urban environments. A large number of guest speakers provided a broad exposure to natural resource management issues at various jurisdictional levels.

7.2 IES 1433S Natural Capital: Valuing Ecosystems and Biodiversity (2001)

This course brought together the many ideas and views focussing on valuing biodiversity, ecosystems and natural resources from the two perspectives of embedding the economy into the ecological system or embedding the ecology into the economic system. The course presented practical applications for agencies to guide their managers in making decisions and investments in countries around the world on sustaining natural resources. Presentations were organized around four main themes: measuring the wealth of natural resources; valuing biodiversity and ecosystems; models for bringing economics and ecology together; and issues on sustainability. The course was a seminar format with student-led discussions directed by the two moderators.

7.3 IES 1433S World Summit on Sustainable Development: A Critical Review of the Outcomes of UNCED Ten Years Later (2002)

The United Nations Conference on Environment and Development (UNCED), also known as the "Earth Summit," was held at Rio de Janeiro, Brazil, in June 1992. This global conference, held on the 20th anniversary of the first international Conference on the Human Environment, (Stockholm, 1972), brought together policy makers, diplomats, scientists, media personnel and NGO representatives from 179 countries in a massive effort to reconcile the impact of human socio–economic activities on the environment and vice versa. A major achievement of UNCED was Agenda 21, a thorough and broad-ranging international agreement of actions demanding new ways of investing in our future to reach global sustainable development in the 21st century. Other UNCED outcomes included the Rio Declaration, the Framework Convention on Climate Change (FCCC), the Convention on Biological Diversity (CBD), and a Statement of Forest Principles. Ten years later, and time to take a critical look back at UNCED, and aim to arrive at a comprehensive, frank and useful review of the past ten years, with some thoughts on future paths to global sustainable development. Johannesburg 2002: The World Summit on Sustainable Development (WSSD also known as Rio + 10) was held in September 2002 in Johannesburg, South Africa to assess global change since the historic UNCED of 1992. This course examined the outcomes of UNCED in 1992, with a review of global and Canadian progress towards meeting these agreements over the past ten years. Also, the WSSD was examined, including the prepatory process, the issues to be examined, the players involved, and the results to be expected.

7.4 IES 2000F International Environmental Agreements: Implications for Canadian Environmental Management (2000, 2001, 2002)

Canada is signatory to a large number of international environmental agreements that govern environmental management in Canada. These include agreements in the areas of wildlife (Birds, Whaling, International Trade in Endangered Species, Biodiversity), atmosphere (Acid Rain, Climate Change, Stratospheric Ozone Depletion, Toxic Chemicals) and water (Wetlands, Law of the Sea). This course examined the international environmental agreement process of negotiation, terminology of agreements, "guts" of a general agreement, ratification of agreements, responsibilities of signatory nations, and effectiveness of agreements. Specific international environmental agreements examined included the Biodiversity Convention, the Climate Change Convention, the Convention on Long Range Transport of Atmospheric Pollutants, and Agenda '21 - the general agreement of environmental action.

8. Conclusions

In 2000, the Institute for Environmental Studies (IES) at the University of Toronto and Environment Canada established an Integrated Mapping Assessment Project (IMAP) Lab at the University of Toronto (UofT). IMAP has been engaged in collecting published maps on topics such as climate, severe weather, air quality, human health, woodlots, wetlands, wildlife, land-use, roads and many other themes, and then functionally linking and integrating these map surfaces together on specific issues, such as atmospheric change and biodiversity. The final maps are then assessed spatially at various scales, from local to global, although the initial focus of the study has been on regions of Ontario, where a range of detailed, high-quality maps are already available. This paper has detailed the history of IMAP; IMAP directors; IMAP research projects; IMAP symposia, conferences, workshops and events; IMAP publications; IMAP student support; and IMAP course support. The co-location of Environment Canada scientists at universities has proved successful in the case of the IMAP Lab at the University of Toronto. The authors support continuing partnerships in this area.

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PART

I

CLIMATE CHANGE

PAPER

2

THE EFFECT OF CLIMATE ON THE WEST NILE VIRUS IN ONTARIO

ADAM FENECH[1] and QUENTIN CHIOTTI[2]

[1]Meteorological Service of Canada, Toronto, Ontario, Canada
[2]Pollution Probe, Toronto, Ontario, Canada

ABSTRACT: As of 2002, the West Nile virus has spread to and throughout Ontario leading to one human death in the late summer. It is not known how the virus entered Ontario – whether it was an infected bird (imported, migratory or overwintering), mosquito, human or other vertebrate host. The West Nile virus is spread when infected birds that have high levels of West Nile virus in their blood are bitten by mosquitoes. The infected mosquitoes can then transmit the West Nile virus to humans or other animals. In North America, the West Nile virus cycles through 3 species of mosquitoes described as initiator, amplifier and bridger with the *Culex restuans, Culex pipiens* and *Culex salinararius* playing each role respectively. Wild birds are the principal hosts of the West Nile virus, especially the American crow which also plays an important role in signaling the epi-centre of the virus outbreak two weeks prior to peak exposures, and the onset of severe symptoms in humans. The West Nile virus fever in humans usually is an influenza-like illness, but occasionally, the more severe symptoms of meningitis or encephalitis occur. Studies have shown that only 20 percent of all humans (1 in 5) infected with the West Nile virus exhibit adverse effects. Temperature and other climate factors can be implicated in the spread and severity of the West Nile virus across North America, yet the range of influence that climatic factors play is not entirely known. Under future climate change scenarios, climatic conditions conducive to the spread and severity of the West Nile virus will increase. Recommended management options include monitoring the spread of infection; reducing human exposure to infected vectors; preventing initiation and magnification of the virus; screening blood supplies and other products capable of spreading the virus; and conducting public information campaigns.

Keywords: West Nile virus; climate; Ontario; vector borne diseases; *Culex*; mosquito; crow;

1. Introduction

In the summer of 1999, the West Nile virus was recognized in the western hemisphere for the first time when it caused an epidemic of encephalitis and meningitis in the metropolitan area of New York City, NY, USA. Intensive hospital-based surveillance identified 59 cases of West Nile virus, including 7 deaths in the region (Mostashari *et al.,* 2001). The virus has spread quickly across North America - south to the southern US states of Florida, Georgia and Louisiana, and north into Canada including the provinces of Ontario, Quebec, Manitoba and Saskatchewan. By the late summer of 2002, Ontario, Canada recorded its first human death attributed to the West Nile virus.

It has been proposed that temperature and other climate factors can be implicated in the spread and severity of the West Nile virus across North America

(Chiotti *et al.*, 2002). Hot, dry summers may promote outbreaks of the West Nile virus in humans. For example, the July 1999 temperatures in New York City were among the highest on record (59 cases of West Nile virus), while 2000 was comparatively cool (21 cases). This paper will examine the link between climate variables and the spread and severity of the West Nile virus across Ontario. Specifically, the paper will trace the spread of the West Nile virus across Ontario in spatial and temporal terms; provide a background to the West Nile Virus; associate climate variables to the spread and severity of the West Nile virus in Ontario under current climate conditions and future scenarios of climate change; and provide management options of the West Nile Virus risk.

2. The Spread of the West Nile Virus in Ontario 2000-2002

Figures 1 through 6 provide a series of maps detailing the spread of the West Nile virus into Ontario from the year 2000 to present. There was no West Nile virus recorded in 2000 for the dead birds that were tested that year, a number totaling 2,288. By 2001, the percentage of infected dead birds tested reached high levels in Toronto, Peel and Windsor-Essex Health Region (as defined by Health Canada). One year later in 2002, the West Nile virus appeared in infected dead birds tested across all of Ontario except the Sudbury Health Region. The highest percentages of infected dead birds tested appears to have moved to the north shore of Lake Erie and east to the Kingston Health Region. Yet, Toronto remains the so-called "epi-centre"[1] for the West Nile virus in Ontario when the other maps are examined. The percentage of infected mosquito pools tested in 2002 is highest in Toronto. The highest number of horses found infected with the West Nile virus in 2002 centres in the Toronto Health Region. And the highest number of confirmed human cases infected with the West Nile virus in 2002 is in the Toronto Health Region, with Canada's first confirmed fatality from the virus occuring in the Peel Health Region immediately west of Toronto. The pace of spread of the West Nile virus in Ontario is surprising and has been called "unprecedented" (McLean, 2002). But what are the conditions that led to such an unprecedented spread of this virus across North America including Canada and Ontario?

1 An epicentre is employed as a term to describe the place where the West Nile virus initiated. Usually, the term epicentre refers to the point on the Earth's surface directly above an earthquake or atomic explosion.

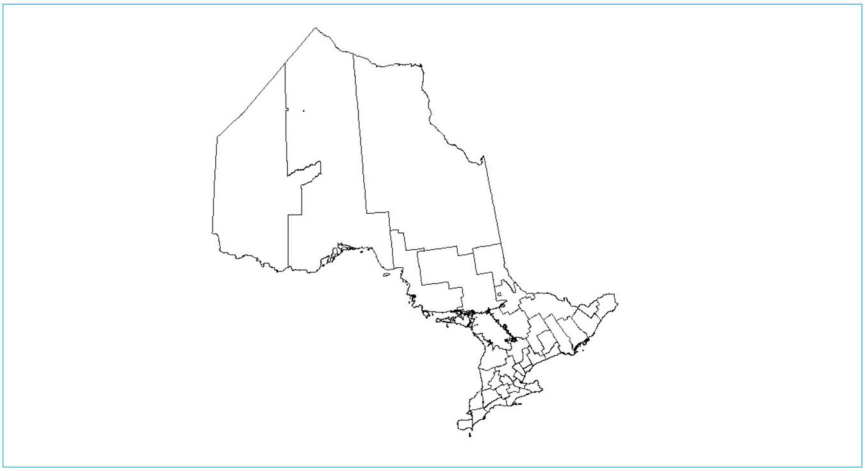

FIGURE 1
West Nile Virus in Ontario infected dead birds, 2000.
Source: Data from Health Canada, 2002.

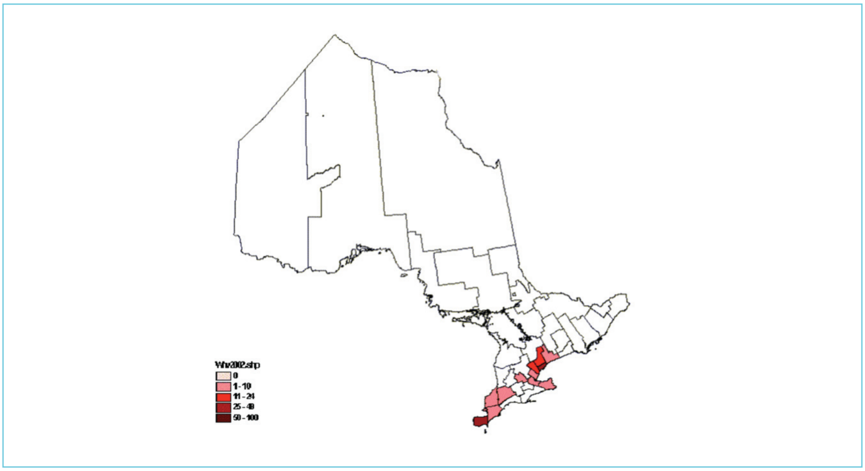

FIGURE 2
West Nile Virus in Ontario infected dead birds, 2001.
Source: Data from Health Canada, 2002.

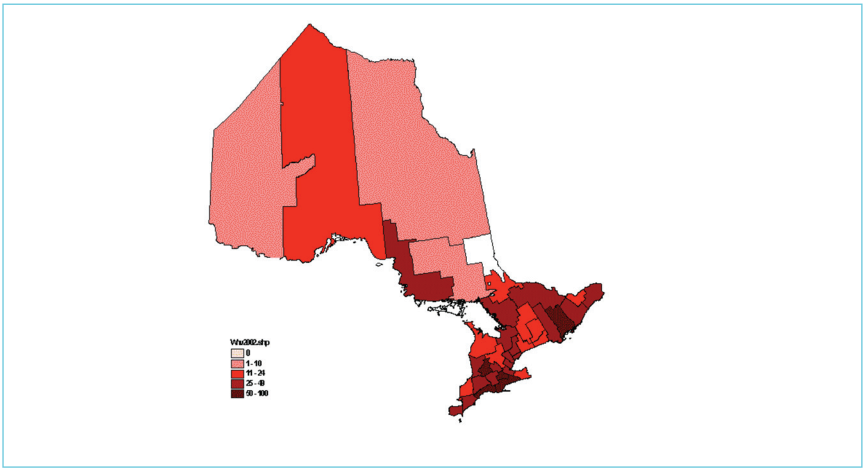

FIGURE 3
West Nile Virus in Ontario infected dead birds, 2002.
Source: Data from Health Canada, 2002.

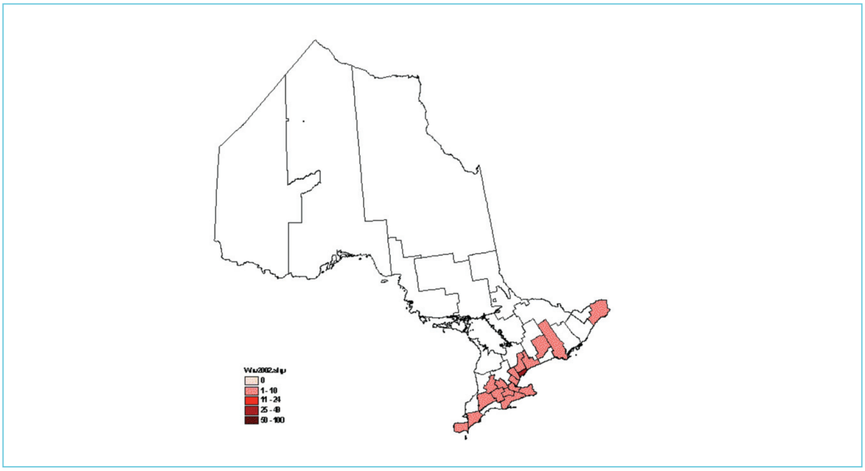

FIGURE 4
West Nile Virus in Ontario infected mosquito pools, 2002.
Source: Data from Health Canada, 2002.

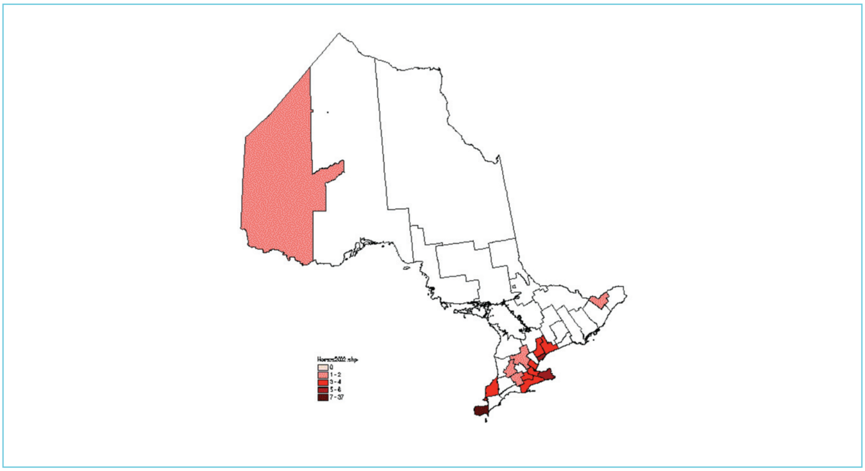

FIGURE 5
West Nile Virus in Ontario infected horses, 2002.
Source: Data from Health Canada, 2002.

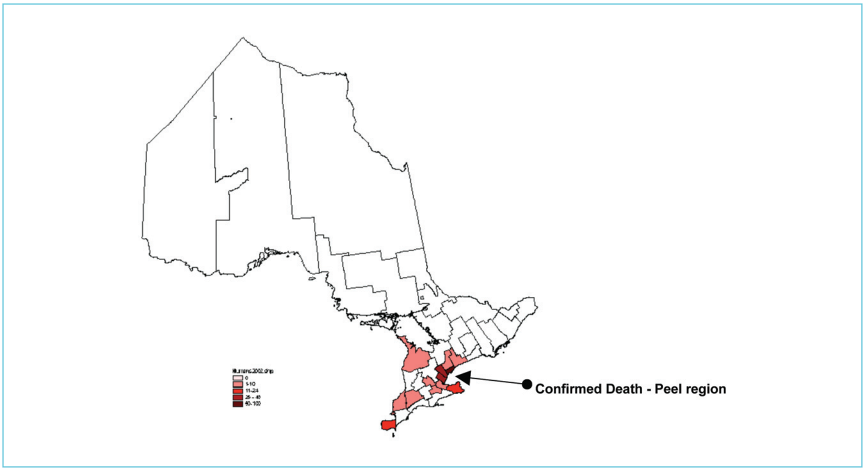

FIGURE 6
West Nile Virus in Ontario infected humans, 2002.
Source: Data from Health Canada, 2002.

3. Background

The West Nile virus, a member of the Japanese encephalitis virus serogroup in the family Falviviridae (genus *Flavivirus*) (Dohm and Turell, 2000) was first isolated in 1937 in the West Nile district of Uganda (Smithburn *et al.*, 1940). Since the original isolation of the West Nile virus, outbreaks have occurred infrequently in humans, those in Israel (1951-54 and 1957) and South Africa (1974) being the most notable (Petersen and Roehrig, 2001). Since the mid-1990s, however, there have been an increase in the frequency of outbreaks of the West Nile virus in humans and horses (Romania 1996; Morocco 1996; Tunisia 1997; Italy 1998; Russia and Israel 1999; and Israel and France 2000).

It is not known how the virus entered North America – whether it was an infected bird (imported or migratory), mosquito, human or other vertebrate host. The literature supports the possibility of all paths of entry mentioned above (Rappole, 2000). Invasive mosquito species have been recorded to arrive in countries via the water trapped in the well of recycled tires (see *Aedes japonicus* arrival in New Zealand) and spread by physcially moving along highways (Womack, 2001). It has been suggested that the West Nile virus was purposefully released in North America by the US military in order to support the sale of a West Nile virus vaccine by the pharmaceutical company, OraVax. The connection is that the military granted OraVax the license for the vacine, and that OraVax Vice President is Col. Monath, a former Ft. Detrick biowar researcher (Jannaccio, 2000). This theory is discounted by these authors. The West Nile virus responsible for the outbreak in New York City in 1999 is a close genetic relative of a virus circulating in Israel from 1997 to 2000 (Giladi *et al.*, 2001) which may help in eventually determining the path of entry.

The West Nile virus is spread when infected birds that have high levels of West Nile virus in their blood are bitten by mosquitoes. The infected mosquitoes can then transmit the West Nile virus to humans or other animals. The West Nile virus is not transmitted directly from human to human. There is no evidence that a person or other animals can be infected from handling infected birds (Toronto Public Health, 2001).

2 Note that the species *Aedes japonicus* needs to be researched further because of its characteristics of being a new species discovered in North America in 1998, the first new mosquito species in a generation. It was found in the states of New York, New Jersey and Connecticut where the West Nile virus first emerged. Yale scientists (Brigockas, 1999) predicted before the New York outbreak of 1999 the potential for this species to act as a bridge vector due to its willingness to feed on both humans and birds. The species is unique for its daytime feedings and is also “highly susceptible” to infection from the West Nile virus. Very little research has been conducted on this species in North America.

Mosquitoes, largely bird-feeding species, are the principal vectors of the West Nile virus (Hubalek and Halouzka, 1999). The virus has been isolated from 43 mosquito species, predominantly of the genus Culex and Aedes. In North America, three species of the *Culex* family – *restuans, pipiens, and salinarius* - are the assumed predominant carriers of the West Nile virus.[2] *Culex pipiens* appears to be the species most responsible for the spread of the West Nile virus in Europe (Rappole, 2000), and is now implicated in the North American outbreak (Bernard *et al.,* 2001). The West Nile virus in Europe circulates in both sylvan (forest) and urban transmission cycles involving different species and populations of mosquitoes (Savage, 1999). In North America, this cycle has been described by Andreadis *et al.* (2001) as follows: *Culex restuans* initiates the West Nile virus transmission among birds in early summer; *Culex pipiens* amplifies the virus later in the season; and *Culex salinararius* is the suspected "bridge vector" of the West Nile virus from birds to humans, horses and other mammals (Andreadis *et al.,* 2001; Bernard *et al.,* 2001). Figure 7 graphically represents the transmission dynamics of the West Nile virus from mosquitoes to mammals. Table 1 provides some results of different studies quantifying the rate of mosquito infection, rate of transmission to progeny, the transmission efficiency and the effect of ambient temperatures on infection rates.

TABLE 1
Transmission of the West Nile Virus by Mosquitoes

Rate of Mosquito infection with WNV	3.53 Minimal Infection Rate (MIR) per 000 mosquitoes in *Culex* species	Turrell *et al,* 2000.
Rate of WNV transmission to progeny	1 in 1,618 females of *Culex* species, varies by temperature	Turrell *et al,* 2000.
Mosquito WNV transmission efficiency to humans	"Nearly all" infected mosquitoes transmit WNV successfully by bite	Turrell *et al,* 2000.
Effect of ambient temperatures on mosquito infection rates	30 degrees Celsius leads to greater than 90 percent of all mosquitoes containing infection after 12 days; 18 degrees Celsius less than 30 percent contained infection after 28 days	Dohm *et al,* 2001.

Studies have shown that environmental temperature increases the ability of mosquitoes to transmit the West Nile virus (Dohm and Turell, 2000; Dohm *et al,* 2001; Nasci, 2001). Results suggest that infection rates are related directly to subsequent incubation temperatures – 30 degrees Celsius leading to greater than 90 percent of all mosquitoes containing infection after 12 days; while 18 degrees Celsius less than 30 percent contained infection after 28 days. Studies also conclude

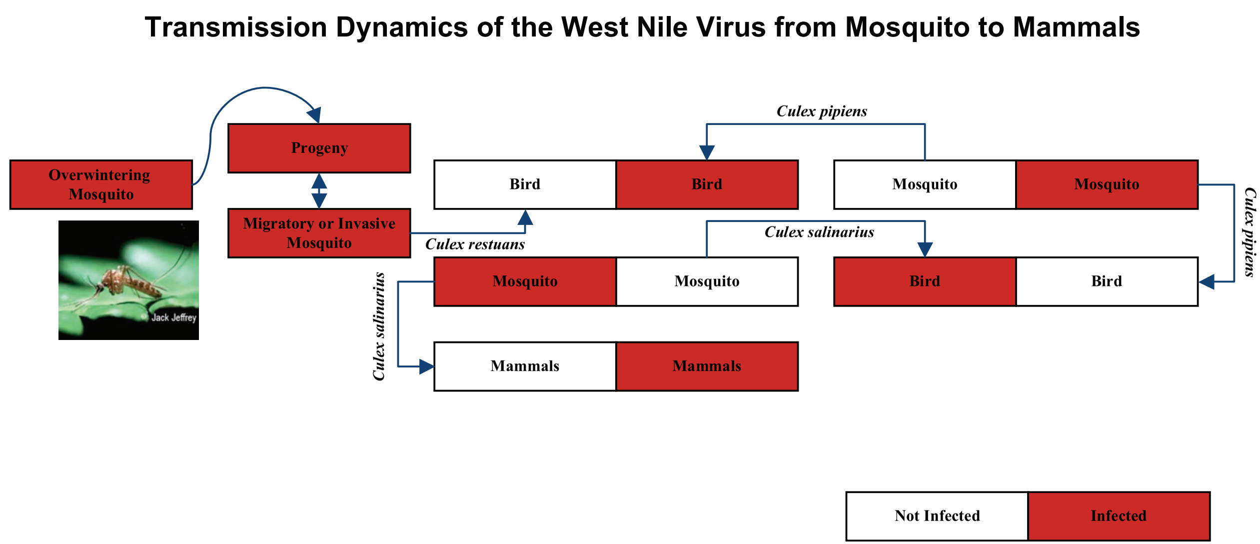

FIGURE 7
Transmission Dynamics of the West Nile Virus from Mosquito to Mammals.

that the West Nile virus can persist in vector mosquitoes at least through midwinter, suggesting that the virus would persist until spring and emerge with mosquitoes to reestablish a transmission cycle in the infected area (Nasci *et al.*, 2001).

Wild birds are the principal hosts of the West Nile virus. The virus has been isolated from a number of wetland and terrestrial bird species of North America (see Table 2). The virus persists in the organs of ducks and pigeons for 20 to 100 days (Semenov *et al.*, 1973). Migratory birds are thus instrumental in the introduction of the virus to temperate areas during migrations (Hubalek and Halouzka, 1999). Eurasian bird populations of several species in which exposure to the West Nile virus has been detected are rare migrants along the eastern seaboard of North America (Rapple *et al.*, 2000). Figure 8 graphically represents the transmission dynamics of the West Nile virus from birds to mammals.

TABLE 2
Bird Hosts of the West Nile Virus in Canada, 2001

American Crow (67%)	Fish Crow (40%)
Blue Jay (40%)	Cooper's Hawk (27%)
American Robin (9%)	House Sparrow (8%)
European Sparling (7%)	Common Grackle (7%)

Percentage of dead birds tested with positive identification for the West Nile virus in Canada

The susceptibility of crows (*Corvus brachyrhynchos*) to infection and death from the West Nile virus is a sensitive surveillance tool that is unique to North America (Komar, 2000). The percentage of crows infected by the West Nile virus was highest in the epicentre of the virus outbreak in New York City in both 1999 and 2000 supporting the importance of crows as indicators of the spread of the virus. Figure 9 shows how, in 2000, the appearance of dead crows forewarned the impending infections in humans two weeks hence. Also, data from the US Geological Survey's National Wildlife Health Center indicate that crows infected with the West Nile virus are likely to be sedentary approximately 4 days before death, suggesting that they can assist *Culex pipiens* in "amplifying" the West Nile virus in areas where crows are found (National Wildlife Health Center, 2000). The range of the American crow and its migrations can be found in Figure 10 with many overwintering in southern Ontario (Environment Canada, 2002a).

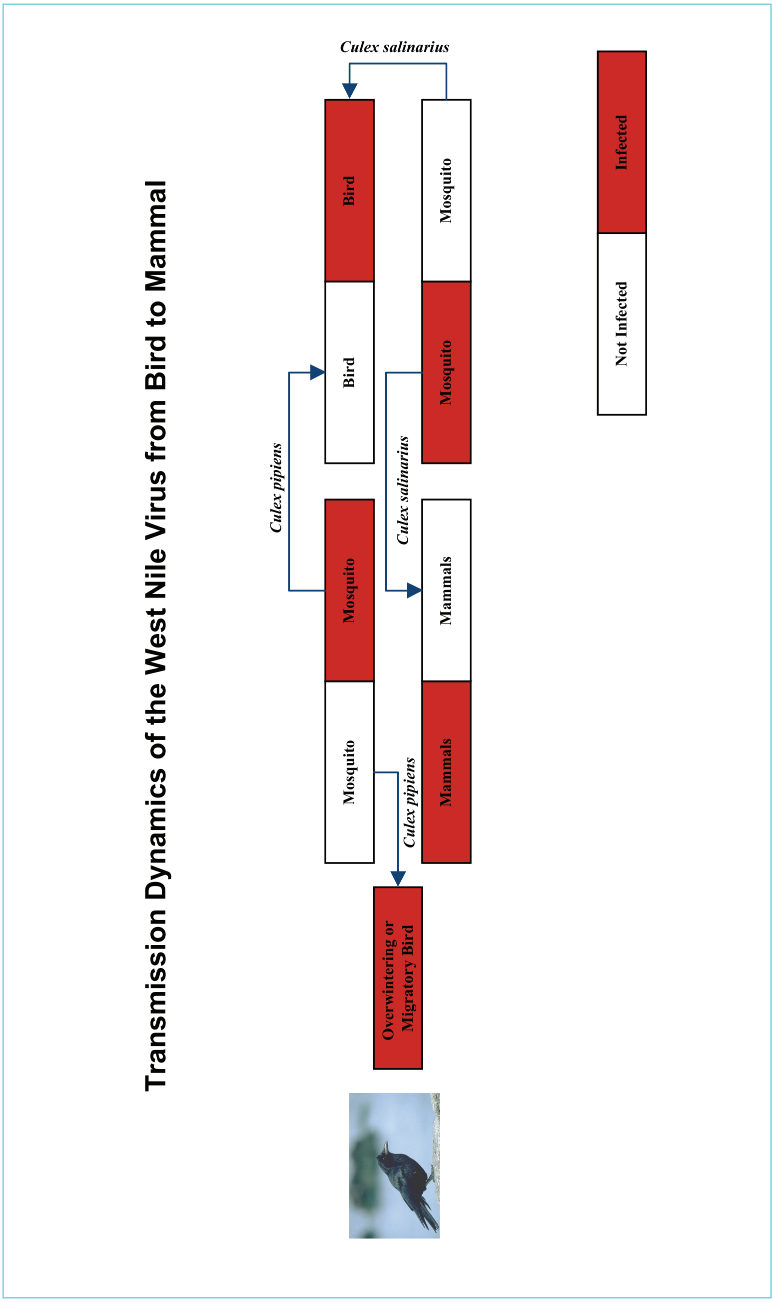

FIGURE 8
Transmission Dynamics of the West Nile Virus from Bird to Mammal.

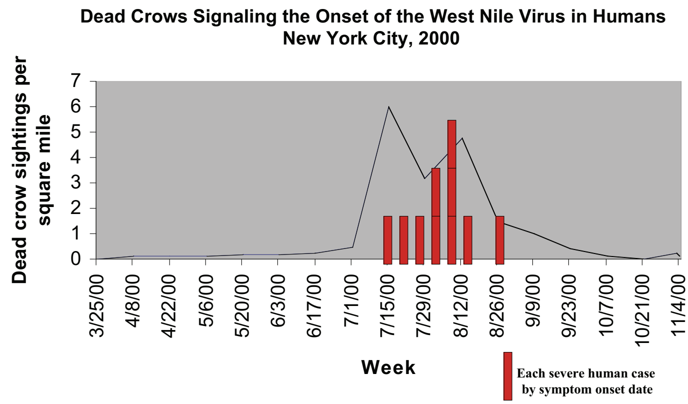

FIGURE 9

Dead Crows Signaling the Onset of the West Nile Virus in Humans, New York City 2000.
Source: Data from Eidson *et al.*, 2001.

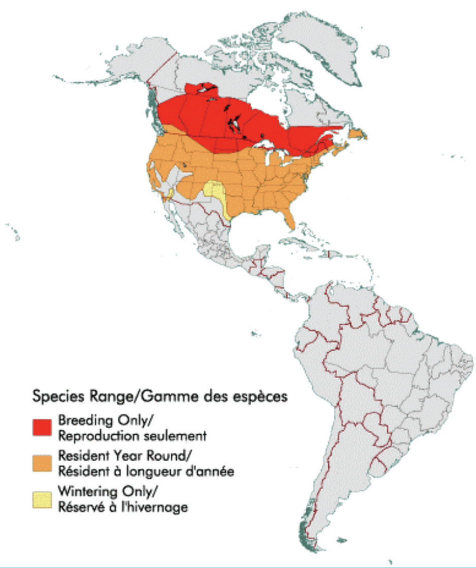

FIGURE 10

Migratory Range of the American Crow, *Corvus brachyrhynchos.*
Source: Environment Canada.

4. Human Exposure to the West Nile Virus

Humans are exposed to the West Nile virus from the bite of a mosquito infected with the virus. Studies of the outbreak of the West Nile virus in New York City in 1999 reveal some interesting results (Mostashari *et al.,* 2001) In the outbreak's epicentre, it was found that 2.6 percent of the total human population (>1200 individuals) was infected by the West Nile virus. The highest infection rates were found among individuals who spent more than 2 hours outdoors after dusk or before dawn, the peak feeding periods of *Culex* mosquitoes. Infection rates were higher for those individuals who did not use insect repellants. However, there were also high infection rates among a group of individuals who spent little or no time outdoors. Having seen a dead bird in one's neighbourhood was independently associated with higher infection rates as well. It is interesting to note that nearly all of the homes surveyed had screens on the windows (96%) and air-conditioners (92%). Other studies in temperate northern hemispheric climates showed human infection rates of up to 4 percent (Tsai, 1998; Platonov, 1999).

Studies have shown that only 20 percent of all humans (1 in 5) infected with the West Nile virus exhibit adverse effects (Mostashari *et al.,* 2001). The West Nile virus fever in humans usually is an influenza-like illness characterized by an abrupt onset (incubation period is 3 to 6 days) of moderate to high fever (3 to 5 days, sometimes with chills), headache, sore throat, backache, fatigue, diarrhea, and respiratory symptoms (Peiris and Amerasinghe, 1994). Occasionally, the more severe symptoms of meningitis or encephalitis occur causing disorientation, muscle weakness, coma and paralysis. This occurs in 3 percent of those adversely affected by the virus (1 in 30) (Mostashari *et al.,* 2001). Most fatal cases have been recorded in patients older than 50 years, and there is no mention in the literature to the susceptibility of children or immune-deficient adults to infection. Figure 11 shows the rate of illness from the West Nile virus among the human population of the New York Metropolitan Area in 1999.

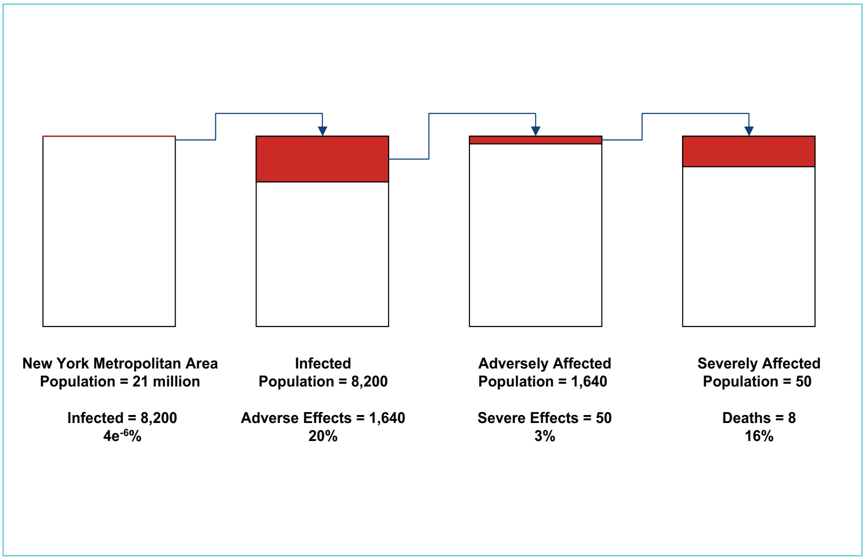

FIGURE 11
Rates of Illness in Humans, New York Metropolitan Area, 1999.
Source: data from Montashari *et al.*, 2001.

5. Linking the West Nile Virus to Climate Variables

For ten years now, scientists have understood that scenarios of global climate change hypothesize warmer, more humid weather that may produce an increase in the distribution and abundance of mosquito vectors (Reeves *et al.*, 1994) that cause the West Nile virus. Chiotti *et al.* (2002) recognized that the July 1999 temperature in New York City was among the highest on record with 59 cases of the West Nile virus recorded while 2000 was comparatively cool with only 21 cases. Recent studies (Dohm *et al.*, 2001) have also shown that mosquitoes held at high temperatures are more efficient vectors of the West Nile virus. Understanding overwintering temperatures are also important in determining the virility of the virus over seasons in the same area (Dohm and Turrell, 2000).

In addition to temperature, precipitation is an important climate variable to consider as an influence on the distribution of the West Nile virus. Epstein and Defilippo (2001) examined three large outbreaks of the West Nile virus around the world associated with drought and excessive heat - Romania, New York City and Russia. They concluded that multi-month drought, especially in spring and early summer, was associated with urban outbreaks of the West Nile virus in

Europe and the USA. Each new outbreak of the West Nile virus requires the introduction or reintroduction of the virus – primarily via birds or wildlife so there have been seasons without outbreaks despite a multi-month drought. Spread of the West Nile virus may occur, even in the absence of conditions that amplify the cycling of the virus from birds to mosquitoes to humans. Epstein and Defilippo conclude that droughts increase the "prior probability" of a significant outbreak. Once the virus becomes established in a region, other factors, such as rains that increase populations of vectors, may affect the transmission dynamics.

Epstein (2000) proposed a hypothesis linking the West Nile virus to climate variables as described in Figure 12. The hypothesis centred on four main climate connections: (1) warmer winters than normal to allow infected mosquitoes to survive the winter; (2) spring or early summer drought to concentrate vectors and hosts around pools of water, and allow for low populations of vector

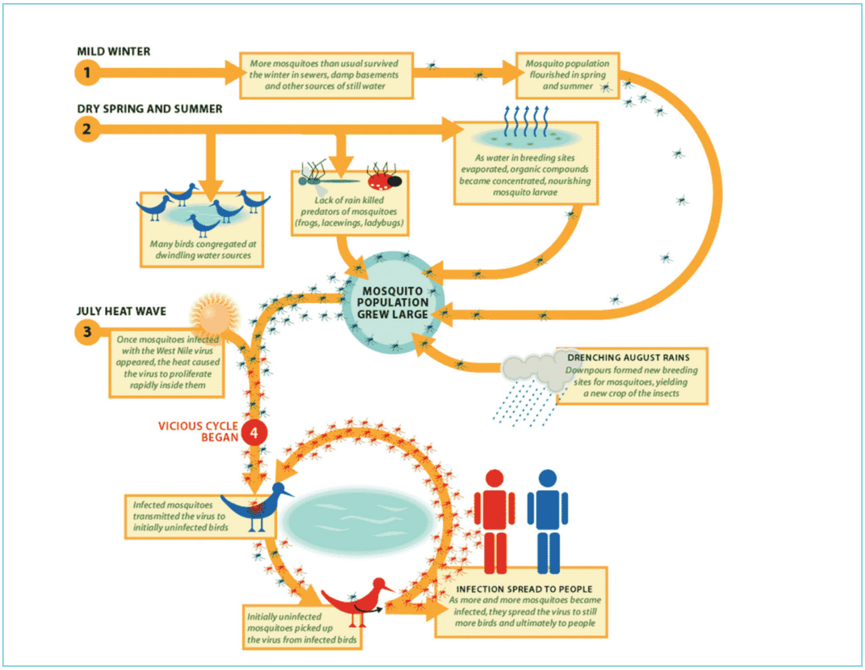

FIGURE 12
Epstein (2000) hypothesis linking West Nile Virus to climate variables.

predators such as lady beetles or amphibians; (3) summer rains to allow for expanded vector populations (mosquitoes); and (4) summer heat to allow for the incubation and transmission of the West Nile virus. Environment Canada's *Climate Trends and Variations Bulletin for Canada* (Environment Canada, 2000; 2001; 2002b) were consulted to test this hypothesis by examining the Great Lakes/St.Lawrence and the Northeastern Forest climate regions of Canada, that is, those that covered Ontario. Winter temperatures, spring precipitation[3], summer precipitation and summer temperatures were examined for the two climate zones of Canada (see Figures 13 to 16), resulting in the conclusions presented in Table 3. It appears as if not all of the conditions that would increase the "prior probability" of the West Nile virus spreading in Ontario have been met for the years of West Nile infection in southern Ontario, and thus the hypothesis needs to be re-examined. It is difficult to tease out the climate variables for the general, regionalized reports from the Climate Bulletins. Focusing on individual daily temperatures and precipitation events at specific locations such as the epi-centre in Toronto is the logical progression of research as a next step.

As a final word on climate, an examination of future climate scenarios based on a simulation output from the latest General Circulation Model – the Coupled Global Circulation Model 2 (CGCM2), developed by the Canadian Centre for Climate Modelling and Analysis of Environment Canada (Natural Resources Canada, 2002), (see Figure 17) - reveals that these climate conditions (winter temperature, summer precipitation, summer temperature) that increase the "prior probability" of the spread and severity of the West Nile virus are expected to increase in the future.

TABLE 3
Epstein Hypothesis Tested

Climate Variable	2000	2001	2002
Warmer Winter Prior	✓	×	✓
Spring Drought	×	✓	×
Summer Rains	✓	✓	✓
Summer Heat	✓	✓	✓

3 Drought is a complex term that has various definitions (Ontario Ministry of Natural Resources, 2002). Drought has been described as a prolonged period of abnormally dry weather that depletes water resources (Agriculture and Agri-Food Canada, 2002). The Ontario Ministry of Natural Resources defines drought as "weather conditions characterized by below normal precipitation that has socio-economic effects" (Ontario Ministry of Natural Resources, 2002). Thus, precipitation is examined as an indicator of drought conditions.

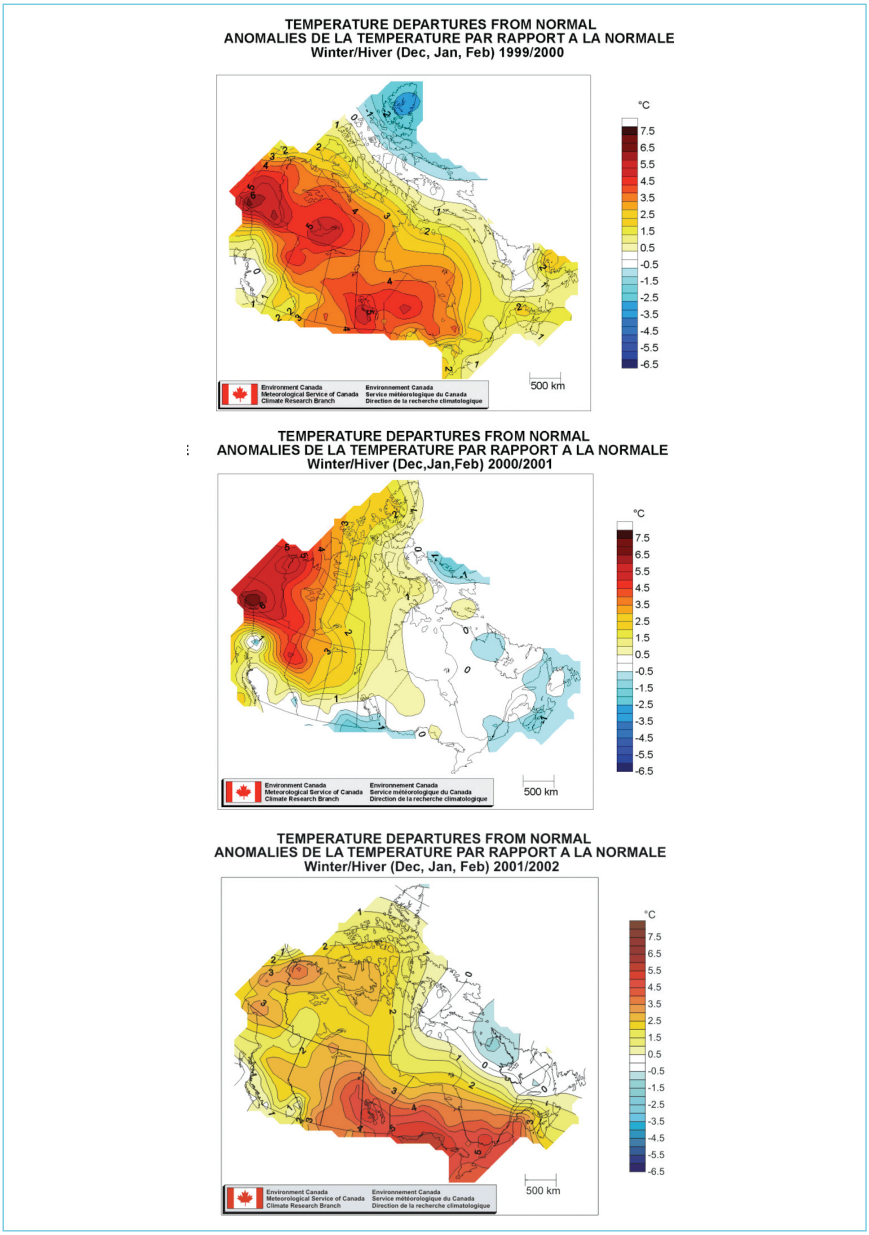

FIGURE 13
Winter Temperatures in Canada 1999-2000, 2000-2001, 2001-2002.
Source: Environment Canada.

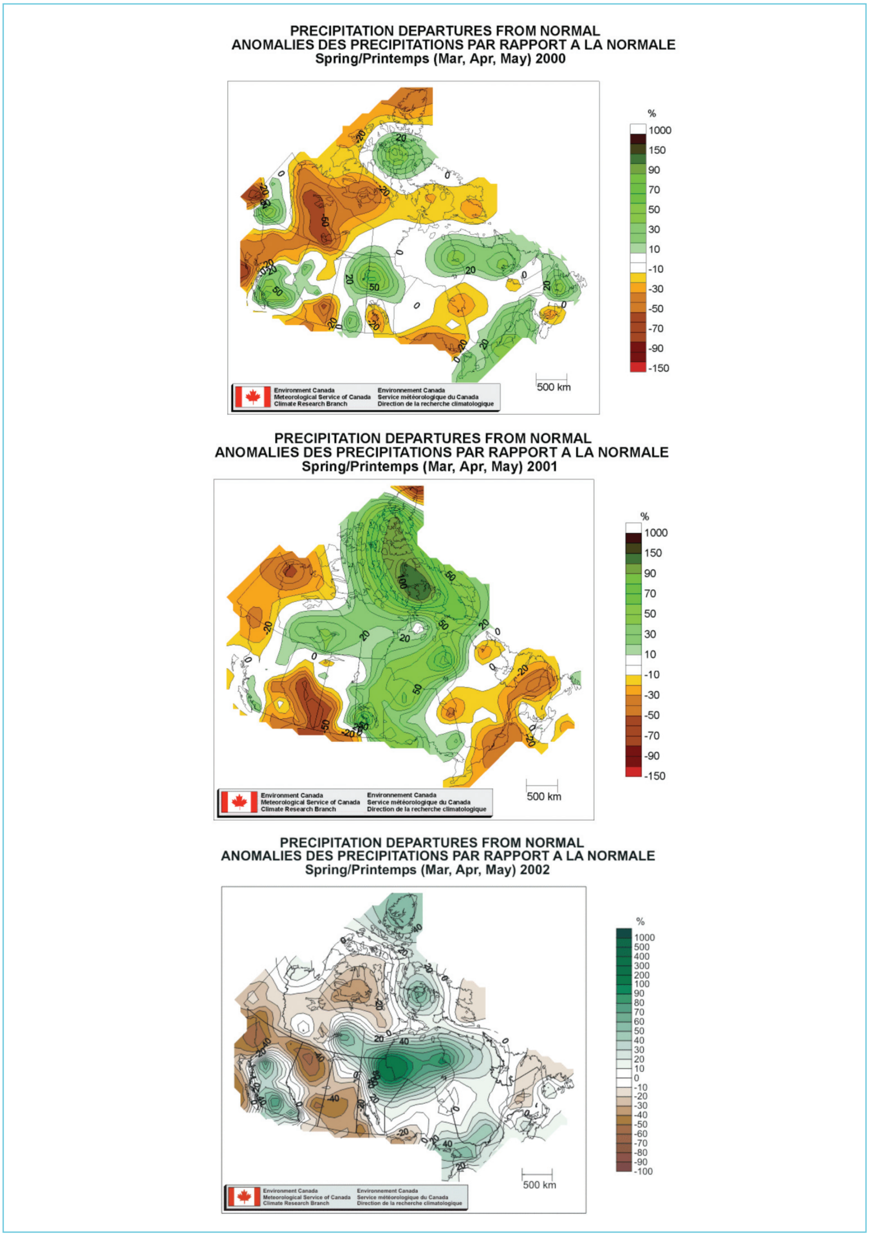

FIGURE 14
Spring Precipitation in Canada 2000, 2001, 2002.
Source: Environment Canada.

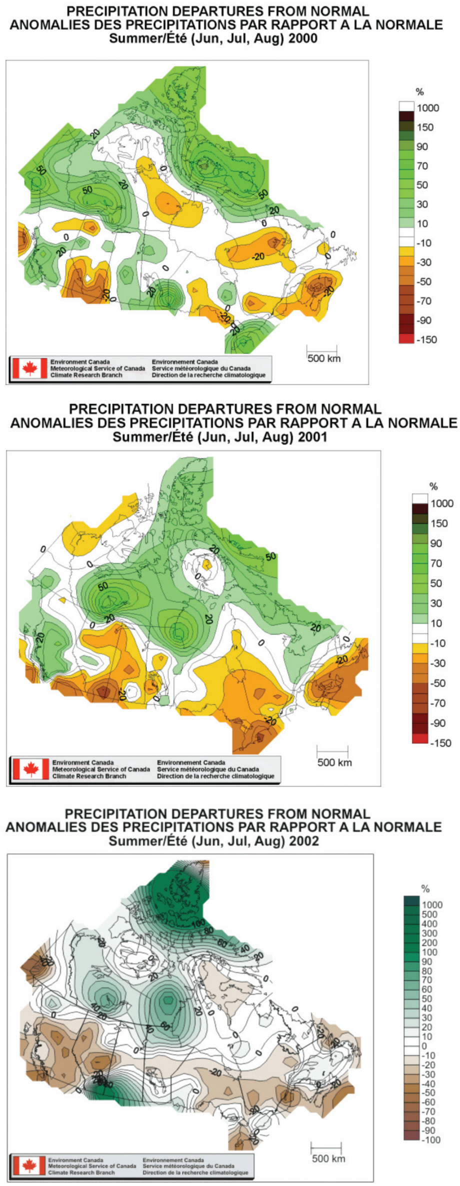

FIGURE 15
Summer Precipitation in Canada 2000, 2001, 2002.
Source: Environment Canada.

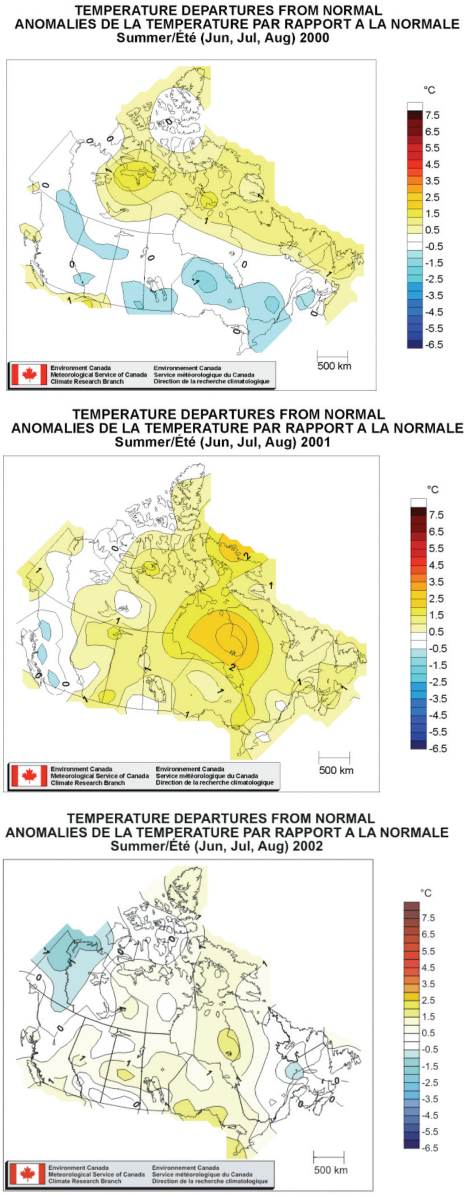

FIGURE 16
Summer Temperatures in Canada 2000, 2001, 2002.
Source: Environment Canada.

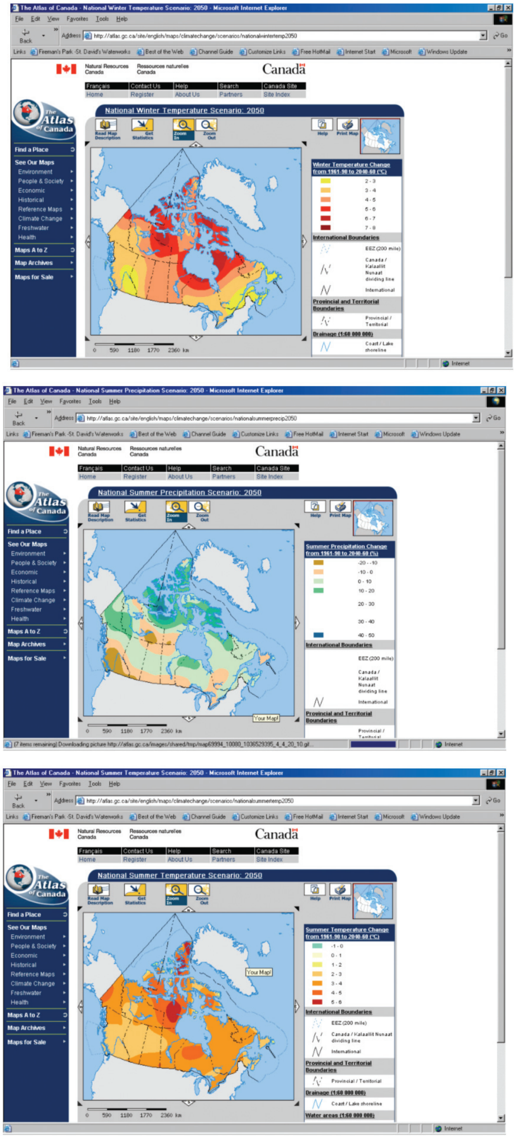

FIGURE 17

Future Scenarios of Climate Change in Canada Winter Temperature, Summer Precipitation, Summer Temperature.
Source: Natural Resources Canada.

6. Management of the Risk of the West Nile Virus

There are many opportunities to manage the risk to humans of the West Nile virus in Ontario including monitoring the spread of infection; reducing human exposure to infected vectors; preventing initiation and magnification of the virus; screening blood supplies and other products capable of spreading the virus; and conducting public information campaigns.

Monitoring infected mosquito pools, birds, mammals and humans allows for an understanding of the progression of the West Nile virus' seasonal cycle, and further analysis and research of events over time. Evidence has been collected on the probable timing of events. The numbers of dead crows play an important role in signaling the epi-centre of the virus outbreak two weeks prior to peak exposures, and the onset of severe symptoms in humans (see Figure 9). Recommendations for risk management should include monitoring crow populations to identify epi-centres of outbreaks, their severity, and to allow for early public alerts to help reduce exposure to the vector (mosquitoes).

Ways of preventing human exposure to mosquitoes include avoiding outdoor activity during peak times for mosquito feedings such as dawn and dusk; wearing insect repellant when outside; wearing long clothing made of a tight material knit to avoid mosquito stinger penetration; and ensuring gateways to indoors are secure including fixing holes in screen doors and windows. All of these personal risk management strategies are recommended, as the literature supports their success (see Mostashari *et al.*, 2001). Individuals can further protect themselves through the use of a vaccine against the West Nile virus once it has been developed. Such a vaccine would be recommended for the high risk groups such as those over 50 years of age, and the immune deficient.

New York City attempted to break the virus life cycle by spraying pesticides over infected locations in September 1999 to control the number and type of mosquitoes. This pesticide spraying has continued with success in controlling the virus over the past 3 years. The amounts of pesticides that lead to the elimination of the virus have been determined through computer modelling (Thomas and Urena, 2001). Spraying is expensive and very hazardous to other insect species important to functioning ecosystems and the environment in general. The pesticide is not always applied appropriately to its target, and pesticide residues can continue to pollute the environment over time. It is recommended that alternative means of reducing the mosquito populations be employed including reducing stagnant pools of water throughout a suspected epi-centre, and promoting the propagation of mosquitoes' natural predators such as bats, birds and lady beetles.

There is a suspected case of the West Nile virus leading to a death in Ontario from a contaminated blood sample following a blood transfusion. If inexpensive and simple tests exist, then all blood supplies and products could be screened for the virus.

Most importantly, public information programs about the preventative measures that can be taken by individuals, and the overall risk to humans are crucial. It is often quoted that influenza kills over 2,000 Canadians per year, and so far in Canada, only one confirmed death from the West Nile virus has been recorded. This comparison of risk should be presented as a means of allowing personal risk evaluation.

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PAPER

3

IMPACT OF EXCESSIVE RAINFALL ON WATERBORNE DISEASES IN SOUTHERN ONTARIO: THE WALKERTON CASE STUDY

A.Q. LIU[1], D. MACIVER[2], H. AULD[2], D. CHARRON[3], A. FENECH[2], J. KLAASSEN[2] and R. HANSELL[1]

[1]Institute for Environmental Studies, University of Toronto
[2]Environment Canada, Toronto, Ontario, Canada
[3]Health Canada, Guelph, Ontario, Canada

ABSTRACT: The occurrence of excessive rainfall over a five day period resulted in one of Canada's most severe waterborne disease outbreaks, killing 7 people with thousands becoming ill in the Walkerton area of southern Ontario. Many factors are associated with the transportation of contaminated water, including rainfall, runoff, soil moisture status, temperature and evapotranspiration. The unique synoptic situation leading to this excessive rainfall event was characterized by two slowly moving deep low-pressure systems, which passed through southern Ontario consecutively, with both of the low-pressure centers crossing the Walkerton area. The five-day cumulative rainfall, beginning with four days of 15-20 mm each day, followed on the fifth day by a 70 mm rainfall, exceeds both the 90th percentile and the two standard deviation of the 30-year rainfall mean for Walkerton. Further analysis of soil moisture budgets showed saturated soil conditions were present during this rainfall event, resulting in surface runoff, an effective mechanism for the transport of contamination into drinking-water systems. Radar images provided an assessment of the spatial extent of this rainfall event plus the timing of the rain events over the five-day period. Interestingly, most of the rain occurred during the late evening or nighttime hours, raising the question whether residents fully understood the amounts and the impact of accumulated rain, runoff and contamination. This paper explores the meteorological forecast potential to develop a WellHead Protection Alert System (WELLPASS) for either municipal or private drinking-water systems. It is proposed that advisories, based on the Quantitative Precipitation Forecast and 90% thresholds, would be issued to warn residents, days in advance, of the risk of excessive rainfall and hence the potential for surface runoff. Drinking-water wells, under the influence of surface water, would be particularly vulnerable during these rainfall alert events, requiring adaptive management actions.

Keywords: excessive rainfall, waterborne diseases, Walkerton.

1. Introduction

The global assessment by the Intergovernmental Panel on Climate Change (IPCC) indicated that the climate was becoming more variable both on global and regional scales. The General Circulation Models suggest scenarios over the next few decades in which the global climate will be characterized by increased temperatures, altered hydrologic cycles increased variability, and increased extreme events (Karl *et al.*, 1995). The major health effects under climate change include temperature-related morbidity and mortality; health impacts of extreme weather events (storms, hurricanes, and precipitation extremes); air-pollution-related health effects; and both water-borne and food-borne diseases (Patz, 2000). The impact of excessive rainfall on waterborne disease is addressed in this study.

Waterborne disease outbreaks are usually caused by contamination of drinking water systems by bacteria, viruses, or small parasites. Most of the cases of waterborne disease involve mild illness, but severe outbreaks, including mortality, have also occurred in North America. An earlier study indicated that heavy rainfall was one of the most important factors in triggering waterborne disease outbreaks (Frost *et al.* 1996). For example, the Milwaukee outbreak in 1993 that resulted in the death of 54 people and more than 403,000 ill, was related to heavy rainfall and associated run-off (Hoxie *et al.* 1997). Based on the analysis of 548 reported water-borne outbreaks in the United States, Curriero *et al.* (2001) found more than half of the waterborne disease outbreaks in the United States in the past 50 years were preceded by heavy precipitation above the 90 percentile threshold.

Waterborne disease outbreaks are considered one of the most severe health threats in Canada. Although most people in Canada have direct access to treated public water supply systems, more than 5000 annual cases of waterborne diseases have been estimated, and this figure is considered to be highly underestimated. In 2000 alone, there were over 4700 cases of giardiasis and 560 cases of cryptosporidiosis reported in Canada, most presumed to be waterborne (Maarouf and Chiotti, 2000). There have been few studies addressing the critical threshold relationship between excessive rainfall and waterborne disease outbreaks in Canada. The word excessive is used to define those rainfall events that exceed a critical threshold, either individually or cumulatively. Because of the Walkerton outbreak in May 2000 where 7 people died and thousands became ill, determining this relationship between excessive rainfall and waterborne disease outbreaks has become a priority for meteorology and public health research. This study also investigated the impact of excessive rainfall on other waterborne disease outbreaks in southern Ontario. For example, critical thresholds for rain on snow situations will require the development of runoff models and associated threshold conditions, a future research project.

2. Climate Data

Detailed information about the Walkerton waterborne disease outbreak was obtained from the Ontario Government's official report of the Walkerton inquiry (O'Connor, 2002). The daily rainfall database from the Meteorological Service of Canada (MSC) was supplemented by the hourly radar reflectivity from the

National Climatic Data Center (NCDC) to better analyze the variation in the rainfall events. Also the mosaic WSR_88D radar image from NCDC proved to be invaluable in helping to capture time and space continuity for this heavy rainfall. CLI-MAT system, a Matlab based climatology analysis software (Liu, 2002), was employed to process the 30-year rainfall (1972-2001) data set for the Walkerton area. The monthly-mean soil moisture profile calculated from CLI-MAT proved to be very useful in determining the runoff intensity associated with this heavy rainfall. Upper-air reanalysis data from the National Center for Environmental Prediction (NCEP), together with visible GOES satellite image, defined the sequence of synoptic situations that triggered and maintained this heavy rainfall.

3. Overview of the Walkerton Waterborne Disease Outbreak

Walkerton is a small town in southern Ontario. In May 2000, Walkerton's drinking water system was contaminated with deadly bacteria, primarily *Escherichia coli* O157. Through an environmental testing of 13 livestock farms within a four-kilometer radius of the groundwater source for Walkerton's water system, the contamination source of this outbreak, *E.coli* O157, was found in two farms, including a farm near Well 5, the main groundwater source for Walkerton's drinking water system. Further investigation proved that *E.coli* O157 had entered Well 5 and likely originated from cattle manure starting on or shortly after May 12th (O'Connor, 2002). The first illnesses were identified in the community on the 18th of May. The drainage simulation model in the vicinity of Well 5 suggested that with heavy rain and strong surface run-off in contact with the manure in the barnyard and adjacent fields, the water could have drained toward Well 5. This drainage would carry the bacteria entering the well through overland flow and through transport in groundwater (O'Connor, 2002).

4. Rainfall and Run-off Climatology

The daily rainfall variations (Figure1a), based on daily storage rain gauges during 8-17 May 2000, illustrate continuous rainfall occurred from the 8th to the 12th, with two rainfall peaks recorded daily at the 10th and the 12th, separately. The rainfall on the 10th exceeded the top 10% of the last 30-year precipitation records. The rainfall of the 12th far exceeded both the two standard deviation of the 30-year rainfall mean and the top 10 percentile (Figure1b). Understandably, the 70 mm rainfall on the 12th was the main contribution to the five-day accumulation of rainfall and run-off, whereas the preceding four days of rain acted as precursors, contributing to soil moisture saturation, but not in themselves unusual for this area. The return period of such a continuous intense rainfall in May is approximately 1 in 60 years (Auld *et al.,* 2001).

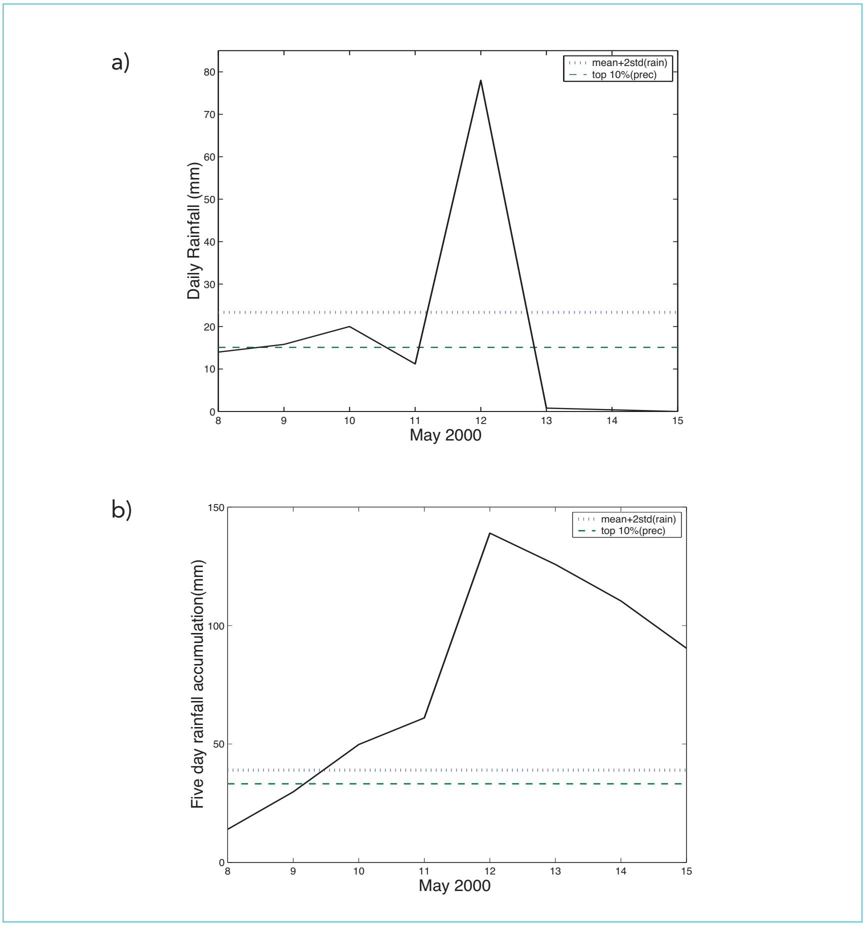

FIGURE 1

Time series of (a) daily rainfall and (b) five-day accumulated rainfall in Walkerton County during the outbreak period in May 2000.

A detailed rainfall variation profile was also extracted from three-hourly radar reflectivity data over the Walkerton area to better describe the variation of this rainfall process. The strong reflectivity from the 9th to the 12th confirmed intense rainfall occurred during this period with the two sharpest peaks occurring during the nights of the 9th and the 12th. The other two lesser intense rainfall periods, prior to these two peaks, were associated with rainfall in front of upper level troughs. The WSR-88D radar reflectivity image on the 10th (0315 UTC) showed a southwest to northeast oriented comma-shaped rainfall band extending from the low center located over southern Ontario. This corresponded to the intense rainfall over the Walkerton area during the night of the 9th (Figure 2a). The WSR-88D radar reflectivity image on the 13th (0100 UTC) shows a more intense and better-organized comma-shaped rainfall band. The southwest-northeast oriented rainfall band had a relatively small but very intense head over southern Ontario, which produced the heaviest rainfall over the Walkerton area during the night of the 12th (Figure 2b).

A soil moisture budget model was used to investigate the amount of run-off associated with such an intense rainfall. Since detailed data about soil layers, depth to groundwater, and vegetation were not available, a simple bucket model is used to model near-surface moisture conditions. The model can predict soil-water storage, evaporation, and water surplus. Water surplus is the fraction of precipitation that exceeds potential evapotranspiration and includes both surface and subsurface flows. The basic equation for calculating surplus is:

$$W = P + M - E - \frac{\Delta S}{\Delta t} \qquad (1)$$

In Equation (1), W is surplus, P is precipitation, M is snowmelt, E is evaporation, S is soil moisture, and t is time.

The budget parameters of snowmelt, potential evapotranspiration and precipitation are computed on a daily basis. As continuous intense rainfall occurred during this event, monthly mean output is sufficient to display surface run-off effects from this heavy rainfall.

The monthly mean water surplus calculated in Figure 4 showed a water surplus or run-off that far exceeds zero from January to May. This saturated soil status is also illustrated by comparing the distribution of the main water input (precipitation) and output (evapotranspiration) in Figure 5. The precipitation exceeds evapotranspiration from January to May with some precipitation stored on the surface as snow during the winter months, hence producing sufficient recharge amounts for soil saturation by the beginning of May. Subsequent rainfall amounts would continue to maintain saturation and produce substantial surface run-off during the intense rainfall period from May 8th to the 12th, especially the major rainfall event on the final day.

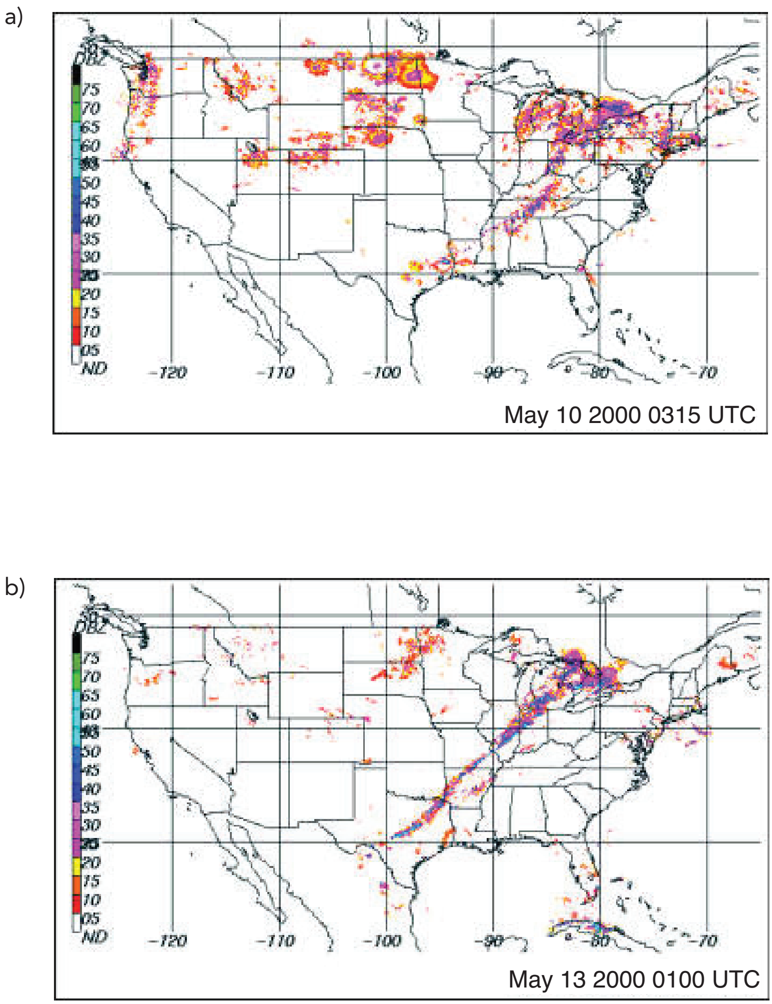

FIGURE 2

Radar reflectivity for the National Weather Service WSR-88 radar at (a) 0315 UTC, May 10, 2000, (b) 0100 UTC May 13,2000.

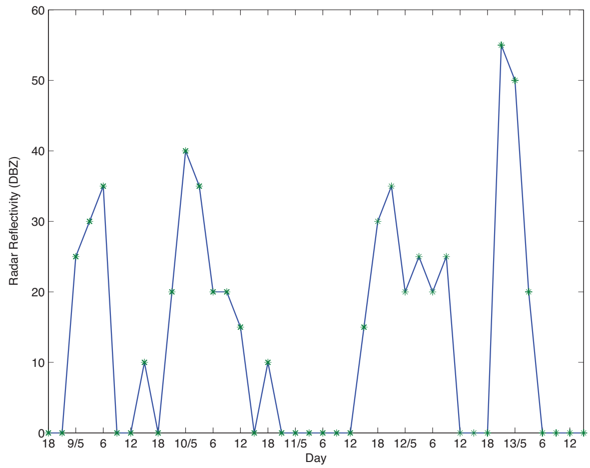

FIGURE 3

Rainfall intensity variation showed in three-hourly radar reflectivity data in Walkerton County during the outbreak period in May 2000.

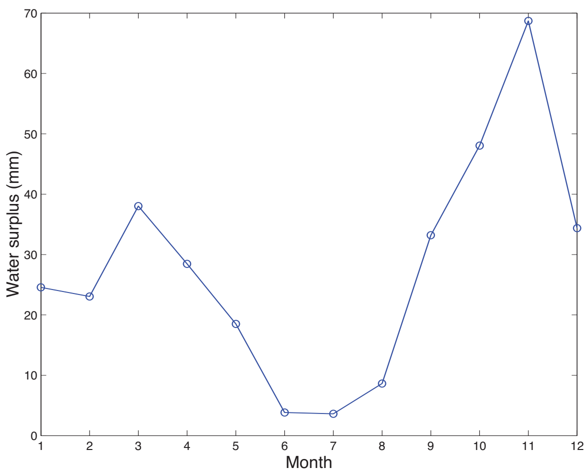

FIGURE 4

Monthly mean water surplus at Walkerton County in the year 2000.

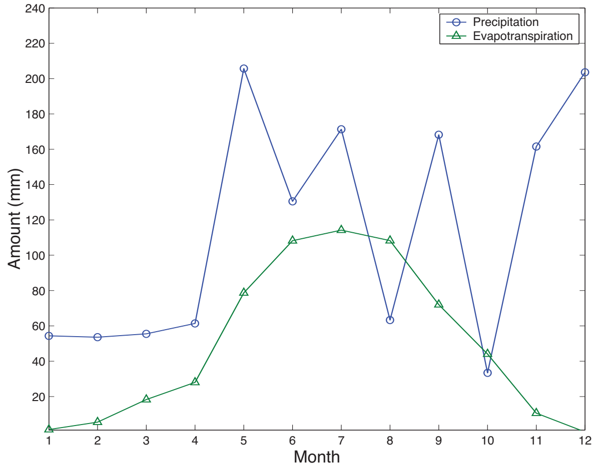

FIGURE 5
Monthly mean precipitation and evapotranspiration at Walkerton County in the year 2000.

5. Synoptic Situation

The synoptic situation associated with this continuous intense rainfall over the Walkerton area showed a unique pattern, as illustrated in the evolution of 850mb weather conditions over southern Ontario (Figure 6). On May 8, a synoptic-scale low centered west of the Great Lakes with a southwest to northeast orientated trough extending deep into the central United States. The cyclonic flow around the low resulted in the cold advection over Winnipeg, and the warm advection over south-western Great Lakes (Figure 6a). The low-pressure system moved east slowly. By May 10, the low-pressure center had reached western Quebec, with the upper level trough tracking over the eastern Great Lakes and southern Ontario (Figure 6b). The GOES-8 satellite image on the 10th shows a well-defined southwest-northeast-oriented comma cloud over eastern North America. Southern Ontario is located under the northeast segment of this cloud shield (Figure 7a). The brighter colour cloud over southern Ontario demonstrates a very cold cloud top temperature and strong vertical movement conducive for the potential of heavy rainfall.

After this initial system passed southern Ontario on the 11th , a second synoptic low system moved in, with the low-pressure center located west of the Great Lakes on the 12th (Figure 6c). This second low-pressure system was much deeper than the former one and intensified between May 12 and 13. The associated advection with this system brought relatively cold air from high latitudes into contact with lower level warm and moistening air from the southeastern coast, forming a very strong surface front over the Great Lakes region (Figure 6d). The surface front passed the Great Lakes during the night of the 12th. This intense

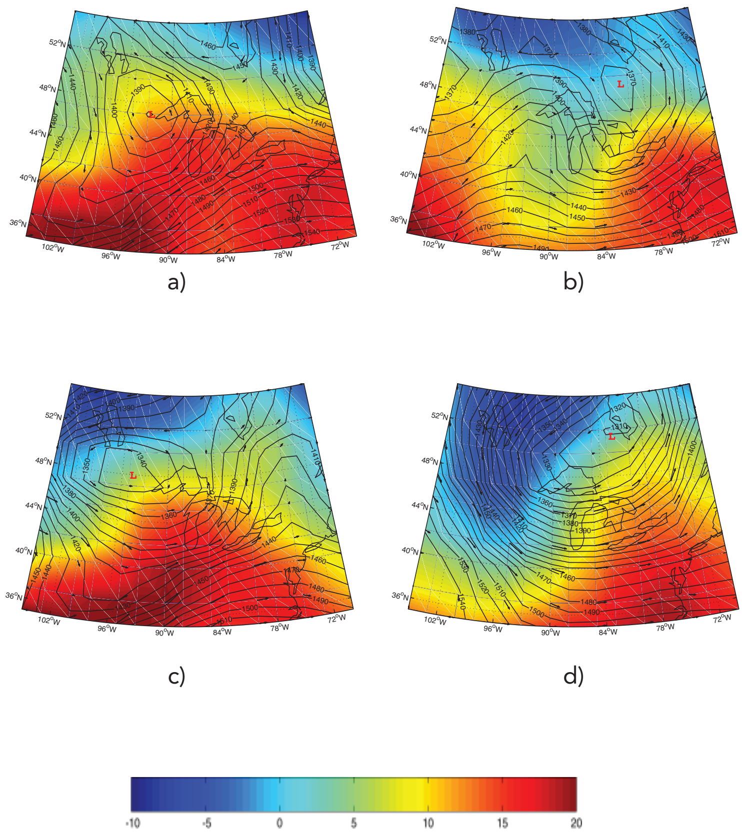

FIGURE 6

Evolution of synoptic situation on 850 mb field during 8-13 May 2000: (a) May 8, (b) May 10, (c) May 12, (d) May 13.

frontal system and the associated strong vertical motion produced the heaviest rainfall. A bright color comma-shaped cloud with strong convective cloud over southern Ontario in the GOES-8 Satellite image also indicates a favorable environment for excessive precipitation (Figure 7b).

a)

b)

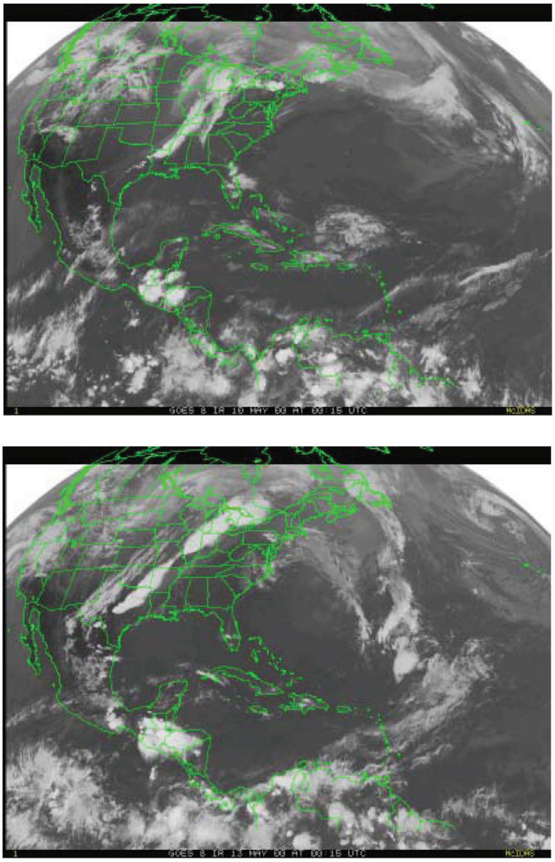

FIGURE 7

GOES-8 image at (a) 0015 UTC May 10 2000 and (b) 0015 UTC May 13 2000, showing comma shaped cloud associated with the surface front system.

6. Summary and Future Directions

By reconstructing one of the most severe waterborne disease outbreaks in Canada, the contributing role of excessive rainfall has been demonstrated, including the critical thresholds that directly affect the runoff and transport of contamination. Multiple factors are associated with run-off, such as, rainfall, soil moisture status, temperature and evapotranspiration. The special synoptic situations that triggered and maintained this continuous and heavy rainfall event; the night time timing of the rainfall events; and rainfall exceeding the 90 percentile threshold are all especially noteworthy.

Analyses of the daily rainfall database from the Meteorological Service of Canada, coupled with the hourly radar reflectivity from NCDC, demonstrated that continuous intense rainfall occurred between 8 – 12 May, 2000, with an extreme intense period at midnight on May 12th, that exceeded the 90th percentile and two standard deviations of the 30 year mean. The soil moisture budget analyses showed a saturated soil existed during this event that ensured a strong run-off, especially during the very intense precipitation period on midnight of May 12th. The upper-air reanalysis data and visible GOES satellite image showed a very special synoptic situation that triggered and maintained this heavy rainfall. Two slowly moving low-pressure systems passed through southern Ontario, centered on Walkerton, resulting in continuous intense precipitation. The first low seemed to act like a precursor by contributing to the recharge of soil moisture and increasing the run-off risk whereas the second low pressure system was much deeper as it passed Southern Ontario yielding excessive rainfall and strong run-off conditions.

The rainfall that triggered the Walkerton waterborne disease outbreak was above both the two standard deviation of the mean rainfall and the 90th percentile of the precipitation. The latter index has been demonstrated to be a critical value to define excessive rainfall and triggering waterborne disease outbreaks in the United States (Curriero, 2001). The same critical threshold criterion of over 90th percentile of the precipitation, confirmed in the case study of Walkerton, plus the Quantitative Precipitation Forecasts provided by the Meterological Service of Canada (MSC), could provide an operational WellHead Protection Alert System (WELLPAS) for Canada. More importantly, based on the radar data, it became apparent that most of the intense rainfall occurred during the night and it most probably escaped the attention of the community. The WellHead Protection Alert System would be designed to issue public advisories for exceedences above the 90% level, days in advance, thereby allowing for adaptive and preventative management actions. In return, WELLPAS could provide a meteorological-health service to Canadians for both municipal and private drinking-water systems. Additional research is on-going between the Meteorological Service of Canada and Health Canada to examine other waterborne disease outbreaks to further refine the critical threshold levels for precipitation and run-off, especially during rain on snow events, across Canada.

7. Acknowledgments

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PAPER

4

IMPACT OF CLIMATE ON CHANGES IN THE SEASONAL TIMING OF LIFE CYCLE EVENTS OF EASTERN CANADA FROM 1901 TO 1924

ADAM FENECH[1], DON MACIVER[1], HEATHER AULD[1] AND STU BEAL[2]

[1]Environment Canada, Toronto, Ontario, Canada
[2]Qvidnon Solutions, Burlington, Ontario, Canada

ABSTRACT: From 1900 to 1923, an influential inspector of schools in Nova Scotia, Dr. A.H. MacKay, recruited a number of knowledgeable teachers around the province to use their students to observe 100 natural occurrences each year, and report them in a standardized way. This is the science of phenology - the study of the seasonal timing of life cycle events. These observations included the appearance of blooming wildflowers, cultivated plants, migratory birds, mammals, amphibians plus the freezing of lakes and rivers, appearance of frost and snow, number and severity of thunderstorms, hurricanes, etc. In addition, the timing of human agricultural practices was also recorded, including calving, seeding, potato planting, and haying. Tracking the timing of naturally occurring events helps show trends in the effects on biota and human activities as a result of climate change and weather variability. Analysis has shown that earlier Springs can be linked to El Niño events, and a trend has been observed towards earlier plant development over the last 40 years in the Edmonton, Alberta area - a trend that matches trends in warmer January to June temperatures in Western Canada. Some plant and animal life cycle events integrate the effects of various climate factors and can be used to detect subtle trends against the noisy background of normal weather variability. Many centuries of plant phenology records from Europe show us that plants and animals are sensitive weather instruments: they can be used for recording climate variables (heat, precipitation, wind) and for forecasting the best time for planting, harvesting, treating for pests, avoiding pollen or planning your holidays. Knowing valuable seasonality information such as the timing of spring flowering helps decision making for farmers and foresters, that is, to correctly time operations such as planting, fertilizing, crop protection (integrated pest management) and to predict harvest timing. It also is useful in wildlife management (the survival of deer fawns is greater in years with early spring arrival); human health (pollen warnings for allergy sufferers), and tourism (best times to photograph flowers or animals, or to go fly fishing). MacKay was an acclaimed botanist whose lichen collection and publications are part of the Nova Scotia Museum resources. The records from his environmental observation project are also part of the Nova Scotia Museum of Natural History collection, and are a valuable source of data. With over 1500 Nova Scotian schools participating, MacKay filled 20 thick volumes with meticulous records of the natural environment (6 are summary volumes). In 1998, these records were digitized, put into a database, and are now available for study. This paper examines the 20 years of MacKay data identifying trends in phenology and human activity, and its possible messages for climate change in eastern Canada.

Keywords: phenology, climate, monitoring

1. Introduction

Phenology is the study of the synchronization of developmental stages of plants and animals with the seasons. The timing of these cycles depends on factors such as temperature, moisture and day length. The phenological events of plants, which are easily observed such as buds opening or plants leafing out, can be used to characterize climate for a region (Spano *et al.,* 1999) for any given year.

Researchers have long identified how phenology can contribute to the examination of climate change and its impact (Kramer, 1996; Lechowitz and Koike, 1995; Schwartz, 1999). Schwartz (1999) calls on researchers to examine the great variety of phenological data that exists worldwide, and to carefully interpret these records in their regional and ecological context. An historical dataset of phenological observations exists in the Canadian province of Nova Scotia.

Nova Scotia is an eastern province of Canada in North America (see Figure 1). One of the Maritime Provinces, Nova Scotia comprises a mainland peninsula and the adjacent Cape Breton Island. It is bounded on the North by the Gulf of St. Lawrence and Northumberland Strait, across which lies Prince Edward Island; on the East and South by the Atlantic Ocean; and on the West by the province of New Brunswick, from which it is largely separated by the Bay of Fundy. Nova Scotia is positioned between 44° and 47° latitude and has a temperate climate with abundant rainfall.

From 1897 to 1924, Alexander Mackay (see Figure 2) was superintendent of Nova Scotia schools. Mackay enlisted the help of teachers and school children from across the province to collect phenological observations of over 100 plants, animals and features of the physical environment. From 1901 to 1923, Mackay mandated schools to teach natural history through his program of phenological observations.

FIGURE 1
Nova Scotia in North America.

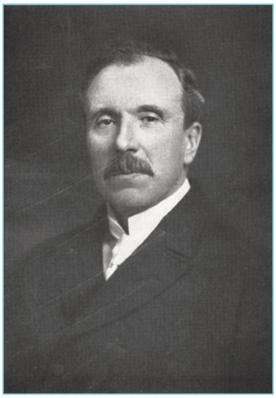


FIGURE 2
Alexander Mackay, School Superintendent of Nova Scotia, 1897 to 1924.

The Mackay observations include the appearance of blooming wildflowers, cultivated plants, migratory birds, mammals, amphibians plus the freezing of lakes and rivers, appearance of frost and snow, number and severity of thunderstorms, and hurricanes. In addition, the timing of human agricultural practices was also recorded, including calving, seeding, potato planting, and haying. Over 1,400 distinctly different schools across Nova Scotia reported these observations (see Figure 3), although observations varied each year from about 50 to over 500 schools reporting.

Mackay was very serious about his observation program. Training was provided to teachers, and meticulous records were kept. Each teacher was required to submit an annual sheet with the timing of the over 100 observations. These were tallied into ledgers (see Figure 4) of which any accountant would be proud. Mackay himself was not simply another government administrator, but he was a member of the Royal Society of Canada and published regularly on lichens and his phenological observation network across Canada.

In 1997, the Mackay ledgers were "rediscovered" at the Nova Scotia Museum of Natural History (Austen, 2000). Environment Canada provided funding to digitize the contents of the ledgers in hopes of having the data analyzed. To-date, analysis conducted on the digitized observations has been limited.

FIGURE 3
Location of Nova Scotia Schools in the Mackay Observations.

FIGURE 4
Mackay Ledger of Observations.

This paper presents an introduction to the Mackay dataset, some phenological calendars for Nova Scotia, and a preliminary investigation of the role of climate in the timing of Nova Scotian phenological events.

2. Data and Methods

2.1 Phenological data

The Mackay phenological observations of Nova Scotia span the years from 1901-1923, with some years missing including 1903, 1904, and 1909. The digitized observations are available as location of observation (an x and y co-ordinate), year of observation, and Julian day of observation (from 1 to 365). Data available in the digitized Mackay dataset were examined from the years 1901, 1902, 1905, 1906, 1907, 1908, 1910, 1911, 1912, 1913, 1914, 1915, 1916, 1917, 1918, 1919, 1920, 1921, 1922, and 1923.

The dataset is divided into three categories of observations – plant, animal and agricultural. The plant category represents 73 observations of plants flowering, shedding pollen, shedding spores, leafing of trees, florets opening, and fruit ripening. The animal category has 22 observations of bird migrations (both northward and southward), and first appearances of snakes and amphibians. The agricultural parameters are limited to seven observations including ploughing, planting, sowing, sheep-shearing, cutting and digging. This paper shows only the results from the plant observations.

2.2 Climate data

Although an official weather observatory was established in Toronto in 1839, Canadian governmental attempts to organize a national meteorological service were not begun until 1871 (Thomas, 1991). Storm warnings and general weather forecasts for Eastern Canada were instituted in 1876, and this service was extended across the West and throughout the settled portions of the country by the early years of the 20th century. Historical climatology data were published annually after 1871, but very little statistical data, delineating the climate of the country, were available prior to 1900. A beginning was made at expanding meteorological activities throughout Canada before World War I, but it was not until the 1920's that a significant number of observing stations were located nation-wide.

Climate data from 1901 to 1925 for Nova Scotia that exists today in electronic form can be found at an internal Environment Canada website archive. Interrogating the database revealed 50 climate stations in Nova Scotia (see Figure 5) with data that exists in the database during this time period. A systematic review of the data from these 50 stations revealed that few (only five) of these stations had continuous data from 1900 to 1925 - Halifax, Parrsboro, Sable Island, Sydney and Yarmouth – although these represented the four corners of the province as well as an offshore site.

2.3 Methods

The paper records of phenological observations in the Mackay ledgers were hand-processed into a digital database. Processed records were checked for accuracies, and an exercise was conducted using a random check of the digital records that were then verified with the paper originals.

The digital Mackay database was dynamically linked to a Website using a Common Gateway Interface (CGI) script (Fenech, 1999) that allows for statistical summaries of data to be produced, as well as geo-referenced maps of the observations. The link allows for queries to be made for specific observations (plants), years of data, as well as locations of data within specific ecoregions or phenochrons. Ecoregions are areas of similar ecology identified and mapped within a hierarchy of ecosystems where broad to specific levels of detail are presented on a series of maps (Neily *et al.*, 2003). The ecological data used to delineate these ecosystems include, among other things, the climatic normals for Nova Scotia. Mackay himself used an equivalent to climate zones that he called "phenochrons". A "phenochron" – the word derived from the roots of phenology

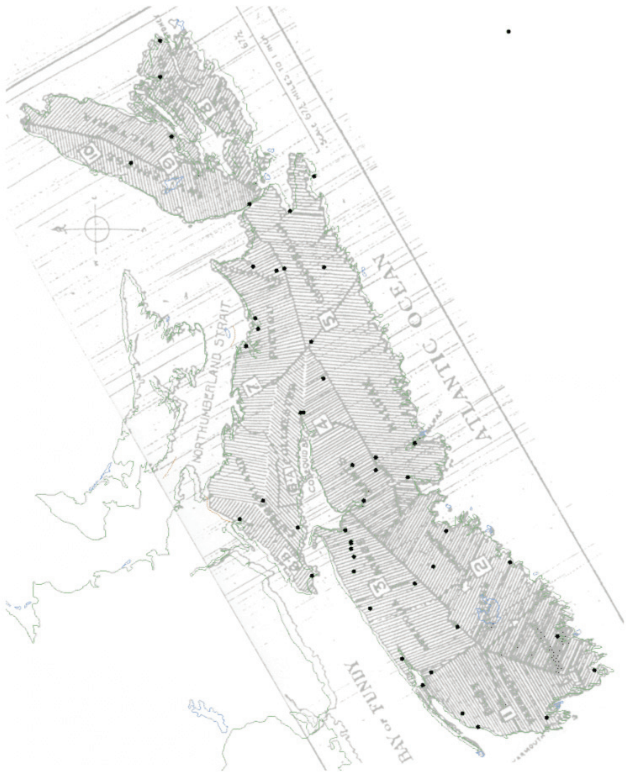


FIGURE 5
Nova Scotia Climate Stations with Data in the Archive for the years 1901-1923.

and chronology - was defined as a "climatic slope or region" each divided into a series of "belts" such as coastal, low inlands and high inlands. For Nova Scotia, Mackay defined 10 "regions or slopes"; each with 3 defined "belts", and mapped them. These can be viewed as the backdrop to Figures 3 and 5.

Summary statistics for all years of available data were computed for the plant observations to develop a phenological calendar based on mean day-of-year that the observation occurred. The maximum, minimum, standard deviation and number of observations (n.) were also recorded and graphed.

Records of climate data for Nova Scotia were compiled in a similar database to be queried. Specifically, maximum, minimum and mean temperatures, and precipitation data were added to the database. Formulae for climate indices such as accumulated growing degree days, corn heat units, water deficit, etc. were programmed into the database to produce output for given years and locations.

3. Results and Discussion

A phenological calendar for plant observations in Nova Scotia from 1901 to 1923 is shown in Figure 6. It shows the *Epigea repens,* L. as the earliest plant phenological event over the years examined. Known as the Mayflower in Nova Scotia because of its legend as the "harbinger of spring", *Epigea repens,* L. (see Figure 7) has been the official provincial flower of Nova Scotia since 1901. The *Epigea repens,* L. is known to flower before mid-June, which means it is more sensitive to daily weather than the day length (photo period).

The flowering dates of the *Epigea Repens,* L. are used as a simple examination of the role of climate in the phenological observations. Figure 8 shows the yearly mean blooming dates for the *Epigea repens,* L. for the available data. The two earliest years are 1902 (DOY 93.5) and 1910 (DOY 93.6); and the two latest years are 1914 (DOY 114) and 1923 (DOY 118). The difference between the two sets is about 3 weeks.

The daily mean temperatures for Nova Scotia for these four years are graphed in Figure 9. It is clear from the graphs that temperatures above zero degrees Celsius were more frequent in the first three months of the year for 1902 and 1910 – the years of earlier bloom times for the *Epigea repens,* L. Subsequently lower temperatures for the first three months appear in the years 1914 and 1923 – the years of latest blooming of the *Epigea repens,* L.

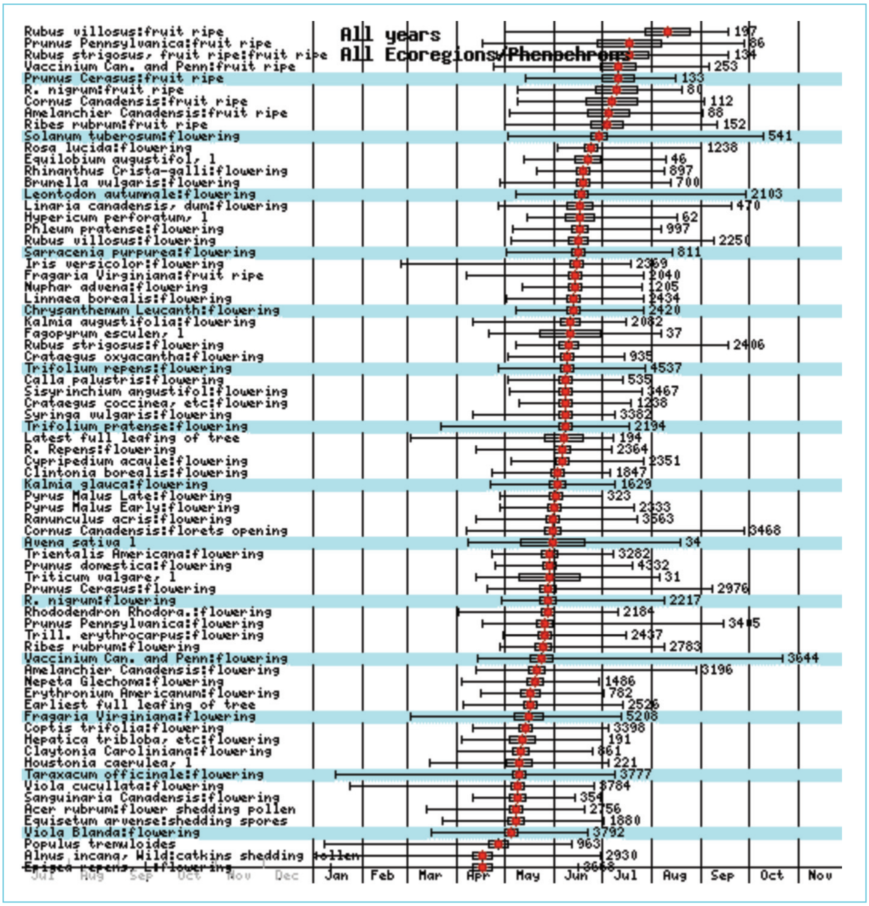


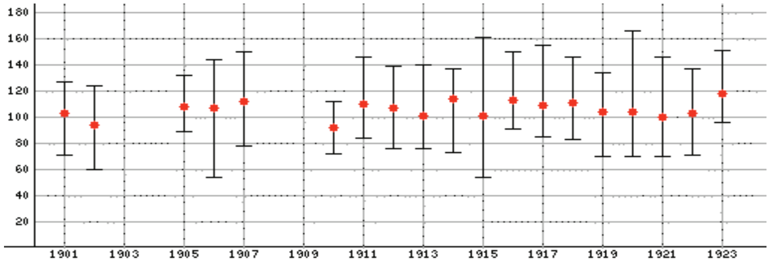
FIGURE 6

Plant Observations in Nova Scotia 1901 to 1923.

Mean shown by dot, range shown by bar (max and min at ends), standard deviation shown by rectangle, and number following bar is count (n). For common names, see appendix.

FIGURE 7

Epigea Repens, L. known as the Mayflower in Nova Scotia and its provincial flower.



Mean shown by dot, range shown by bar   x axis = year, y axis = day of year blooming

FIGURE 8

Epigea Repens (Mayflower) blooming in Nova Scotia 1901 to 1923.

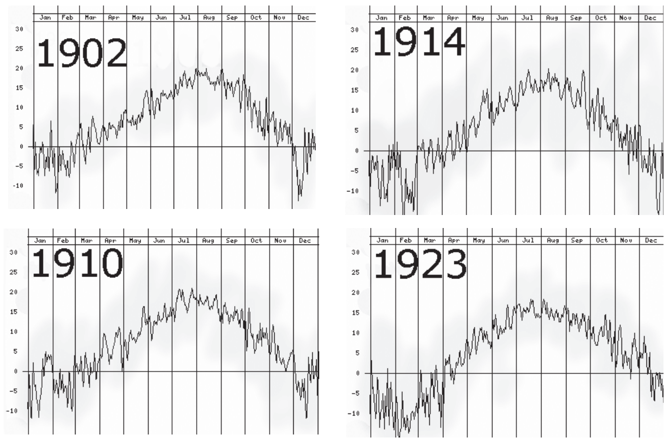


FIGURE 9
Daily Mean Temperatures for Nova Scotia in degrees Celsius.

The results of this simple examination lead to some additional areas of study. First, accumulated growing degree days should be derived from the climate database for all years and compared with each of the phenological events. Spano *et al.* (1999) have shown that using a threshold temperature of between zero and five degrees Celsius to calculate growing degree days has little effect on accuracy. A common use of zero degrees Celsius is recommended for further study. Second, from these data, a mean calculated cumulative degree-day value for each phenological event can be derived with an appropriate standard deviation. This can link the two parameters – temperature and phenological observation – together statistically, and provide results for comparing different plant species (be they native or non-native) and their sensitivities to temperature and other climate parameters. Third, the other parts of the database should begin to be studied including the animal parameters and the agricultural parameters, and their links to climate parameters should be examined.

4. Conclusions

The Mackay phenological observations provide an interesting dataset to begin examining the role of climate in the natural processes of Nova Scotia in the early 20th century. The Mackay ledgers have been successfully digitized and have provided a phenological calendar for 70 plant observations. Of these observations, the earliest, *Epigea repens,* L. has shown to be responsive to the regional temperature with warmer temperatures leading to earlier flowering times, and colder temperatures leading to later flowering times. This paper is but the beginning of a long examination of this valuable dataset.

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APPENDIX 1
Phenological Observations in Mackay Dataset 1901 to 1923

Phenological Parameter	Common name	Stage
Acer rubrum	Red Maple	flower shedding pollen
Actitis macularia	Spotted Sandpiper, migrating north	migrating north
Alnus incana	Speckled Alder	catkins shedding pollen
Amelanchier canadensis	Wild Pear	flowering
Amelanchier canadensis	Wild Pear	fruit ripe
Bombycilla cedrorum	Cedar Waxwing, migrating north	migrating north
Prunella vulgaris	Heal-All	flowering
Calla palustris	Wild Calla	flowering
Ceryle alcyon	Belted Kingfisher, migrating north	migrating north
Chordeiles minor	Common Nighthawk, migrating north	migrating north
Chrysanthemum leucanthemum	Ox-eye Daisy	flowering
Claytonia caroliniana	Spring Beauty	flowering
Clintonia borealis	Corn-Lily/Clintonia-lily	flowering
Closing of lakes		
Closing of rivers		
Coptis trifolia	Golf Thread	flowering
Cornus canadensis	Bunchberry	florets opening
Cornus canadensis	Bunchberry	fruit ripe
Crataegus coccinea	Scarlet Hawthorn	flowering
Crataegus monogyna	English Hawthorn	flowering
Cypripedium acaule	Pink Lady's-slipper	flowering
Dendroica petechia	Yellow Warbler, migrating north	migrating north
Dendroica coronata	Yellow-rumped Warbler, migrating north	migrating north
Dolichonyx oryzivorus	Bobolink, migrating north	migrating north
Epigaea repens	Mayflower	flowering
Equisetum arvense	Field Horsetail	shedding spores
Erythronium americanum	Yellow Adder's Tongue Lily	flowering
First appearance, snakes		
First autumn frost, hard		
First autumn frost, hoar		
First piping of frogs		
First snow to fly in air		
First snow to whiten ground		
Fragaria virginiana	Strawberry	flowering
Fragaria virginiana	Strawberry	fruit ripe
Grain-cutting		
Hay-cutting		

APPENDIX 1 cont...

Phenological Observations in Mackay Dataset 1901 to 1923

Phenological Parameter	Common name	Stage
Hepatica americana	Hepatica	flowering
Iris versicolor	Blue Flag	flowering
Junco hyemalis	Dark-eyed Junco, migrating north	migrating north
Kalmia angustifolia	Lambkill	flowering
Kalmia polifolia	Pale Laurel	flowering
Last snow to fly in air		
Last snow to whiten ground		
Last spring frost - hard		
Last spring frost - hoar		
Leontodon autumnalis	Fall Dandelion	flowering
Linaria vulgaris	Butter-and-Eggs	flowering
Linnaea borealis	Twinflower	flowering
Melospiza melodia	Song Sparrow, migrating north	migrating north
Glechoma	Ground Ivy	flowering
Nuphar variegatum	Yellow Pond-lily	flowering
Opening of lakes		
Opening of rivers		
Phleum pratense	Timothy	flowering
Ploughing first of season		
Populus tremuloides	Trembling Aspen	
Potato-digging		
Potato-planting		
Prunus cerasus	Sour Red Cherry	flowering
Prunus cerasus	Sour Red Cherry	fruit ripe
Prunus pensylvanica	Wild Red Cherry	flowering
Prunus pensylvanica	Wild Red Cherry	fruit ripe
Prunus domestica	Plum	flowering
Pyrus malus	Apple	flowering
Ranunculus repens	Creeping Buttercup	flowering
Ribes nigrum	Black Currant	flowering
Ribes nigrum	Black Currant	fruit ripe
Ranunculus acris	Tall Buttercup	flowering
Rhinanthus crista-galli	Yellow Rattle	flowering
Rhododendron canadense	Rhodora	flowering
Ribes rubrum	Red Currant	flowering
Ribes rubrum	Red Currant	fruit ripe
Rosa virginiana	Common Wild Rose	flowering
Rubus strigosus	Raspberry	flowering
Rubus strigosus	Raspberry	fruit riope
Rubus pensilvanicus	High Blackberry	flowering
Rubus pensilvanicus	High Blackberry	fruit ripe
Sanguinaria canadensis	Bloodroot	flowering
Sarracenia purpurea	Pitcher Plant	flowering

APPENDIX 1 cont...

Phenological Observations in Mackay Dataset 1901 to 1923

Phenological Parameter	Common name	Stage
Setophaga ruticilla	American Redstart, migrating north	migrating north
Sheep-shearing		
Sisyrinchium montanum	Blue-eyed-grass	flowering
Solanum tuberosum	Potato	flowering
Sowing		
Carduelis tristis	American Goldfinch, migrating north	migrating north
Sturnella magna	Eastern Meadowlark, migrating north	migrating north
Syringa vulgaris	Lilac	flowering
Taraxacum officinale	Dandelion	flowering
Trees appear green		
Trientalis borealis	Star Flower	flowering
Trifolium pratense	Red Clover	flowering
Trifolium repens	Creeping White Clover	flowering
Trillium undulatum	Painted Trillium	flowering
Archilochus colubris	Ruby-throated Humming Bird, migrating north	migrating north
Turdus migratorius	American Robin, migrating north	migrating north
Tyrannus tyrannus	Eastern Kingbird, migrating north	migrating north
Vaccinium myrtilloides, Vaccinium angustifolium	Dwarf and Canadian Blueberry	flowering
Vaccinium myrtilloides, Vaccinium angustifolium	Dwarf and Canadian Blueberry	fruit ripe
Viola blanda	Sweet White Violet	flowering
Viola cucullata	Blue Violet	flowering
Water in streams - high		
Water in streams - low		
Wild ducks		migrating north
Wild ducks		migrating south
Wild geese		migrating north
Wild geese		migrating south
Zonotrichia albicollis	White-throated Sparrow, migrating north	migrating north

PAPER

5

RESEARCH ON BIODIVERSITY AND PLANT HARDINESS ZONES ACROSS A SOUTHERN ONTARIO TRANSECT

MARIANNE B. KARSH

ABSTRACT: This research paper will compare expected species lists for the new plant hardiness zones with species lists collected by volunteers in SI/MAB plots along a longitudinal gradient in the Niagara Escarpment from Long Point to Wiarton. Scientists have currently documented 12 families at Long Point and nine families at Wiarton. The expected loss in the number of families in Long Point, as predicted by the new plant hardiness zones, could result in a potential biodiversity crisis for Ontario. Our native species diversity could be threatened, especially species growing in the Carolinian Region of Ontario, one of the most diverse areas in Canada. Native species may potentially be lost that have been naturally adapted to Canadian climates. Detailed examples of biodiversity data will be discussed using a Southern Ontario case study. In addition, recommendations will be presented for future paired SI/MAB plots. Ongoing monitoring on these paired 1 ha SI/MAB sites by the volunteer sector and ACER (Association for Canadian Education Resources) can provide scientists with early detection of changes in the landscape, especially in high impact areas.

1. Introduction

A new plant hardiness zone map of Canada is now available on the web from Agriculture Canada (**http://sis.agr.gc.ca/cansis/nsdb/climate/hardiness**). The original plant hardiness map was based on 1931-1960 climate data (Ouellet and Sherk, 1967). The new hardiness map, based on the same formula is for the 1961-1990 data period (McKenney *et al.*, 2001).

The plant hardiness map outlines different zones in Canada where various types of trees will most likely survive. In 1967, Ouellet and Sherk created a plant hardiness map using Canadian plant survival data and seven climate variables, including minimum winter temperatures of the coldest month, length of frost-free period, rainfall of the frost free months, maximum temperatures, January rainfall, snow cover and maximum wind gust. In 2001, McKenney *et al.* produced a new plant hardiness zone map using the same variables and climate data from 1961-1990, applying automated computerized climate mapping techniques.

A large number of SI/MAB biodiversity observation plots (>25) exist across a southern Ontario transect along and adjacent to the Niagara Escarpment from Wiarton at Georgian Bay to Long Point along Lake Erie. The ability to interrogate and field validate the results of existing and new plant hardiness zone maps is now possible by comparing actual with predicted indicator species that flourish in areas within this transect. The plant hardiness zone map is perhaps the most widely used climate-based map by gardeners as they select their plant varieties at nurseries depending on their respective hardiness zones.

2. Climate, Agricultural and Ecological Relationships of the Southern Ontario Transect

Distinct climate differences exist between Wiarton and Long Point. The observations at Wiarton and Long Point will be used for illustration purposes only; the comments and conclusions in this paper apply throughout southern Ontario and elsewhere in Canada. The average annual temperature at Wiarton is 6°C and 7.8°C at Delhi, the closest long term Bioclimatic station to Long Point (Figures 1a, b). Corn Heat Units and Growing Degree Days also differ significantly between the two stations. There are 947 available growing degree days above 10°C at Wiarton compared to 1,268 growing degree days above 10°C at Delhi (Figures 1c, d).

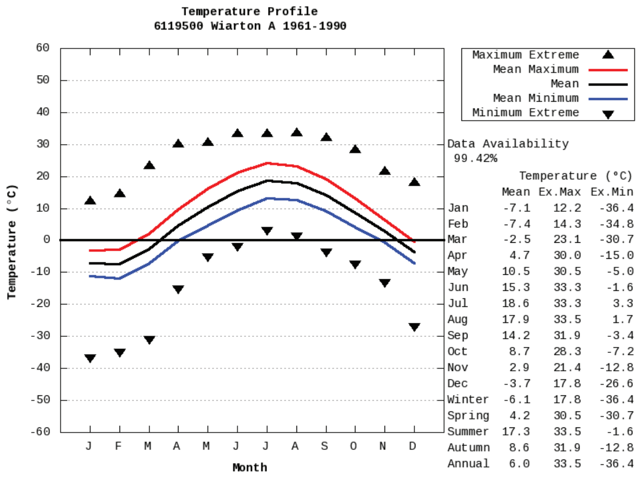

FIGURE 1a

Temperature Bioclimate Profiles for Wiarton.

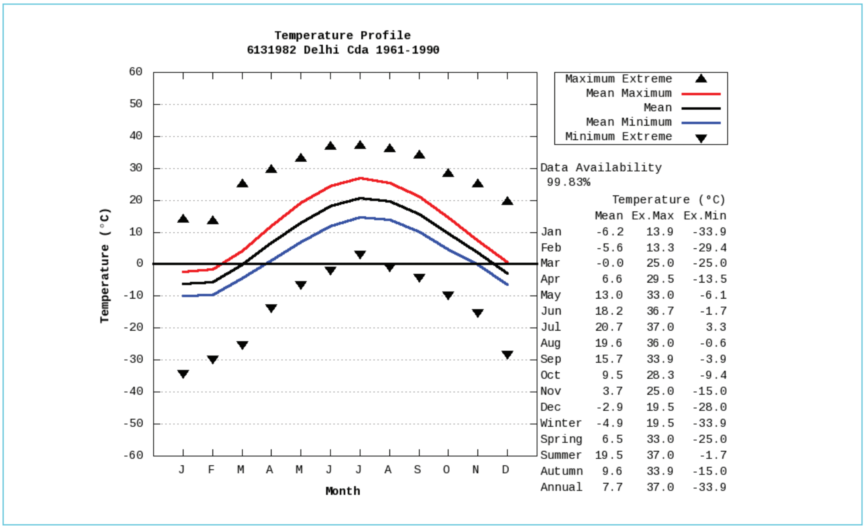

FIGURE 1b

Temperature Bioclimate Profiles for Delhi CDA.

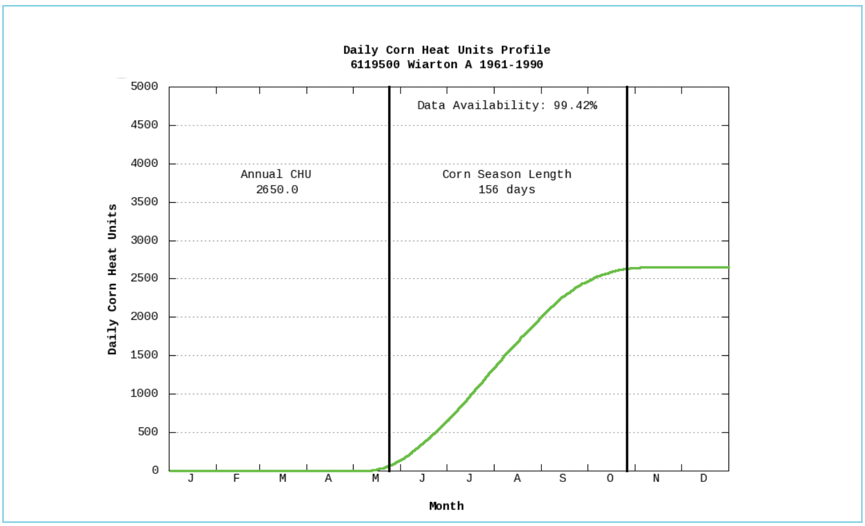

FIGURE 1c

Corn Heats and Growing Degree Days for Wiarton.

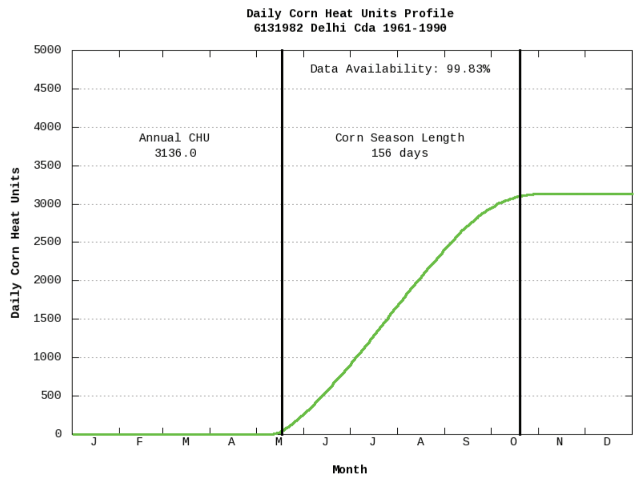

FIGURE 1d

Corn Heats and Growing Degree Days for Delhi CDA.

This difference of 321 in growing degree-days impacts significantly the agricultural crop potential in each region. According to Dumanski and Stewart (1981), cash crops such as soybean are moderately suitable for growing in Long Point (Class 3) but have no potential in Wiarton (Class 6). Likewise, seed or grain corn have low potential in the Wiarton region, different than Long Point.

One of the most distinct forestry transition zones in southern Ontario is the Carolinian Zone in the Lake Erie Lowland Ecoregion (**www.on.ec.gc.ca/glirnr/images/maps/carolinian.git**). Above this zone is the Great Lakes-St. Lawrence Forest Region with a very different forest biodiversity at the ecosystem, species and genetic levels. This major ecological zone occurs along the transect between Wiarton and Long Point. To show some of the tree species differences across this transect we can interrogate the relatively large number of Climate-Based Biodiversity Mapping and Global (SI/MAB) Sites in southern Ontario (Figure 2a).

3. SI/MAB Program

The Smithsonian Institution and the UNESCO Man and the Biosphere Biological Diversity Program (now the Monitoring and Assessment program) tested procedures for establishing permanent forest inventory plots in world biosphere reserves. The purpose of this program was to 1) document plant diversity, 2) provide long term data on the growth, mortality, regeneration and dynamics of forest trees and 3) create a research and education base that will foster the conservation and management of biosphere reserves.

One of the very fortunate aspects of having this data available and analyzed is the ability to compare sites across Canada and globally. For the purpose of illustration, the global versus Long Point families by proportional abundance classes show greater biodiversity at Long Point with 12 families compared to 9 families in Wiarton and relatively few families compared to a site in Asia with over 50 families (Figure 2b).

For the first time a globally standardized plot design has been adopted that is flexible and accommodating to different forest environments. This standardized design allows compatibility and comparable reliability in data collected at different sites around the world. The design is a square, one-hectare size (subdivided into 25 individual 20 x 20 m quadrants).

The use of a one-hectare plot gives a relatively large sample and has been shown to be robust enough to capture the biodiversity of a site in the tropics and also in some of the most biologically diverse areas in the Carolinian Zone of southern Ontario. The globally agreed upon protocol requires that all trees above a certain diameter (10 cm dbh in the tropics and 4 cm dbh in southern Ontario) are mapped, identified for species and measured for diameter at breast height (dbh) and total height (m). Parameters such as tree health, understory vegetation and other species may also be monitored in these plots using standardized protocols.

This long term mapping of tree species and vegetation in urban impacted areas makes these sites ideal for interrogating existing and previous plant hardiness zone maps. The Canadian Biodiversity SI/MAB sites continue to expand at an unprecedented rate. It is an extremely successful program and the first comparative results of the data from sites right across Canada have been documented (EMAN 2001).

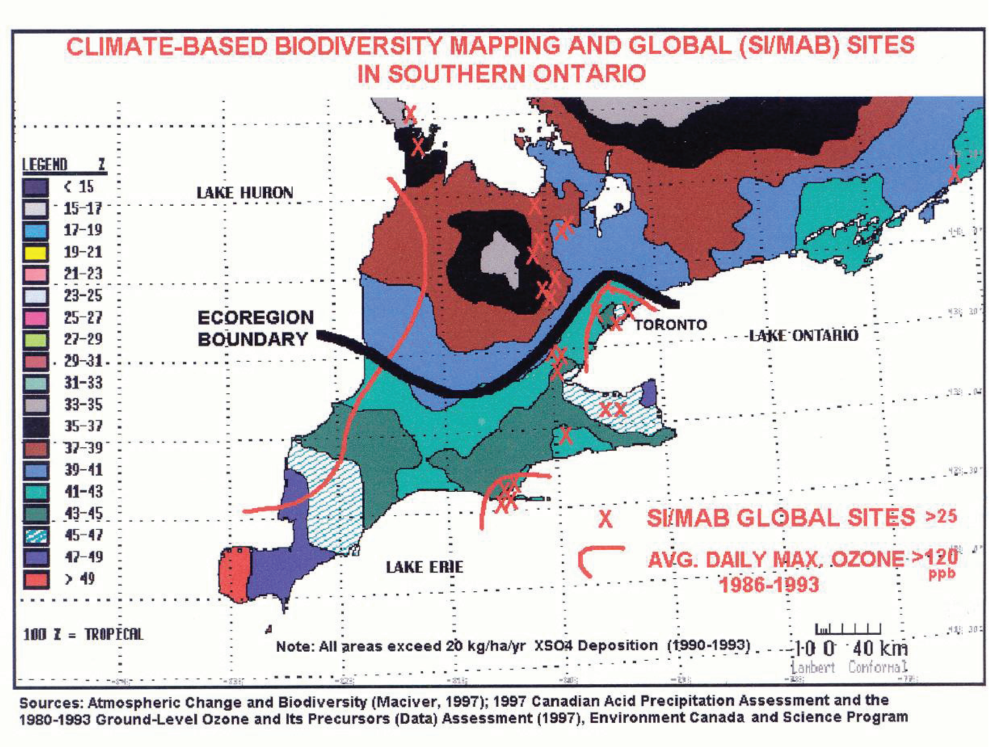

FIGURE 2a

Climate-Based Biodiversity Mapping and Global (SI/MAB) Sites in southern Ontario.

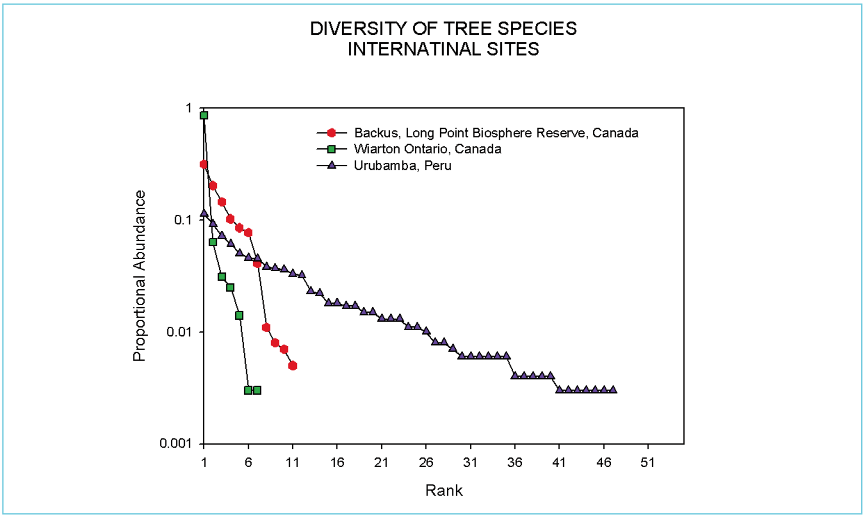

FIGURE 2b

Global Versus Long Point Families by Proportional Abundance Classes.

4. Plant Hardiness Zone Map Changes

The original map by Oueuet and Sherk (1967) shows two zones removed between Wiarton and Long Point. On this map Wiarton is in zone 5b and Long Point is in zone 6b (Figure 3a). The first noticeable difference between the maps is the classification of the old versus new hardiness zones. The new map shows cooler species zones by one or two classes for southern Ontario. Toronto shows a cooler species zone by one class and the region of Long Point along the Lake Erie shoreline shows a cooler species zone by two classes (6b to 5b). The original 7b zone south of Windsor in the 1967 publication is not reproduced in the 1967 map. The two warmest species zones on the 1967 map, namely 8b and 9a, are entirely omitted in the 2000 map (Figure 3b).

The second important difference between the old and new maps is the spatial mapping of, for example, the Long Point area along Lake Erie. A noticeable difference is the joining of Long Point with Wiarton and Owen Sound in the Bruce Peninsula (now all in 5b). The former 6b zone (now 6a) is no longer joined across Lake Erie. There is a separation around the region of Long Point, and Long Point has dropped from 6b into 5b. This means that Wiarton, Owen Sound, Collingwood, Kincardine, Stratford, Woodstock, Brantford, Richmond Hill, Long Point, Oshawa, Coburg, Kingston and Ganonoque are all in this cooler species 5b zone.

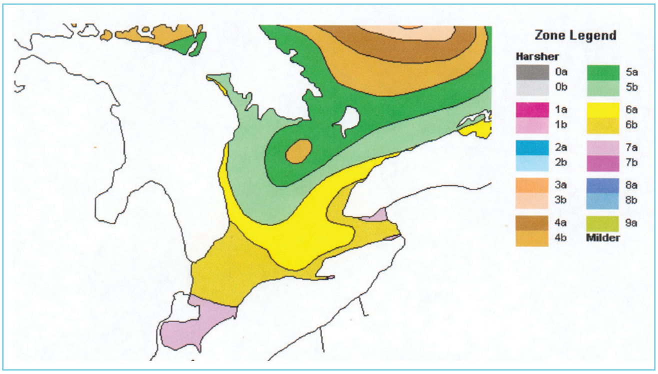

FIGURE 3a
Plant Hardiness Zones of Canada for 1967 (Ouellet and Shark 1967).

FIGURE 3b
Plant Hardiness Zones of Canada for 2000 (McKenney *et al.*).

5. Predicted Indicator Species and Species Lists on SI/MAB Sites

For the purpose of illustration, one of the main indicator species for zone 6b, which formally included Long Point in the 1967 map, is Eastern Flowering Dogwood (*Cornus florida*). The indicator species associated with the 6b zone in the 2000 map is still Eastern Flowering Dogwood (for the most part the indicator species remain unchanged between the old and new maps). Similarly, the indicator species in the USDA Plant Hardiness Zone Map (**www.usna.usda.gov/Hardzone/html.hzm-ne**) for the Long Point region is *Cornus florida*. Field data show that *Cornus florida* flourishes at Long Point, comprising 4 percent to 6.5 percent of the total number of stems per hectare in two SI/MAB mixed-wood plots at Long Point. Eastern Flowering Dogwood continues to be found in significant proportion in 2000 after the fifth year remeasurement (EMAN 2001).

Today, based on this new 2000 plant hardiness zone map, colder species are recommended throughout southern Ontario. Current and future temperature scenarios illustrate a "less cold" environment within the rotation life span of any tree species selected for planting today. Equally important is the lack of agreement between the new plant hardiness zone and current tree species. Likewise, the mapping algorithms are suspect when the spatial patterns are generated that link together locations such as, Long Point, Kitchener, Wiarton and many other areas that cross distinct ecological, agricultural and climate regions. If this new plant hardiness map continues to be used by Canadians as the fundamental basis for selecting and planting species, then the validity of the map raises serious concerns for future biodiversity.

6. Conclusions and Recommendations

We have a tremendous database available to us in the SI/MAB plots across southern Ontario and in other parts of Canada as well. These SI/MAB plots, using standard global protocols, provide an essential ground-truthing knowledge base for the evaluation of new climate-based products, including remote sensing.

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PART

II

LANDSCAPE CHANGE

PAPER 6

CHANGES IN THE LANDSCAPE OF SOUTHERN ONTARIO, CANADA SINCE 1750: IMPACTS OF EUROPEAN COLONIZATION

SADIA BUTT[1], PREETI RAMPRASAD[1] and ADAM FENECH[2]

[1]University of Toronto, Toronto, Ontario, Canada
[2]Environment Canada, Toronto, Ontario, Canada

ABSTRACT: As European settlement in southern Ontario began in the 18th Century, land was prepared for agriculture by draining wetlands and removing trees, leading to altered and continually stressed ecosystems. To illustrate the changing landscape, a Geographic Information System (GIS) was used to create a first approximation map of the pre-European land cover of southern Ontario. This was derived from survey notes of the original land surveys of European settlement completed from 1798-1850. When compared to a modern day map of landscape coverage, results show a decrease in forested land from more than 80 percent to less than 20 percent. The implications are decreasing forest diversity and loss of forest cores to support sensitive wildlife species resulting in significant changes in the overall forest ecology.

Keywords: landscape, Ontario, maps, forests, wetlands, history

1. Introduction

This study focuses on the natural landscape of southern Ontario prior to European settlement. Natural landscapes are defined by the American Society of Landscape Architect's committee on historic landscape preservation as "those that are relatively unchanged by human intervention." In the past, before significant European settlement, the landscape of southern Ontario has been described as "wetlands from horizon to horizon and a mass of forests" (Jameson, 1838). Subsequent human settlement, agricultural activities and urban sprawl have reduced this historic natural landscape to the point where little is left; and the woodlands are remnants completely surrounded by agricultural lands. European settlers arrived in the 18th and 19th Centuries clearing land of trees and other vegetation, as well as draining wetlands, for agricultural purposes. As an early observer stated (Jameson, 1838) "A Canadian settler hates a tree, regards it as his natural enemy, as something to be destroyed."

Prior to European settlement, the aboriginal peoples of southern Ontario had an influence on overall land cover for their own uses, but it allowed for the remainder of natural wetlands and forests to remain. The aboriginal peoples used fire as a means of clearing land for campground and portage maintenance, habitat improvement for game animals, and preparing agricultural land (Bakowsky and Riley, 1992). Also, land cover change occurred for transportation as a network of foot trails were established crisscrossing southern Ontario, often parallel to major waterways, between waterways, and following lake shorelines (current and glacial). This damage to the natural landscape was minimal compared to that invoked by the Europeans to follow.

Surveyors

In 1783 British General Haldimand, commanding in Quebec, was considering where to place the prospective flood of United Empire Loyalist refugees - those loyal to Mother England looking to resettle after finding themselves south in the newly independent United States of America since 1776. To get the survey of potential settlement lands, the government in London, England approved a survey asking for "as accurate an Account as you can obtain of the Quantity" of land in question and of its likely produce. Later in 1791, John Graves Simcoe, the first lieutenant governor of Upper Canada (now southern Ontario) pushed for a survey of lands as he pictured himself as the "Romulus" of a new imperial province, which he would develop largely from scratch, using a corps of soldiers who would open up the country, then retire to settle on land grants very much on the Roman model (Dunbabin, 2005). The surveying helped settle the area as the human population of Upper Canada grew from under 100,000 to over 1 million from 1800 to 1871 (Figure 1). The surveys were conducted in a piecemeal

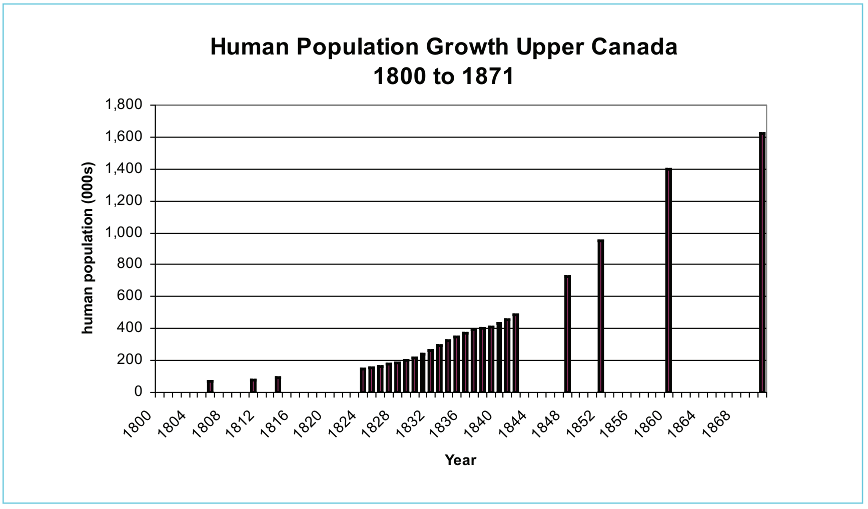

FIGURE 1

Growth of human population of Upper Canada from 1800 to 1871.
Source: Data from Statistics Canada.

fashion using different standards (much of which had to be revised, checked, and even re-done by their successors (Ladell 1993) until 1869 when the Canadian government adopted a survey system founded on the United States of America design (sections were to be 200 acres each).

Surveyors were tasked with laying out basic lines (drawing of base lines and boundaries) and doing detailed land surveys. Crown Land Surveyors underwent a 6-month license training period in surveying methods and vegetation identification to the level that it would be defendable in court should their work be contested (Ladell, 1993). Thus, the surveyors were obliged to record the type of trees available to a potential settler accurately. This information is found today in archived surveyor field notes and is the only human recorded data that was collected in a relatively methodological and uniform manner.

Surveyor methodology involved the running of concession lines that were measured using the simple tools of a compass and chains. Along the concessions, lots were marked off at 67 chains (1 chain = 66 feet = 20.12m). The surveyors initially used mounds to mark these locations and in later surveys these were replaced by wooden stakes (Ladell, 1993). As the surveyors walked along these concessions they noted the forest type or tree composition, the slope of the land, the wetlands, and any unique features of the lot. The information in these field notes is valuable to document pre-settlement land cover; and due to the methodological manner in which it was collected, is the only systematic eye-witness account indicating the type and location of forest types.

Finlay maps

The information in the surveyors' notes was used by Finlay (1978) to create land cover maps for counties in Southern Ontario. Finlay researched the Ontario and National Archives for field notes, and when field notes were not available, information was gleaned from diaries and township plans. To create polygons, the assumption was made that the vegetation would be present for half the lots on either side of the concession line. The polygons were hand drawn on Ministry of Transportation county maps with a scale of 1:64,000 (Figure 2). In addition, layers of the tall-grass prairie and oak savannah land covers were obtained from the Natural Heritage Institute of Canada (NHIC), since the NHIC found that some surveyor notes had discrepancies in describing these types of vegetation covers, NHIC has resolved these using other sources of information.

FIGURE 2
Hand drawn polygons by Finlay (1978) on Ministry of Transportation county maps with a scale of 1:64,000.

2. Methods

Digitized county base maps were obtained from the Ministry of Transportation to provide the outline of each township in southern Ontario. Finlay maps were geo-referenced accordingly, and then each of the polygons created by Finlay depicting land cover was digitized. After polygons were digitized in a township they were individually classified using Finlay's legend for both tree species and groups of trees. Where possible (due to time and clarity of information), the groupings were made according to the Ecological Land Classification (ELC) System. At the same time, the accuracy of the digitization was checked and any required amendments completed. The database was created using the geographic information software ESRI Arcview 3.2 in the Universe Mercator

Projection with UTM co-ordinates nad83 and zone 17. To determine area calculations, the final map was projected into an Albers Equal Area Conical Projection. To determine the present day forest cover, land cover maps created by Natural Heritage Institute of Canada based on satellite images were obtained. These allowed for comparisons of both forest and wetland cover change from pre-European settlement to the present. The database contains polygon information with regard to polygon area, perimeter, T-code (refers to tree groupings or Ecological Land Classification vegetation type), Ecological Land Classification series code and Ecological Land Classification class code. In addition, a field was created for notes that indicate the common name for dominant and accessory tree species.

3. Results

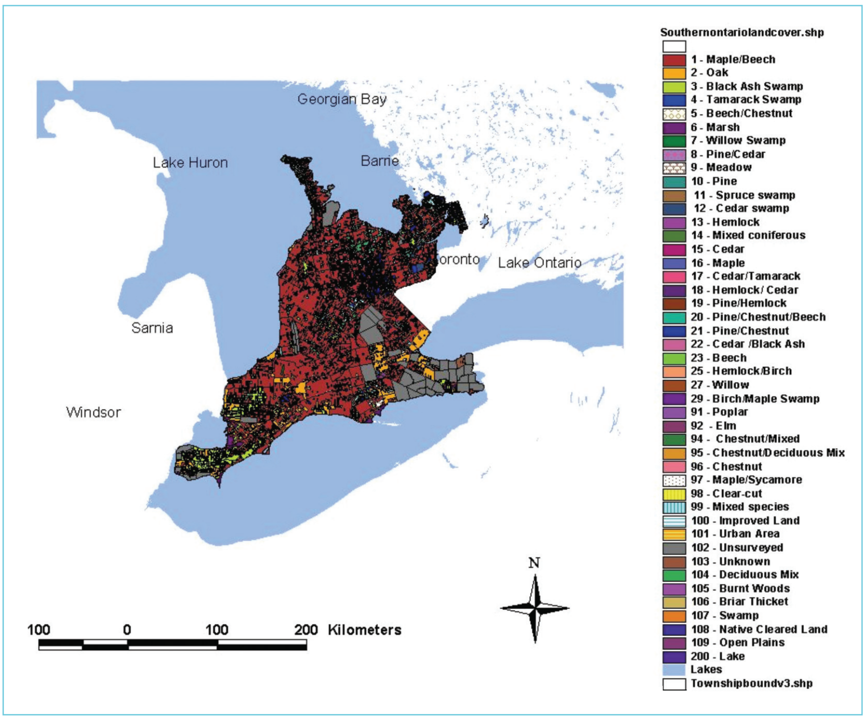

FIGURE 3

Pre-European settlement land cover in southern Ontario classified by tree groups. Note the grey areas are regions for which data has been lost or missing in the archives.

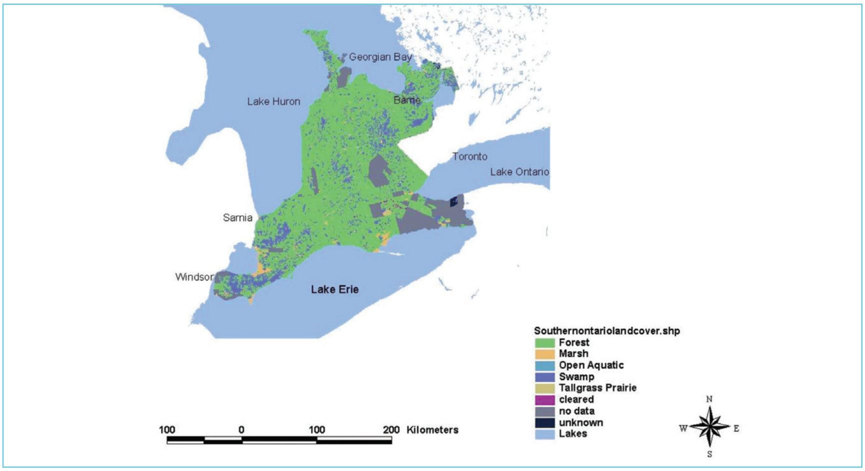

FIGURE 4

Pre-European settlement land cover in southern Ontario classified by Ecological Land Classification (ELC). Note the grey areas are regions for which data has been lost or missing in the archives.

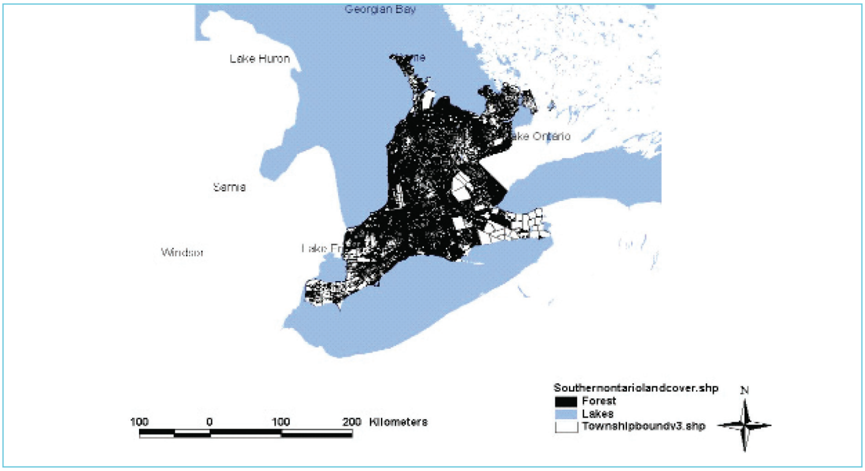

FIGURE 5

Pre-European settlement land cover in southern Ontario classified by Forest and Non-Forest areas. Note the white areas are regions for which data has been lost or missing in the archives, or is outside the study area.

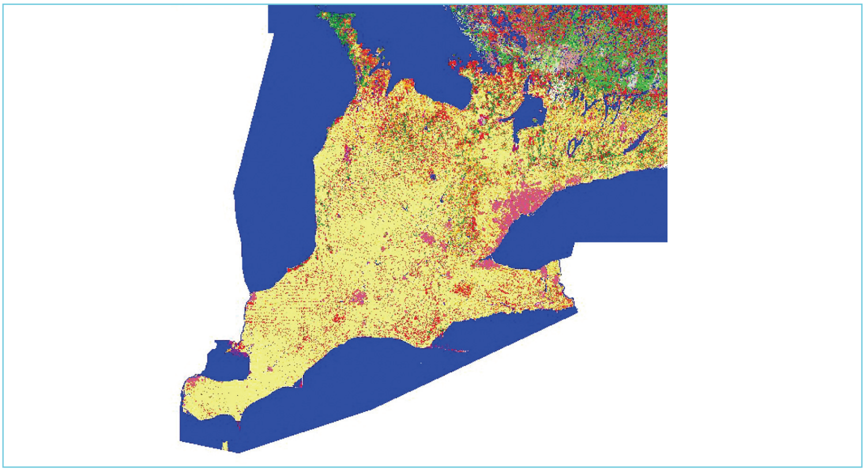

FIGURE 6
Present day forest cover adapted from Ontario Ministry of Natural Resources Provincial Landcover Map (OMNR, 2000). Note that forest cover is shown in red, non-forest in yellow, and urban areas in grey.

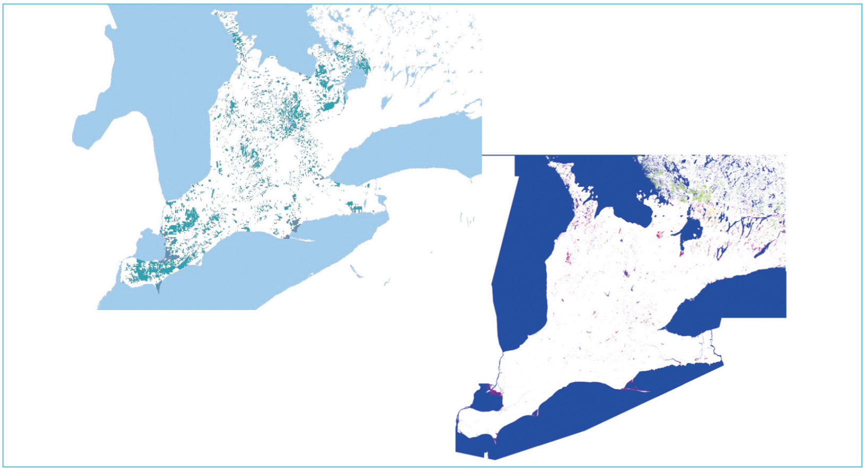

FIGURE 7
Comparison between pre-European settlement wetland cover in southern Ontario (top left) and present day wetland cover (bottom right) adapted from Ontario Ministry of Natural Resources Provincial Landcover Map (OMNR, 2000).

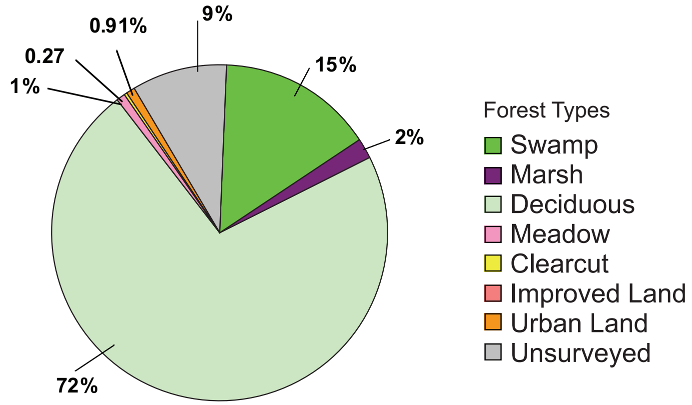

FIGURE 7
Percentage of Forest Cover Type in Southern Ontario at Pre-European Settlement.

4. Discussion and Conclusions

It is clear from the digitized maps that land cover in southern Ontario has changed dramatically since the settlement of Europeans in the 18th and 19th centuries. The change in forest cover can be attributed to the changing socio-economic needs of people as they settled in the area over time (Drushka, 2003). In addition to agricultural purposes, the settler's cultural attitudes and fears of predators and enemies of the forest that could invade livestock and settler safety influenced how forests were managed around settled areas almost 200 years ago (Drushka, 2003).

From the late 18th Century, southern Ontario was logged primarily for the building of the Queen's navy ships, roads fuel wood and for settler habitats. After 1850, export logging declined and agriculture increased. Agriculture remained the dominant land use until the mid-20th Century when development began to increase with the advent of automobiles and increased human population. All these activities resulted in the decline in forest cover from over 80% in the pre-European settlement period to less than 17% presently.

The digitization of the Finlay maps allows for a first approximation of the pre-European settlement land cover. This allows for general characterizations and comparisons of forest types on a large scale at the pre-European settlement period and to document change over time. Although the dataset is not suited to pinpoint site-specific land cover type (unless located in and along a concession line) it can be used to determine both the types of forest or tree species that can be expected within an area. By using this dataset with soil and climate data, it is possible to model a more realistic distribution of forest types which will be useful for conservation and restoration programs. In addition, such a model would allow for the interpolation of forest type in areas where records from surveyor field notes have been reported as destroyed, missing or incomplete.

TABLE 1

Remaining woodlots in percent of various towns in the GTA region (CVCA, 1956).

Township	1851	1861	1891	1911	1921	1931	1941	1951	1954
Amaranth	97.2	89.6	40.4	11.6	6.6	5.4	4.9	6.4	2.6
Mono	87.9	64.8	29.4	13.1	16.2	16.1	14.6	12.3	17.6
Garafraxa East	95.0	73.2	17.9	7.0	7.4	7.5	7.7	7.0	11.6
Erin	72.6	55.1	20.1	11.8	16.5	14.8	14.6	13.5	20.8
Albion	70.4	47.8	19.7	8.1	8.9	9.1	10.0	9.1	16.6
Caledon	69.3	55.8	23.7	10.1	10.8	15.3	13.5	14.3	22.6
Chinguacousy	49.2	34.4	10.0	5.8	6.1	5.5	4.9	5.0	9.8
Esquesing	56.8	48.4	19.7	13.4	13.3	13.5	12.0	11.5	17.8
Trafalgar	41.6	30.7	16.8	5.0	6.8	8.4	5.2	5.6	4.6
Toronto	47.4	37.9	17.1	8.7	5.9	5.0	5.1	4.8	6.6
Total	**67.3**	**52.6**	**21.7**	**9.5**	**10.0**	**9.8**	**9.5**	**9.0**	**16.3**

From historical evidence (Table 1), one can see that Toronto, for example, has gone from a forest cover of 47.4% in 1851, to 6.6% over one hundred years later. Since 1954, forest cover has continued to be reduced in all areas of southern Ontario. Any increase in forest cover is due to the reversal of agricultural lands to forest (Friesen 1998) and to conservation attempts to reforest (Drushka, 2003). This study also demonstrates that there has been a significant reduction in southern Ontario wetlands since the pre-European settlement due mostly to the draining of wetlands for conversion to agricultural use.

The pre-European settlement landcover map for southern Ontario is a useful tool to document historical landcover and the changes that have occurred. The data can be used to determine historical locations of species that are now in decline such as elm (*Ulmus americana*) and chestnut (*Castanea dentata*). Also, the decline of wetland areas can be further investigated by quantifying the amounts changed and the spatial distribution of change. This information along with other databases can be used as a tool for restoration and conservation at regional and municipal levels. Future considerations are compiling this data for the entire province and nation with other groups interested in determining the pre-European settlement vegetation for large scale analysis such as carbon sequestration and forest fragmentation, and the impacts on biodiversity. Overall, this study provides maps of historical land cover for the counties of Peel, York, Etobicoke and Toronto which provide useful information for local land-use planning, policy development, resource management, environmental monitoring and environmental modeling.

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PAPER

7

CHANGES IN THE MAJOR ROADS OF SOUTHERN ONTARIO, CANADA 1935-1995: IMPLICATIONS FOR PROTECTED AREAS

ADAM FENECH[1], BRENT TAYLOR[2], ROGER HANSELL[3] and GRAHAM WHITELAW[4]

[1] Meteorological Service of Canada, Toronto, Ontario, Canada;
[2] Ministry of the Environment, Toronto, Ontario, Canada;
[3] University of Toronto, Toronto, Ontario, Canada;
[4] University of Waterloo, Waterloo, Ontario, Canada

ABSTRACT: Roads are important indicators of environmental change as forested lands are cleared and wetlands are drained to make the roads. Roads also open up areas to further human development leading to declining wildlife habitat and increased introduction of invasive species. This study examines changes in the major roads of southern Ontario every decade from 1935 to 1995. The authors began with a digitized 1995 road map of Ontario and hard copy road maps from the Ontario archives for 1985, 1975, 1965, 1955, 1945 and 1935. Using a geographic information system, roads not present on the 1985 map were removed from the 1995 digitized map. This was repeated for every ten year interval map. Maps are presented to illustrate the dramatic changes in roads around three areas of southern Ontario with varying levels of environmental protection: the Oak Ridges Moraine, the Niagara Escarpment and Algonquin Park.

Keywords: roads; environmental impacts; wildlife; Oak Ridges Moraine; Niagara Escarpment; Algonquin Park; southern Ontario

1. Introduction

Roads have existed for several hundred years in southern Ontario, originally for the movement of humans by foot or by animals, and for transportation using animal-drawn vehicles. It is only in the twentieth century, with the enormous increase in the number of motorized vehicles and the greater scale of movements, that there has been a large expansion in the network of road systems. Roads and motorized transport are now an integral part of the way humans live in Canada. Roads are transport corridors imposed on the environment by humans for the movement of people and the goods and materials required by human society (Bennet, 1991).

Studies (Andrews, 1990) have revealed the following harmful effects of roads:

1. habitat loss and modification with accompanying effect on wildlife populations;
2. intrusion of the edge effect into the core of natural areas;

3. subdivision and isolation of wildlife populations by acting as a barrier;
4. a source of disturbance to wildlife;
5. increased road-kills; and
6. increased human access to natural areas with undesirable impacts.

This study first examines the overall changes in the major roads of southern Ontario every decade from 1935 to 1995. Then, in an attempt to focus on areas of southern Ontario with ecological significance and under threat of human development, the study focuses on changes in roads around three geographic areas with varying levels of environmental protection: the Oak Ridges Moraine, the Niagara Escarpment and Algonquin Park.

2. The Implications of Increased Road Networks on Ecosystems and Human Health

As urban areas continue to expand and the human population steadily grows, pressure for more roads and more lanes on existing roads also rises. Even though the economic and social benefits of road network improvements may seem obvious - for example, improving linkages between communities, reducing commuter times, transporting goods - the impacts of roads on the natural environment and human health should be considered.

Roads impact the natural environment directly through habitat destruction and fragmentation. Roads affect many habitat types and exert their influences at a range of scales; road networks can alter the functional integrity of habitats throughout while individual roads have direct, localized effects. Roads through natural areas reduce the amount of mature vegetative cover, increase the amount of edge habitat, and fragment the landscape into isolated patches (Andrews, 1990). These habitat impacts can have damaging effects on wildlife populations. The removal of natural cover eliminates habitat required by locally adapted organisms. An increase in the amount of edge habitat causes additional stress by attracting edge-adapted, generalist species that compete with native wildlife for diminishing resources.

Habitat fragmentation by roads, and its associated barrier effects to species movement, leads to the severance of wildlife communities and their gradual isolation from one another. The degree of isolation depends on the relative success of different species in crossing roads. A number of studies have shown how roads inhibit wildlife movement and in many cases affect population numbers. For example, small mammals demonstrate a reluctance to cross roads where the distance between forest margins exceeds 20 metres (Mader, 1984). Similarly, amphibians, insects, and even some species of birds exhibit this behaviour. In most cases, the barrier effect of the road is dependent on traffic flow levels and the type of road surface.

Increasing traffic intensity has been shown to reduce the population densities for many types of species within fragmented habitats. For roadside breeding bird populations, low densities are attributed in part to collisions with cars, but mostly to the disturbances (i.e., noise and visibility) caused by traffic (Reijnen *et al.,* 1995). Steady traffic flow is believed to cause stress and hinder communication among bird populations, affecting their ability to reproduce and inciting them to emigrate from the area. Road-related wildlife mortality or "roadkills" of ground-dwelling animals are much more prevalent than birds. Conservative estimates suggest that 5.5 million reptiles and frogs are killed annually by traffic in Australia and that tens to hundreds of millions of snakes have been victims of roadkills in the United States (Fahrig *et al.,* 1995).

The direct loss of habitat from road network construction is important, but the progressive fragmentation and isolation of habitats will eventually reach the point where populations of associated species can no longer be sustained. For this reason, habitat fragmentation, of which roads play a major role, has been identified as a contributing factor to biodiversity loss.

Roads are built for use by motorized vehicles – cars, trucks, motorcycles, and buses - that are the source of air pollution. With an increase in the number of vehicles operating in a region, the problem of air pollution intensifies. Currently, almost all motorized vehicles operate on some form of fossil fuel (e.g., gasoline, diesel) and the emissions from exhaust contain harmful pollutants. Individually, the impact of an automobile's emissions is negligible. Collectively, the hundreds of thousands of vehicles operating in the region have a dramatic effect on air quality. Among other compounds, exhaust contains nitrogen oxides and carbon dioxide.

Photochemical reactions in the atmosphere turn nitrogen oxides into tropospheric ozone, which is the principle component of SMOG. Because the reactions are dependent on temperature and radiation, ground-level ozone accumulation tends to be greater on hot, humid summer days. The impacts of ozone and SMOG on plants and human health are well documented. Long-term exposure to even low concentrations of ozone can cause changes in plant growth productivity and quality (MacIver and Urquizo, 1998). Acute symptoms in plants include chlorosis, delayed growth, premature senescence and necrosis. Ozone levels of 40 parts per billion can also cause respiratory problems in humans, particularly among the elderly and children (MacIver and Urquizo, 1998). Ozone damages lung tissue, reducing breathing capability and making airways more susceptible to air-borne irritants and other allergens. Records indicate that when ozone concentrations peak, hospital admissions increase (Last *et al.*, 1998).

Another major pollutant emitted from motorized vehicles is carbon dioxide. Carbon dioxide is among the three most important greenhouse gases that are contributing to global climate change. Climate models, based on elevated atmospheric carbon dioxide concentrations, predict a global warming between 1.0°C and 3.5°C by the year 2100 (MacIver and Urquizo, 1998). Carbon dioxide is produced by both natural and anthropogenic sources. The contribution from anthropogenic sources has increased dramatically since the 1700s due to industrial emissions and deforestation. Collectively, automobiles and their relatives have become one of the largest contributors of carbon dioxide. In the Greater Toronto Area, transportation accounts for over 25 percent of carbon dioxide emissions (Harvey, 1993).

3. Selected Areas of Southern Ontario

Three areas of southern Ontario with varying levels of environmental protection have been selected for the study: the Oak Ridges Moraine, the Niagara Escarpment and Algonquin Provincial Park (see Figure 1).

3.1 Oak Ridges Moraine

The Oak Ridges Moraine is one of the most significant natural features in southern Ontario. It is the largest moraine in the province and among the largest in Canada, spanning 160 km east-west from the Niagara Escarpment to the Trent River (see Figure 1). The Oak Ridges Moraine was formed over 10,000 years ago from sand, gravel, and till deposited at the meeting point of two lobes of glacial ice (Ontario Ministry of Natural Resources, 1999). Natural forests and reforested areas cover 28 percent of the Moraine, representing most of the larger linked forest blocks that remain throughout the GTA. Wetlands are less common on the Moraine, covering 2 percent of its surface area, occurring either as isolated depressions, or kettles (thirty-one kettle lakes in all exist on the Moraine, varying in size from 5 to 130 hectares) along the top of the moraine or as headwater wetlands, where groundwater discharges to the surface at the margins of the moraine.

The diverse tracts of woodland and wetland on the Moraine provide habitat for a wide variety of plant and animal species, many of which require large,

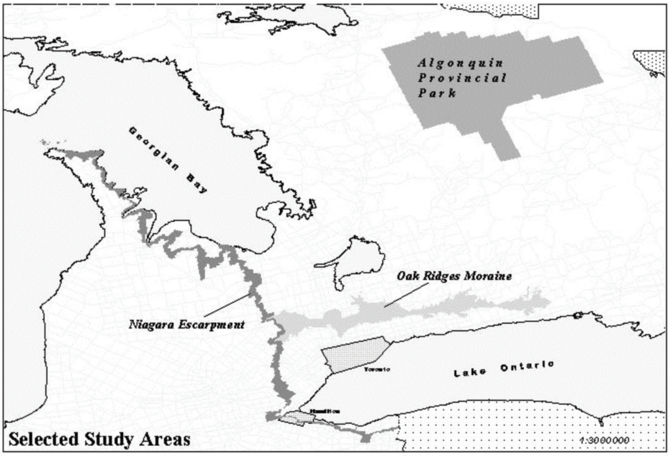


FIGURE 1
Selected Study Areas of Southern Ontario.

undisturbed natural areas. The Moraine's spring-flooded wetlands serve as breeding areas for woodland amphibians and support a variety of waterfowl species. The kettle lakes sustain rich fish assemblages and provide habitat for a large number of plant and animal species. The woodland areas harbour many plant and animal species that are rare in the GTA and several that are threatened in the province. The Moraine is one of 6 major centres for forest birds in southern Ontario, supporting a large and diverse breeding population.

The Moraine's aquifers are essential for maintaining base flow in the 65 watercourses that have headwaters on the Oak Ridges Moraine. The Moraine serves as a fresh-water source for more than 250,000 people in the GTA, providing water for numerous uses including agriculture, residential, commercial, recreation, and industrial. Public lands occupy about 6% (or 9,000 hectares) of the Moraine within the GTA and approximately 4 million people are within an hour's drive of the moraine. All of the natural features of the Oak Ridges Moraine add significant recreational value to the area.

Today, demands for urban expansion are placing unprecedented development pressure on the Moraine. Recent development approvals forecast a 175 percent increase in urbanized area over the next 20 years (OMNR, 1999). Within the GTA, York, Durham, and Peel Regions have approved a population increase of

98,000 on the Moraine over the next 20 years. If pending Official Plan Amendments in York and Durham Regions are approved, a further 56,000 people could settle on the Moraine, 47,000 of whom would live outside of existing urban areas. Most urban development in the GTA is occurring within York Region, along the Yonge Street corridor in the municipalities of Vaughan, Richmond Hill, and Aurora, as well as in Markham (Toronto and Region Conservation Authority, 1999). A series of contentious development proposals involve an extensive development of the Yonge Street corridor portion of the Moraine in the Town of Richmond Hill (from Bathurst Street to Highway 404), a plan that would permit the construction of approximately 17,000 homes in the area (Pim, 2000). There is serious concern over the fragmenting affect of the proposed development on a significant natural corridor, as well as impacts on the major recharge areas for the Moraine's deep aquifers. The municipality of Richmond Hill rejected the proposal in March, 2000, and hearings are currently being undertaken at the Ontario Municipal Board which could order the town to allow housing development, as this arms-length provincial board has the ultimate authority in land-use matters in the province.

3.2 Niagara Escarpment

The southern Ontario portion of the Niagara Escarpment stretches 725 kilometres from Queenston (near Niagara Falls) to Tobermory. The total protected area of the Escarpment is 1,837 square kilometres, representing almost 2 percent of the total area of southern Ontario. The Niagara Escarpment has over 60 waterfalls (including Niagara Falls) and also contains the greatest concentration of cold-water streams in the southern Ontario region, involving 7 different watersheds.

Given its unique topography, the Niagara Escarpment supports an especially high diversity of plant and animal species (Coalition on the Niagara Escarpment, 1998). The southern extent of the Escarpment is within the Carolinian, or deciduous forest region, while the north of the Niagara Peninsula is in the Great Lakes-St. Lawrence forest region. Many plant species found on the Niagara Escarpment are regionally, and even globally significant. The Niagara Escarpment also supports a wide variety of wildlife – 36 species of herptiles, 55 mammal species, and over 300 species of birds.

Public concern about protecting the Niagara Escarpment began to emerge in the early 1960s (CONE,1998) primarily in response to mineral resource extraction. The government responded with the enactment of the Niagara Escarpment Protection Act, 1970 and the Pits and Quarries Control Act, 1971 which served to restrict aggregate extraction along the escarpment. In 1973, the Niagara Escarpment Planning and Development Act was enacted to: "provide for the maintenance of the Niagara Escarpment and land in its vicinity substantially as a continuous natural environment, and to ensure only such development occurs as is compatible with that natural environment" (Government of Ontario, 1990). The Act established the Niagara Escarpment Commission and required it to develop a land-use plan which would achieve several important objectives for the escarpment including protecting unique ecological and historic areas, and providing adequate opportunities for outdoor recreation and public access.

A process that had begun in the mid-1970s culminated in the 1985 Ontario government approval of the Niagara Escarpment Plan of land-use policies, development criteria and open space systems (Government of Ontario, 1994). All lands within the Niagara Escarpment Plan area were placed into one of seven land use designations - natural (protected in a natural state to protect ecological significance), protection (landforms of visual or environmental significance that have been altered by existing land uses and act as a buffer for natural), rural (another buffer acting as a transitional zone between natural/protected and human use), recreation (ski centres, cottage areas or resorts), mineral extraction (aggregate resource extraction areas), minor urban (villages and hamlets) and urban (larger towns and cities). About 92 percent of the Plan area has been designated as natural, protection or rural area.

The Niagara Escarpment was granted the international Biosphere Reserve designation by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 1990 as one of the world's important ecosystems that expresses the balance between biological conservation and human development.

3.3 Algonquin Park

Algonquin Park, the largest canoe-camping park in Ontario, occupies over 7,500 square kilometres of land and water in the northern part of Southern Ontario (Algonquin Provincial Park, 1974). The Park has been described as an ecotone where the southern deciduous hardwood forests meet the boreal coniferous forests. The geographical position of the Park creates unusual variations in elevation, climate, soils, vegetation and aquatic conditions resulting in diverse wildlife habitat. Moose, timber wolf, deer, marten and fisher are the better known mammals of the Park area. The birds which are accorded special protection are the loon and blue herons. The majority of the lakes of the park contain cold water species including brook trout.

The Park was established in 1893 through the passage of the Algonquin Park Act which set aside a portion of the ungranted Crown domain as a forest reservation and "national" park. The report that led to the establishment of the Park reflected a commendable interest in all aspects of land management (Algonquin Provincial Park Advisory Committee, 1973) including forest preservation and conservation, climate influences, soil, watershed and wildlife protection, recreation, and logging. They projected the ends to be attained by the reservation or park as the maintenance of water supply in half a dozen major water systems, preservation of a primeval forest, protection of birds and animals, a field for experiments in forestry, a place of health resort and beneficial effects on climate. The Act did not refer to roads specifically, but one of the overriding objectives of the park act was "the maintenance of the Park in a state of nature as far as possible" (Ontario Ministry of Natural Resources, 1980).

In 1933, construction of a highway through the park was begun, partly as a "make work" project during the depression (Lambert and Pross, 1967). By 1936, this new highway, now known as Highway 60, was used by 3,809 automobiles (Sutter, 1967), and provided a road that intersected the park. This road provided at least two-thirds of the access to the Park interior (Master Plan). In 1968, public hearings on a park Master Plan were held, focussing on the conflicting land-uses (primarily development/logging versus preservation/recreation). None of the briefs in the summary published (Department of Lands and Forests, 1969) mention road development, either from those advocating protection, or the economic development councils. When the Algonquin Provincial Park Advisory Committee reported in 1973, it was well recognized that "under no circumstances should another high speed through-highway be directed through the park", a recommendation accepted by the government of the day and extended to include the construction or widening of transmission lines (Ontario Ministry of Natural Resources, 1973). The primary purpose of the park changed at this time "to provide the means for a wilderness recreational experience for park visitors who will travel within the park, by canoe, horseback, on foot or by scenic automobile roads". The Master Plan encouraged the development of "a comprehensive road system both leading into, and inside, the Park".

The movement away from settlement and development in the Park area was balanced with the need to allow recreational access to the park. As the 1974 Master Plan says, "access to the Algonquin interior is gained through points scattered around the perimeter of the Park and along the parkway corridor", and an elaborate "ring of roads" was planned to allow for this access. Scenic road access corridors, as they came to be known, were suggested for Algonquin Park to be linked with perimeter parks and the ring of major highways surrounding the Park. The balance was to "scale down internal development" so that the character of Algonquin Park could be maintained. The Master Plan provided for a ban on roads in historic, nature reserve, or wilderness zones, and phasing out existing roads in these zones; a minimum of roads in recreation/utilization zones; and roads crossing the Park boundary to be kept at a minimum (Master Plan), all of which were adhered to in the first five years of the Plan according to the 1979 Master Plan Review (Ontario Ministry of Natural Resources, 1979).

The discussions on the conflicting land-uses of development/logging versus preservation/recreation continue, with the added issues of privatization of Park operations, and increased pressures for economic development.

4. Methodology

4.1 Methods to Determine Changing Roads of Southern Ontario

Full-size photocopies of original hardcopy road maps for southern Ontario were obtained for 1935, 1945, 1955, 1965, 1975, 1985, and 1995 from the Ontario Archives. A digital layer of 1995 southern Ontario roads was provided by the Ontario Ministry of Transportation (MTO). Relevant road data for the study was contained in the ORMROADS ArcInfo coverage of the MTO's Digital Cartographic Reference Base (DCRB). A digitized version of the 1995 roadmap provided a starting point so that earlier maps could be created by editing backwards from the digital 1995 map within a geographic information system (GIS).

Prior to proceeding with map creation, two potential problems had to be addressed:

1. Consistency of the original roadmaps from decade to decade (i.e., Do the hardcopy maps accurately reflect the changes in the southern Ontario road network between 1935 and 1995?). Specifically, were smaller loose surface and earth roads included on older maps displayed on more recent roadmaps?

2. Each of the original maps used a unique classification system for roads. Furthermore, the ORMROADS coverage uses 30 distinct road type classifications, distinguishing between the jurisdiction (e.g., provincial vs. upper tier/lower tier) and characteristics of roads (e.g., multilane divided/undivided vs. two-lane paved/loose). To observe road network changes over the time period would require a simplified standard legend for all of the maps. A simple classification system had to be developed that

would adequately represent the physical differences between different road types and be applicable to all of the maps in the time series.

MTO was consulted to resolve each of these concerns. MTO confirmed that the representation of roads was consistent on hardcopy maps between 1935 and 1995. Therefore, the digital maps created would accurately reflect road changes over the study period (e.g., all roads included on earlier maps were carried over to later versions.)

On advice from the MTO, a simplified road classification scheme was devised, including the following four categories: *multilane paved, two-lane paved, two-lane loose, and earth/unimproved*. These four categories would adequately represent the major road type differences from all source maps.

Digital road maps for 1935, 1945, 1955, 1965, 1975, and 1985 were created using a geographic information system (GIS). Roads on the 1995 digitized map were re-classified according to the simplified scheme. The 1995 digital map was then edited to match the 1985 hardcopy map. Roads not present on the 1985 map were removed. Road classification changes were also made (e.g., multilane _ two-lane, paved _ loose). The process was repeated for each ten-year interval map.

Note that all road estimations of this study are based on road maps and have not been ground-truthed.

4.2 Methods to Determine Changing Roads of Selected Areas of Southern Ontario

Digital boundaries of the Oak Ridges Moraine, the Niagara Escarpment and Algonquin Park were layered on the road maps of southern Ontario using the geographic information system (GIS). The GIS was then used to query the length (in kilometres) of roads in the Oak Ridges Moraine, and the Niagara Escarpment, every ten years. Note that, in some cases, these roads were beyond the planning boundaries but no more than 1 kilometre. The GIS was used to query the area of each protected area, and the road densities were determined from both results (road density = kilometres of road/square kilometre area).

Roads in the Algonquin Park that appeared on the southern Ontario maps were limited to Highway 60 only. Information on the other roads in the Park for logging and other uses is not readily available. There are maps available of historical and current logging roads, and these will be digitized in future research. Instead, the roads around Algonquin Park were mapped, and historical maps were viewed to show the changes in "access" points to the Park.

The digital layer for the Niagara Escarpment was divided by classifications of land use - natural, protection, rural, recreation, mineral extraction, minor urban and urban. The GIS was used to query the changes in roads in each of the land use classifications for 1975, 1985 and 1995 (note: urban land designations were combined).

5. Results

5.1 Changes in the Roads of Southern Ontario 1935-95

The major roads of southern Ontario increased from 7,133 kilometres in 1935 to 23,806 kilometres in 1965 to 35,637 kilometres in 1995 (see Figure 2) - a time of increasing human settlement and economic growth in southern Ontario.

Examining major road growth in southern Ontario by decade from 1935 to 1995 shows that 1955 to 1965 had the most growth at 7,567 kilometres with 1945 to 1955 and 1965 to 1975 following close behind. Multi-lane paved road development in southern Ontario by decade from 1935 to 1995 shows that 1955 to 1965, at 983 kilometres, was the busiest expansion decade while 1975 to 1985, at 838 kilometres, was the second busiest.

The major road development from 1935 to 1995 spreads throughout southern Ontario, yet most occurred around the major human population centres of the Golden Horseshoe (1945 to 1955) that wraps around the tip of Lake Ontario; the city of Toronto (1945-1965) and the city of Ottawa (growth through all decades). The incentive to settlement of having a transportation corridor to markets and employment is enhanced through the development of multi-lane paved highways, shown as blue areas, around the Golden Horseshoe and around the city of Ottawa.

5.2 Changes in Major Roads in the Oak Ridges Moraine 1935-95

The major (paved) roads in the Oak Ridges Moraine increased from 126 kilometres in 1935 to 554 kilometres in 1965 to 1016 kilometres in 1995 (see Figure 3). Most roads, which by 1995 includes four multi-lane highways, run north to south creating a series of paved barriers to wildlife movement.

The road density of the Oak Ridges Moraine was 0.065 kilometres in 1935, 0.283 kilometres in 1965, and 0.518 kilometres in 1995. Compared with a typical county in the region (see Figure 4), the road density of the Oak Ridges Moraine

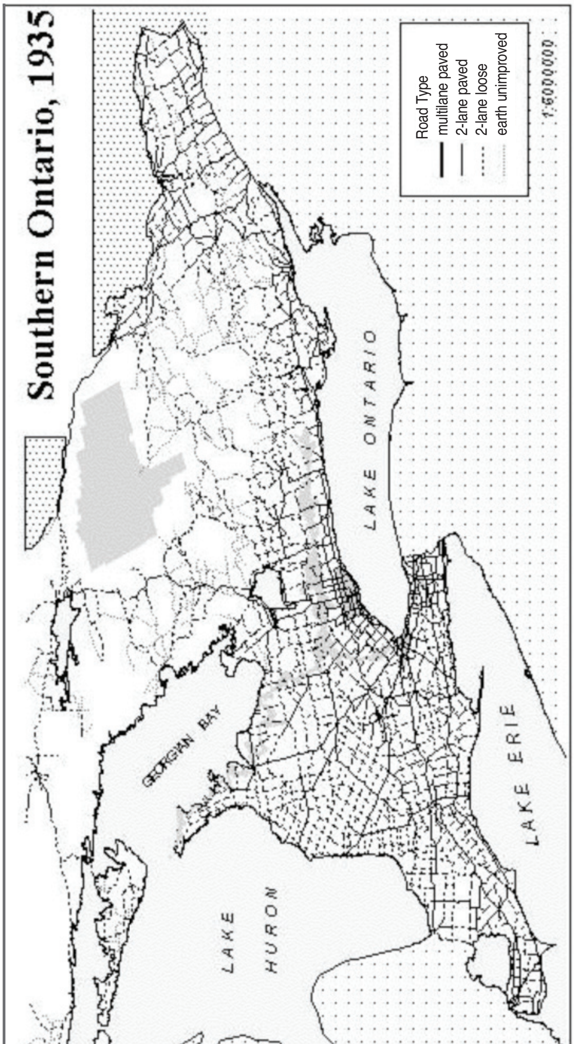


FIGURE 2
Changes in the Major Roads of Southern Ontario, Canada 1935 to 1995.

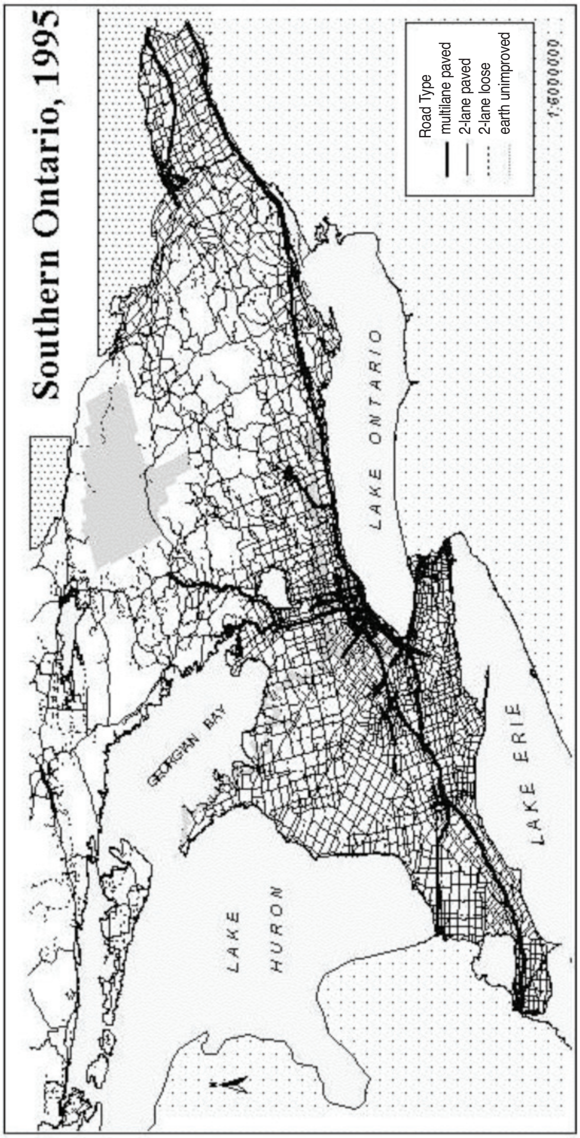


FIGURE 2 continued
Changes in the Major Roads of Southern Ontario, Canada 1935 to 1995.

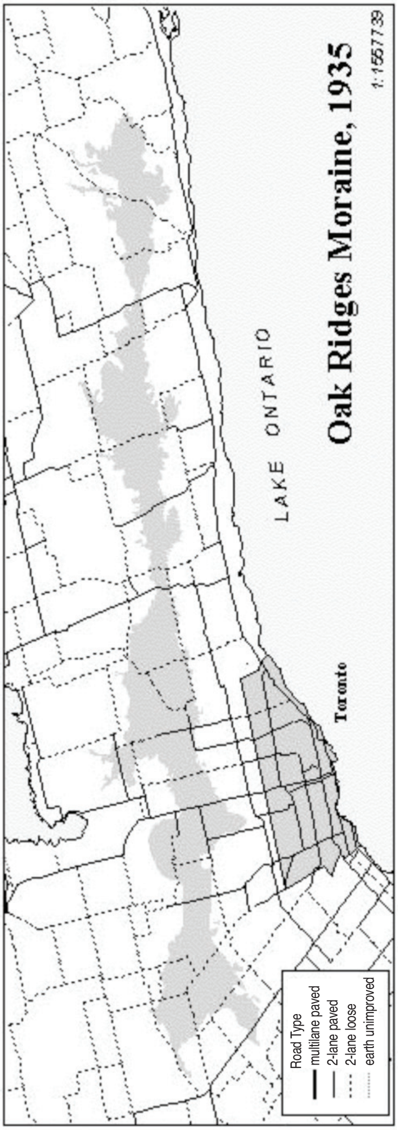


FIGURE 3
Changes in the Major Roads on the Oak Ridges Moraine, Ontario, Canada 1935 to 1995.

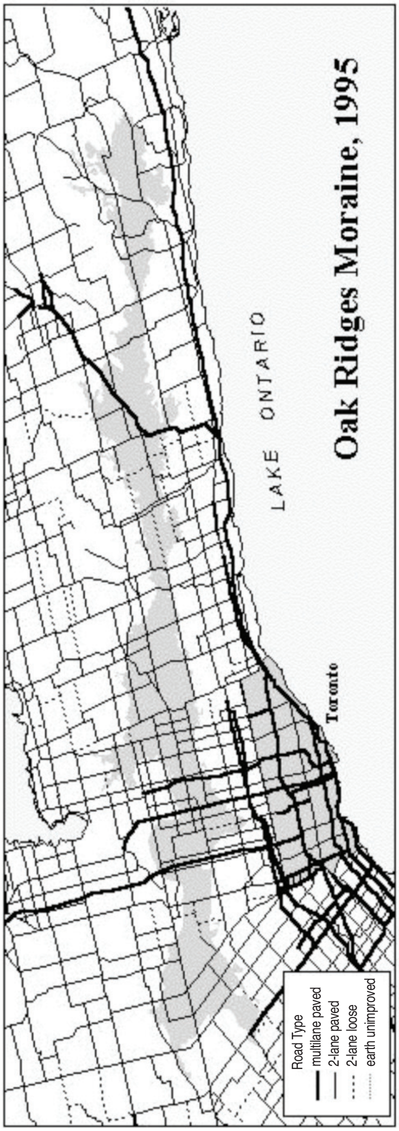


FIGURE 3 continued
Changes in the Major Roads on the Oak Ridges Moraine, Ontario, Canada 1935 to 1995.

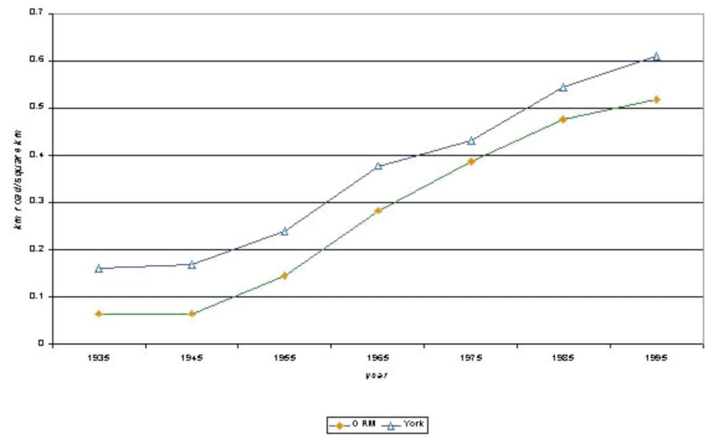


FIGURE 4

Changes in the Densities of Major Roads on the Oak Ridges Moraine and York Region 1935 to 1995, a comparison.

is about one-half that of York Region, yet changes at about the same rate over time to the point where the road density in the Oak Ridges Moraine is about 90 percent of the road density in York County.

5.3 Changes in Major Roads in the Niagara Escarpment 1935-95

The major roads in the Niagara Escarpment increased from 173 kilometres in 1935 to 567 kilometres in 1965 to 923 kilometres in 1995 (see Figure 5). This is equivalent to a road density of 0.094 km in 1935 to 0.309 km in 1965 to 0.503 km in 1995. What is obvious from the maps is the increasing number of intersections of the natural corridor that the Niagara Escarpment is intended to protect. By 1995, there are 9 points at which multi-lane highways cross the escarpment, presenting an significant barrier to wildlife movement.

The major road changes in the Niagara Escarpment since the enactment of the 1973 Niagara Escarpment Planning and Development Act increased from 712 km in 1975 to 842.5 km in 1985 to 923.5 km in 1995 - a steady increase. These represent the changes in paved roads only. Overall roads (including the 2-lane loose and earth roads) did not change as dramatically during the 1975 to 1995 time period. In recent history, the overall roads did not

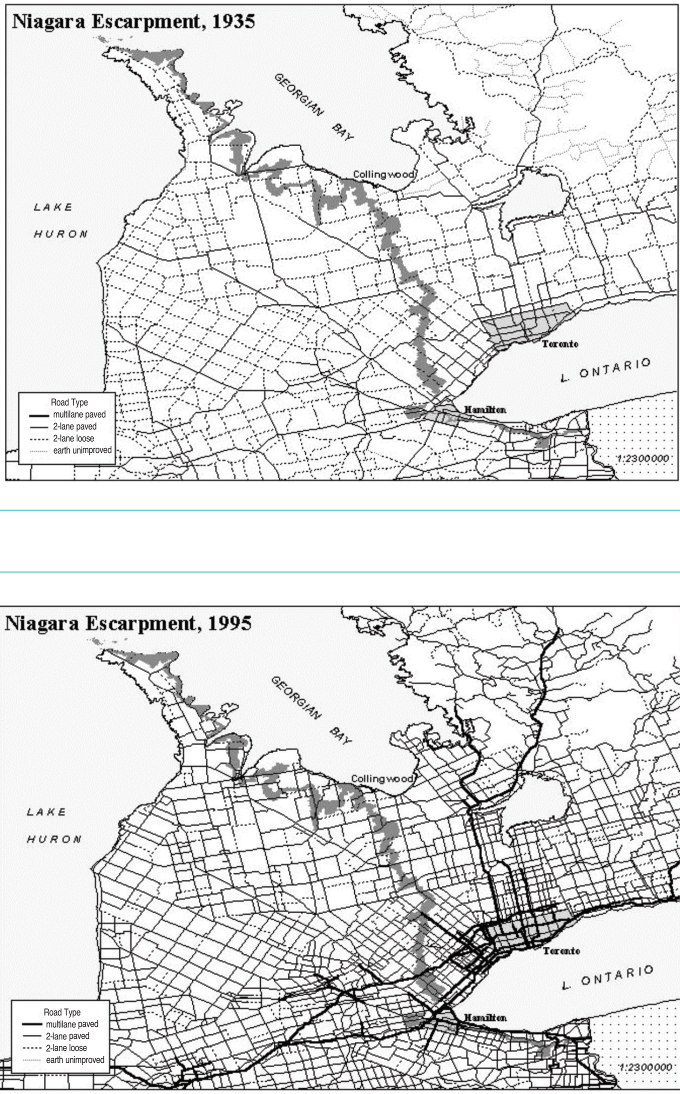


FIGURE 5

Changes in Major Roads Along the Niagara Escarpment 1935 to 1995.

change within the Niagara Escarpment Planning Area from 1985 to 1995 with a total of 1075.5 kilometres of roads. During this time period, 81 kilometres of gravel road were paved, but no new roads were added. Paving dirt or loose roads tends to increase the speed and volume of road traffic which impacts wildlife more significantly and leads to further human development of the area.

The land designations of the Niagara Escarpment reveals that 8 percent of the land falls within the urban, minor urban, recreation and mineral land designations (known as the zone of co-operation by the UNESCO Biosphere Reserve design), while 92 percent lies within the natural, protected and rural designations. From an environmental perspective, roads would be clustered ideally in the zone of co-operation. However, examining the distribution of roads within the Niagara Escarpment in 1975 shows that 12 percent of the roads were in the zone of co-operation while fully 88 percent were in the natural, protected and rural lands designations. By 1995, with an additional 100 kilometres of paved roads, this has changed little with the additional paved roads occurring in the lands designated as Escarpment “natural”.

5.4 Changes in Major Roads Around Algonquin Park 1935-95

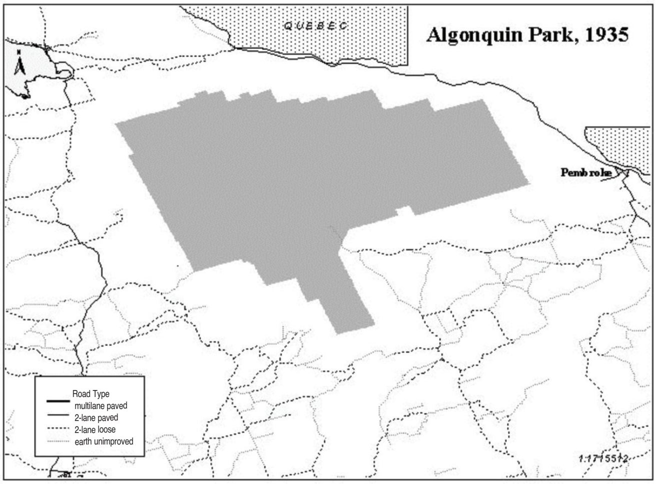
While no quantitative analysis has been possible for the roads around Algonquin Park, it is clear from viewing the maps that a series of access roads (see Figure 6) now branch out to reach the Park, creating the “ring of roads” for recreation use at various access points to the Park. The primary concern now is not so much the barrier effect but the potential for increases in invasive species and the potential increases of traffic volume into the Park as the number of access roads has increased, yet remains not very large in number when compared with the Oak Ridges Moraine and the Niagara Escarpment.

6. Future Research

This analysis of road changes in southern Ontario provides an interesting graphic of human development and the potential environmental and human health changes that accompany this development. It also calls for additional studies.

6.1 National Scale Studies

Probably most important, at this time, is to conduct a study of the changes in major roads of the remainder of the province of Ontario, of other provinces and territories, and of the entire country in order to have a database of major road changes for all of Canada that can be used for environmental assessment purposes.



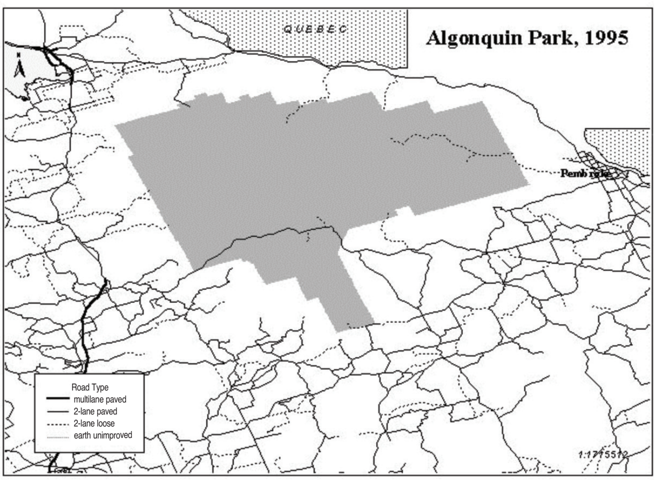


FIGURE 6

Changes in the Major Roads around Algonquin Park, Ontario, Canada 1935 to 1995.

6.2 Southern Ontario Scale Studies

These maps of the major road changes in southern Ontario from 1935 to 1995 provide an excellent basis for comparison with other road-related databases including traffic densities and emissions; use of road salt and water quality; road-related wildlife mortality or "roadkill"; and road and weather hazards.

Another fruitful research area would be to examine the issue of climate change as a result of increasing anthropogenic emissions of greenhouse gases. The change in overall greenhouse gas emissions from the transportation sector in southern Ontario can be studied through the shift from railway transport to road transport as a result of the "just-in-time" delivery increases.

Several international studies have examined the effects of traffic densities and its subsequent noise and disturbance for roadside breeding birds. The major road change maps of this study can be related to overall changing traffic density and noise, as well as direct mortality on breeding birds of southern Ontario.

It is important to test the magnitude of the effects, and the timing of the effects, of major road changes on human settlement, economic activity, overall agricultural land and overall forested land in order to better understand how roads lead to significant environmental change.

6.3 Selected Areas Scale Studies

Additional studies need to examine the questions raised by the analysis of road changes in the Oak Ridges Moraine, the Niagara Escarpment and Algonquin Park including: digitize the historical maps of roads within Algonquin Park; examine the reasons for paving the 100 kilometres of gravel roads in the protected areas of Niagara Escarpment; examine the road changes and forest cover changes in the Niagara Escarpment; examine the cumulative effects of road development on the Oak Ridges Moraine; investigate the possibilities for wildlife crossings in these areas; and investigate recommendations for roads and land use planning on the Oak Ridges Moraine.

7. Acknowledgements

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PAPER

8

LANDSCAPE CHANGES AT CANADA'S BIOSPHERE RESERVES: AN OVERVIEW OF LAND CHANGE STUDIES

ADAM FENECH[1], GRAHAM WHITELAW[2] and SHERRY SIAN[3]

[1] Meteorological Service of Canada, Toronto, Ontario, Canada;
[2] University of Waterloo, Waterloo, Ontario, Canada;
[3] Mackenzie Valley Environmental Impact Review Board, Yellowknife, Northwest Territories, Canada

ABSTRACT: Results of landscape change studies at six of Canada's Biosphere Reserves show that resource development and human settlement are the major drivers of landscape changes at Biosphere Reserves since European settlement of Canada. Most of the major landscape changes occurred in the early days of European settlement of Canada, yet significant changes are occurring today. Resource development and human settlement is common across all the studies resulting in landscape changes including: the removal of forests, conversion of grasslands and draining of wetlands in order to convert land for agricultural purposes; and the building of houses, roads and other infrastructure to support an ever-increasing human population. Landscape changes at Biosphere Reserves have significantly fragmented wildlife habitats threatening wildlife species such as the grizzly bear (Waterton), caribou (Charlevoix) and scarlet tanager (Niagara Escarpment). These species are reflecting the impacts of land use change as indicators of overall wildlife habitat decline. The protected areas at Biosphere Reserves provide an opportunity to support wildlife species, but when species require more undisturbed area than the protected areas can provide, then certain wildlife become threatened. The paper demonstrates the significant insights about changes that humans have brought on the landscapes around Biosphere Reserves since European settlement of Canada that can be gathered from existing landscape data and information around protected areas.

Keywords: landscapes, land-use change, environment, biosphere reserves, wildlife, habitat, protected areas, sustainable development

1. Introduction

In October 1995, the Honourable John Fraser, Chair of Canada MAB, signed a Memorandum of Co-operation along with the MAB programs of the United States and Mexico that included the commitment for Canada to make available land cover maps from Canada's Biosphere Reserves (US National Committee for the Man and the Biosphere Program, 1995). Two years later, a partnership of the Ecological Monitoring and Assessment Network (EMAN) of Environment Canada, the Land Use Policy Branch of the Ontario Ministry of the Environment (MOE) and the Canadian Biosphere Reserve Association (CBRA) initiated the Biosphere Reserve Landscape Change Project - a project to conduct a landscape change analyses using original land survey records, air photos, satellite imagery or some combination of all three. The objective of the analyses was to provide an understanding to decision-makers and the Biosphere Reserve communities of the dramatic changes that humans have brought on the landscape since European settlement, and some understanding of the natural environment that surrounds them, or “sense of place”.

The objectives of the analyses were:

- To test approaches to landscape change analysis within diverse landscapes and environments across Canada;
- To highlight the dramatic changes that humans have brought on the landscape since European settlement through landscape change data and information;
- To provide government agencies and others with landscape change data and information to better inform their decision making; and
- To provide Biosphere Reserve communities with some understanding of the natural environments that surround them (and how these environments have been changing) toward further developing each communities "sense of place". A community’s “sense of place” is in part awareness of the local environment and a shared history of the area, but also involves something more in terms of individual values and feelings towards the land or values attributed to the elements of the land.

Each of the studies was undertaken with a different set of local objectives, available technologies, and available resources. Their results reflect these differences. This paper recognizes that each study has great value individually, yet this paper focuses on certain patterns that emerge across all the studies that can be used as valuable lessons for future landscape change studies.

2. Biosphere Reserves in Canada

Biosphere Reserves are areas of terrestrial or coastal ecosystems that are internationally recognized within UNESCO's Man and Biosphere Program for promoting and demonstrating a balanced relationship between people and nature. Presently there are 440 Biosphere Reserves in 97 countries (United Nations Educational, Scientific and Cultural Organization, 2004).

Each Biosphere Reserve is intended to fulfil three basic functions, which are complementary and mutually reinforcing.

- a conservation function - to ensure the conservation of landscapes, ecosystems, species and genetic variation.
- a development function - to promote, at the local level, economic development which is culturally, socially and ecologically sustainable.
- a logistics function - to provide support for research, monitoring, education and information exchange related to local, national and global issues of conservation and development.

Since 1978, eleven areas in Canada have been recognized internationally as World Biosphere Reserves (see Figure 1): Mont St. Hilaire (Quebec, 1978); Waterton (Alberta, 1979); Long Point (Ontario, 1986), Riding Mountain (Manitoba, 1986); Charlevoix (Quebec, 1989); Niagara Escarpment (Ontario, 1990); Clayoquot Sound (British Columbia, 2000); Redberry Lake (Saskatchewan, 2000); Lac St. Pierre (Quebec, 2000); Mount Arrowsmith (British Columbia, 2000); South West Nova (Nova Scotia, 2001); and Thousand Islands – Frontenac Arch (Ontario, 2002).

FIGURE 1

Map of Canada's Biosphere Reserves.

Source: Canadian Biosphere Reserve Association, 2004.

3. Methods

The Project started with a workshop co-sponsored and co-organized by the Ontario Ministry of the Environment and Environment Canada. The workshop brought together a youth hired under the Environment Canada's *Science Horizons Youth Employment Strategy* from each Biosphere Reserve to: explore and develop common landscape change protocols for Canadian Biosphere Reserves; train Science Horizon youth in the protocols through demonstrations involving experts in historical records, air photo interpretation and earth observation; undertake assessments of each Biosphere Reserve in terms of their needs with respect to landscape change information (what has been done, what is needed); address what is feasible for each Biosphere Reserve given technological, temporal and financial constraints; and set out a strategy to deliver the project.

Each Science Horizon youth undertook their component of the Project using the training provided at the workshop and local resources. Each of the studies was undertaken with a different set of local objectives, locally-available technologies, and locally-available resources. Therefore, each study was significantly different, yet followed the same steps to completion.

Each Biosphere Reserve conducted the study by:

1. determining whether work had been completed on land survey records, air photo or satellite interpretation and, if so, acquired the work;
2. seeking land survey records, air photos and satellite imagery as far back in time as possible;
3. evaluating the expertise of their Science Horizon youth and partners assisting the Biosphere Reserve, e.g. National Parks, Universities and Colleges;
4. selecting a study area appropriate for the information sources; where applicable, mapped and classified land survey records, digitized and classified air photos, digitized and classified satellite imagery;
5. analyzing landscape changes based on the mapping;
6. drafting reports on causes and implications of landscape changes; and
7. submitting a final report to the Canadian Biosphere Reserve Association and Environment Canada.

TABLE 1

Summary of Geographical Area and Time Periods for Landscape Change Studies at Canada's Biosphere Reserves

Biosphere Reserve	Total Area Studied	Time Changes Examined	Main Approach
Waterton	795 km^2 in southwestern Alberta	Logging since 1950s Roads 1951-1997	aerial photos satellite imagery road/trail digital data clearcut digital data
Niagara Escarpment	corridor stretching 725 km in southwestern Ontario	regional 1976-1995 area study 1974-1994	aerial photos satellite imagery baseline digital data
Long Point	270 km^2 on shore of Lake Erie in southern Ontario	presettlement 1985-1990	land survey digital base maps
Charlevoix	148.52 km^2 located east of Quebec City, Quebec	1970-1990	ecological forestry maps
Riding Mountain	144 km^2 in Manitoba	1873, 1948, 1993	land survey aerial photos topographic maps satellite imagery
Mont St. Hilaire	~ 150 km^2 in southwestern Quebec	1761, 1815, 1839, 1867, 1932, 1963, 1993	topographical maps (recent ones drawn from aerial photos)

4. General Results

4.1 Landscape Changes at Biosphere Reserves

Since European human settlement of Canada in the 1700s and 1800s, resource development and growing human populations are the major drivers of landscape change at Biosphere Reserves (see Table 2). Many of the major landscape changes took place in the early days of European settlement, yet significant changes are still occurring today. Landscape changes include: removal of forests; conversion of grasslands and draining of wetlands in order to convert land for agricultural purposes; and building of houses, roads and other infrastructure to support the material well-being of human populations.

Conversion of landscapes for agriculture happened primarily during the early days of European settlement while development of human infrastructure has occurred more recently. Most of the ongoing landscape changes today are the result of forest fragmentation due to tree harvesting, house construction for an expanding human population at Biosphere Reserves, and the regeneration of abandoned agricultural lands to forests.

Regeneration of forested lands is occurring in areas where agricultural production is being abandoned. In many cases, the soils of these lands are not sufficient (and perhaps never were sufficient) for successful agricultural production. Observations from the Charlevoix Biosphere Reserve study indicate that years of agricultural production have depleted the soil quality even further, thus constraining regeneration of native forests.

4.2 Habitat Fragmentation, Loss and Degradation at Canada's Biosphere Reserves

Resource development and human settlement at Biosphere Reserves have significantly fragmented wildlife habitats, thus threatening wildlife populations at Canada's Biosphere Reserves (see Table 2) such as: the grizzly bear (Waterton Biosphere Reserve), caribou (Charlevoix Biosphere Reserve) and the scarlet tanager (Niagara Escarpment Biosphere Reserve). These species reflect the impacts of landscape change as indicators of overall wildlife habitat decline. Carolinian tree species are also under threat in the Long Point Biosphere Reserve.

Protected areas provide an opportunity to support wildlife populations, but when particular species require more undisturbed area than the protected areas can provide, then certain wildlife become threatened. For example, parts of the Niagara Escarpment Biosphere Reserve, although not experiencing overall forest area decline, are experiencing more forest fragmentation resulting in smaller forest patch sizes. The smaller fragments and increased forest edge (due to changing shapes) threaten the scarlet tanager, a bird species requiring large, undisturbed forests.

TABLE 2
Summary of Key Pressures Driving Landscape Changes at Canada's Biosphere Reserves

Biosphere Reserve	Key Pressure Driving Landscape Change	Impacts	Specific Findings
Waterton	Road development associated with industrial activity (seismic activity/ gas wells/pipelines/ logging)	Wildlife species more vulnerable to legal and illegal hunting; disturbed ranges.	Grizzly bear Elk

TABLE 2 cont.

Summary of Key Pressures Driving Landscape Changes at Canada's Biosphere Reserves

Biosphere Reserve	Key Pressure Driving Landscape Change	Impacts	Specific Findings
	Off-road vehicle use	Habitat degradation (soil compaction, reduced cover, disturbed ranging patterns)	Grizzly bear Elk
	Logging	Habitat degradation (loss and/or fragmentation)	Grizzly bear Elk
Niagara Escarpment	Mineral extraction (above Escarpment) and Clearing for agricultural activity (below Escarpment); urban development	Forest fragmentation with declining forest interior and increasing nest predation and parasitism.	Scarlet tanager Wood thrush
	Clearing for agricultural activity; urban development	Forest fragmentation leading to the spread of invasive plants.	European buckhorn
Long Point	House or cottage development	Forest fragmentation with declining forest interior.	Neotropical migrants
Charlevoix	Abandoned agricultural areas	Forests re-establishing to create different habitats at a slow rate due to soil degradation in fallow.	change in species
	House or cottage development	Altering natural landscape	change in greenspace patterns
Riding Mountain	Clearing for agricultural activity	Habitat loss and fragmentation, increased conflicts between wildlife and adjacent land owners resulting in wildlife decline and genetic isolation.	Wolves Moose Elk

TABLE 2 cont.

Summary of Key Pressures Driving Landscape Changes at Canada's Biosphere Reserves

Biosphere Reserve	Key Pressure Driving Landscape Change	Impacts	Specific Findings
Mont St. Hilaire	Clearing and drainage of swampy land for agricultural activity	Forest fragmentation	change in greenspace patterns
	Reforestation of unsuitable agricultural land	Forest regrowth	change in greenspace patterns
	House or cottage development; road and railway development	Forest fragmentation, pollution and barrier to ecological processes	change in greenspace patterns

4.3 The Need for Environmental Planning and Management

Additional resource development and human settlement at Biosphere Reserves require thoughtful planning and environmental management to define the appropriate uses of the land.

Specific human activities that continue to threaten the natural environment can be curtailed without disturbing main economic drivers of the community. For example, at the Waterton Biosphere Reserve, the threat to the grizzly bear results from the ongoing use of recreational off-road vehicles on forestry roads - not necessarily the forest harvesting activities themselves.

Planners and environmental managers associated with the Niagara Escarpment Biosphere Reserve have come to understand the importance of monitoring at various scales: the regional level (greater than 1:250,000), the area level (1:50,000 - 1:15,000), and the site level (plot monitoring). The Niagara Escarpment Biosphere Reserve Landscape Change Study illustrated that the regional level monitoring provided an assessment of the significant landscape patterns and trends, and identified the areas of significant ecological importance with respect to human development pressures. The area level monitoring provided an ability to link the cause (human development) with the ecological effect (forest fragmentation) - see above. And the site level monitoring targeted specific threats identified in the regional and area monitoring.

4.4 Options for Landscape Change Studies: Land Surveys, Aerial Photos or Satellite Imagery

The options for conducting landscape change studies using land surveys, aerial photos or satellite imagery have their strengths and weaknesses (see Table 3).

Historical land surveys are valuable in describing pre-settlement land cover. Land surveyor records consist of point source descriptions of forest cover that the land surveyor recorded along concession lines. These land surveyor records can be mapped to provide a valuable picture of pre-settlement land cover. For example, Mont St. Hilaire Biosphere Reserve was able to use land surveyor and topographical maps from 1761, 1815, 1839, 1867 and 1914 of the Richelieu area for early estimates of forest cover. Recent topographical maps are also valuable as Long Point Biosphere Reserve demonstrated in their use of topographical maps from 1985 and 1990 to compare forest cover with earlier land surveys.

Aerial photos are particularly useful in describing land cover over the past 50 years. The photos are usually black and white stereo images at 1:15,000 representing summer seasonal resolution. For example, Riding Mountain Biosphere Reserve used air photos from 1928/9, 1948/9, 1970, and 1986 of the Regional Municipality of Clanwilliam for identifying land cover.

Satellite imagery is valuable for describing recent (last 25 years) land cover, but it is expensive to purchase images and then have them interpreted. For example, Waterton Biosphere Reserve used a 1996 SPOT satellite image for land cover.

TABLE 3

Summary of Methods Used for Biosphere Reserve Landscape Change Study

Method	Strengths of Method	Weaknesses of Method	Biosphere Reserve Using Method
Land Surveys	Historical data	Less accurate due to individual bias of surveyor	Mont St. Hilaire, Long Point
Aerial Photos	Subject to availability along certain flight lines	Relatively recent	Riding Mountain, Waterton, Niagara Escarpment
Satellite Images	Accurate	Recent, expensive	Waterton, Niagara Escarpment

4.5 Quantitative versus Qualitative Landscape Change Studies

There is great value in conducting both quantitative and qualitative land-use change studies (see Table 4). For example, quantitative analysis using a functional geographic information system (GIS) allows for proper inventory, management, analysis and multi-function query abilities such as that used by the Riding Mountain Biosphere Reserve. Qualitative analysis, using the "map and crayons" approach, was applied by Charlevoix Biosphere Reserve. Although less technologically-driven and statistically-sure, the Charlevoix approach still provides valuable estimates and insights about changes in land cover.

TABLE 4

Summary of Techniques Used for Biosphere Reserve Landscape Change Study

Technique	Strength	Weakness	Biosphere Reserve using technique
Map and crayons	Inexpensive, low-technological requirements or expertise	Time consuming, less accurate, non-quantifiable	Charlevoix
Geographic Information Systems	Comprehensive, database creation, querying capabilities	Expensive, high technological and expertise requirements	Riding Mountain, Waterton, Long Point, Niagara Escarpment, Mont St. Hilaire
FRAGSTATS	Analytical tool for assessing fragmentation of forests	GIS and expertise required	Niagara Escarpment

5. Specific Results

5.1 Waterton Biosphere Reserve

The road density in the Castle Region (see Figures 2 and 3) that includes Waterton Biosphere Reserve is 0.912 kilometers per square kilometer (Stewart *et al.*, 1998), a density that researchers estimate is responsible for at least a 25 percent habitat loss for elk (Lyon, 1979). Unfortunately, these roads often follow valley bottoms through the banks of rivers that are inherently good habitat for grizzly bears. Many species, including grizzly bear and elk, avoid roads and habitat adjacent to roads. The habitat loss extends beyond the physical dimensions of the road itself since wildlife avoids the habitat near and around roads as well. Researchers have found that grizzly bears avoid areas within

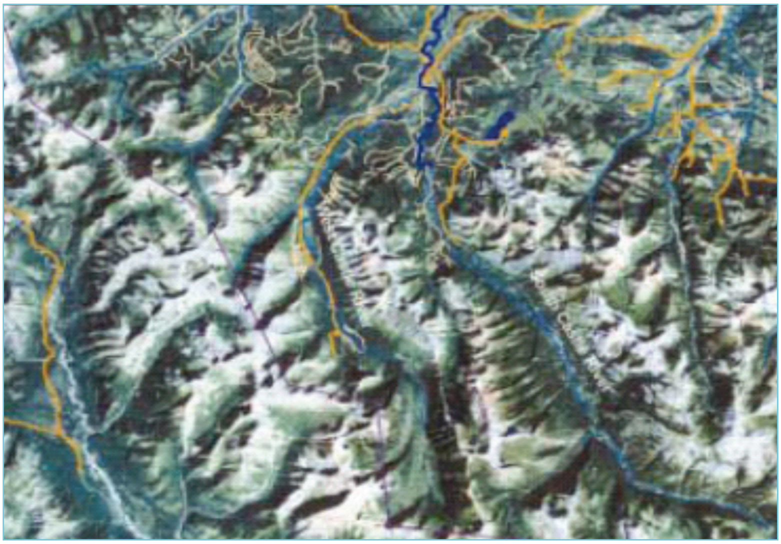

FIGURE 2

Roads in the Castle Region, Alberta, Canada 1951 (Source: Stewart *et al.*, 1998).

FIGURE 3

Roads in the Castle Region, Alberta, Canada 1997 (Source: Stewart *et al.*, 1998).

900 meters of roads (Kasworm and Manley, 1990) and elk reduce their use of habitat 800 meters from the road edge (Perry and Overly, 1976.). Therefore roads that are constructed for the logging industry and left open for vehicle access following operations may decrease the use of clearcut areas by grizzly bears, even if favourable plant material is available as a food source. This leads to what scientists call "effective habitat loss" or an unwillingness of animals to use otherwise suitable habitat (Gibeau *et al.*, 1996).

5.2 Niagara Escarpment Biosphere Reserve

Forest cover in the north Halton study area increased from 3,545 ha in 1974 to 3,696 ha in 1994 (Braid and Ramsay, 1998) - a 4 percent increase mainly associated with minor size increases in shrubland, open mixed, and woodland vegetation types at the outer boundaries of forests. However, connections between the forests were poor or non-existent. Less than 50 percent of the major woodlands (>100 ha) and large forests (20 - 100 ha) provided interior habitat conditions (see Figures 4 and 5). All of the medium and small forests were entirely composed of edge habitat. A decrease in forest interior area due to decreased size of forests and more irregular forest patch shapes is a negative change for indicator species such as the Scarlet Tanager (Geomatics International, 1997). The Scarlet Tanager is a forest interior bird species that requires large (>100 ha), undisturbed, mature to semi-mature deciduous forests. This species is particularly sensitive to disturbances associated with edge effects (Ramsay, 1996).

5.3 Long Point Biosphere Reserve

The historical (1790) forest cover (see Figure 6) and the present (1990) forest cover (see Figure 7) reveal no surprises with the most striking difference being the decrease in regional forest cover (Wilcox, 1998). The agricultural and resource based economies of the Long Point area in the 19th century required extensive forest clearing. It is well documented that by the turn of the 19th century, the amount of forest cover had dropped to levels that were as low as or lower than what is present today. In the early 1900s, forest lands in the entire Long Point region had been reduced to 11 per cent (Barrett, 1977). Farms were turned into blow-sand deserts as a result of the loss of forest cover and were being sold or abandoned. Some lands began to revert back to forest and vast areas were reforested. Those areas where increases in forest cover occurred were largely a result of early forestry efforts, such as those through the St. Williams Forestry Station, and the natural succession of marginal farmland back to forest. Even to this day, most of the remaining forest cover is concentrated in ravines or areas of rugged topography, wet areas such as swamps, and other areas that were unsuitable for cultivation.

FIGURE 4

Minimum Required Habitat for Scarlet Tanager at North Halton Area of Southern Niagara Escarpment, Ontario, Canada 1974 (Source: Braid and Ramsay, 1998).

FIGURE 5

Minimum Required Habitat for Scarlet Tanager at North Halton Area of Southern Niagara Escarpment, Ontario, Canada 1994 (Source: Braid and Ramsay, 1998).

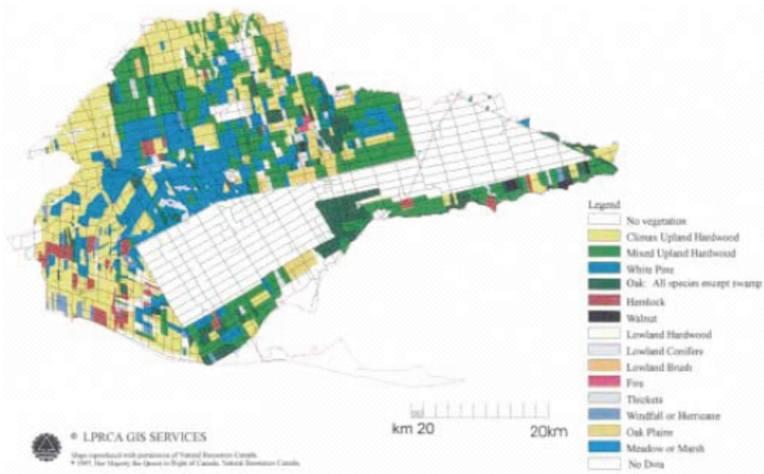

FIGURE 6

Vegetation at the Long Point Biosphere Reserve, Ontario, Canada ~1790. (Source: Wilcox, 1998).

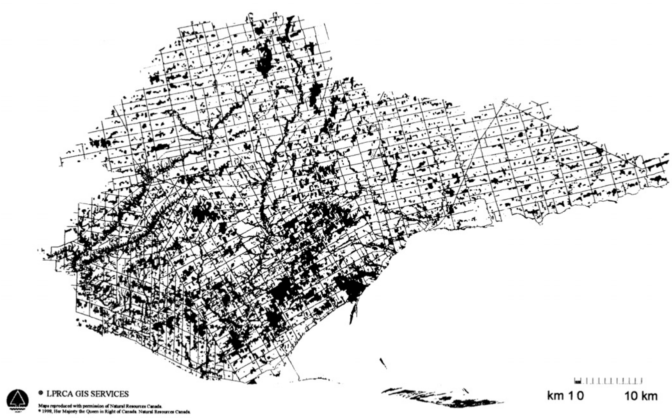

FIGURE 7

Vegetation at the Long Point Biosphere Reserve, Ontario, Canada 1990. (Source: Wilcox, 1998).

5.4 Charlevoix Biosphere Reserve

In 1970 (see Figure 8), the agricultural land was located primarily along rural roads, and there is evidence that these same lands are still heavily used for agriculture (Duschesne, 1998). By 1990 (see Figure 9), agricultural lands had declined severely in many areas, representing no more than one third of their former abundance of 1970. This decrease in agricultural lands corresponds to the regional decrease of agriculture observed in western Charlevoix - a decrease that is still observed today. In 1970, abandoned agricultural land cover (fallow lands) was extensive throughout the study region and the number of abandoned properties in fallow lands was relatively high. Even though agriculture remains important in the area, there was a severe decline in agriculture landscapes because the fallow lands were abundant and well-distributed throughout the entire study area. By 1990, the size of the fallow lands was smaller and reduced in number. The lands used for agriculture in the valleys have much better soil quality whereas the growth in fallow lands has occurred in areas of poorer soil quality. This probably explains why the agricultural activity in the study area is decreasing. This raises the question as to whether these areas with poorer soil quality should be used for agriculture, or whether these areas should be adapted for another types of land-use.

5.5 Riding Mountain Biosphere Reserve

Forest cover has declined from 82% in 1873 (see Figure 10), to 46% in 1948 (see Figure 11), with a further reduction to 34% by 1993 (see Figure 12) (Sobkowich, 1998). The amount of forest clearing done between 1873 and 1948, using mostly non-mechanized means, is surprising. The mechanized era of prairie agriculture essentially began after World War II. The effects on the ecosystem are substantial. The grassland, aspen parkland, and mixedwood forest habitats found throughout the entire Riding Mountain Biosphere Reserve prior to 1873 are now restricted to Riding Mountain National Park, and have been replaced in the area surrounding the Park by a mosaic of annual cropland, perennial forage, and exposed soil (summer fallow). Remaining forest habitat is highly fragmented. Ecological effects in the lands surrounding Riding Mountain National Park have been most severe on large animals, whose presence is not compatible with modern agriculture. Wolves, moose, and elk are visitors to this area, and often are shot as soon as they leave Riding Mountain National Park. The fragmentation of remaining natural habitat in the area surrounding Riding Mountain National Park has made animal movement throughout the whole region difficult, and has increasingly restricted large mammals to the Park. Ongoing research is showing genetic isolation, the implications of which do not bode well for the continuation of such populations over the long term.

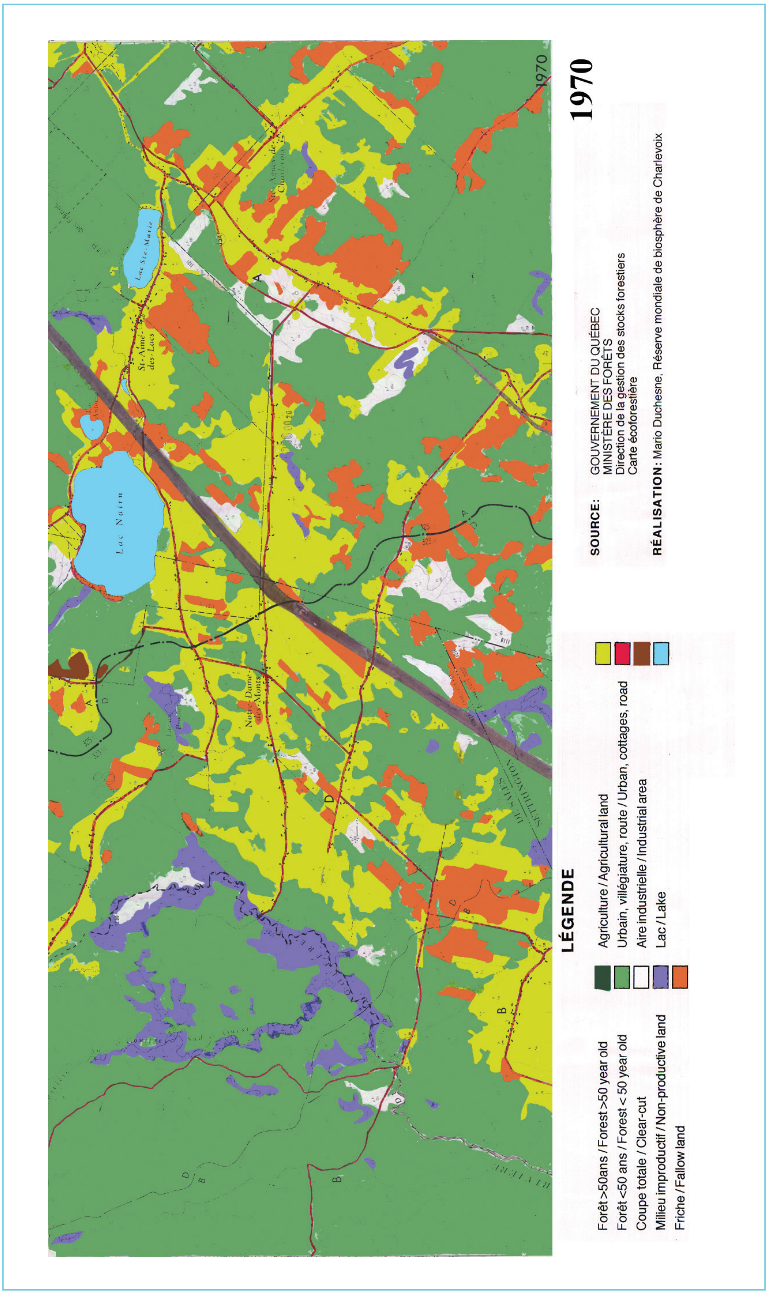

FIGURE 8
Land Cover South of the Laurentian Foothills at Charlevoix Biosphere Reserve, Ontario, Canada 1970 (Source: Duschene, 1998).

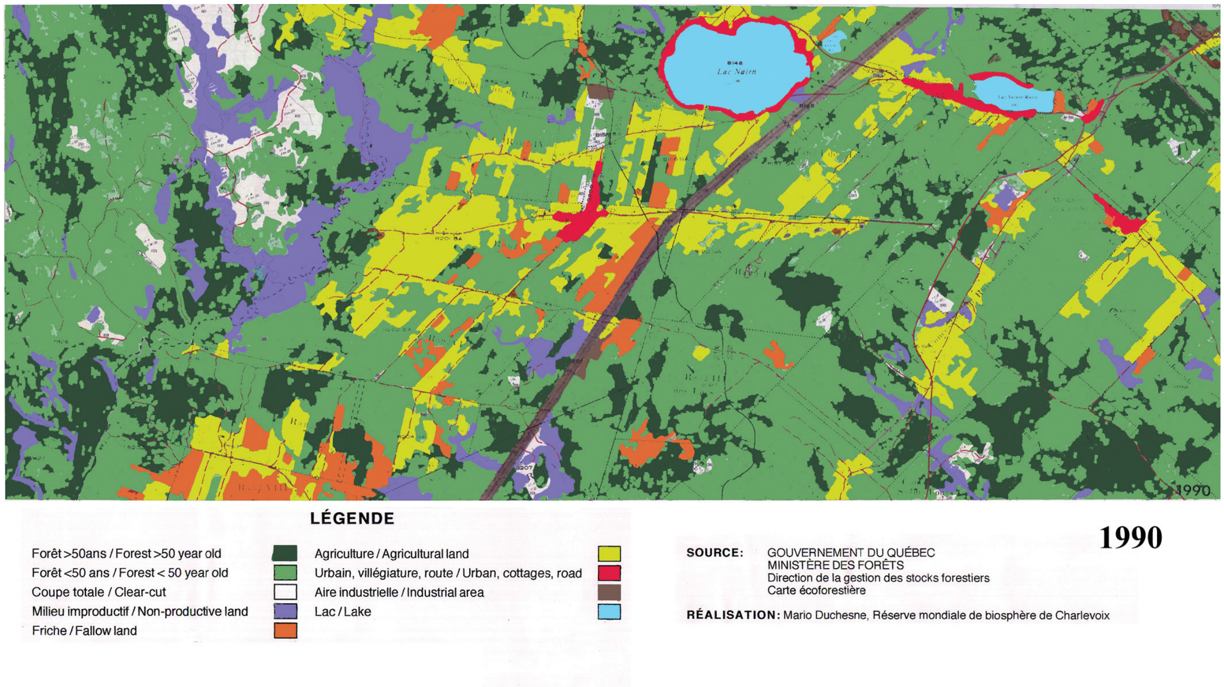

FIGURE 9
Land Cover South of the Laurentian Foothills at Charlevoix Biosphere Reserve, Ontario, Canada 1990 (Source: Duschene, 1998).

FIGURE 10
Land Cover of the Rural Municipality of Clanwilliam, Manitoba, Canada 1873. (Source: Sobkowich, 1998).

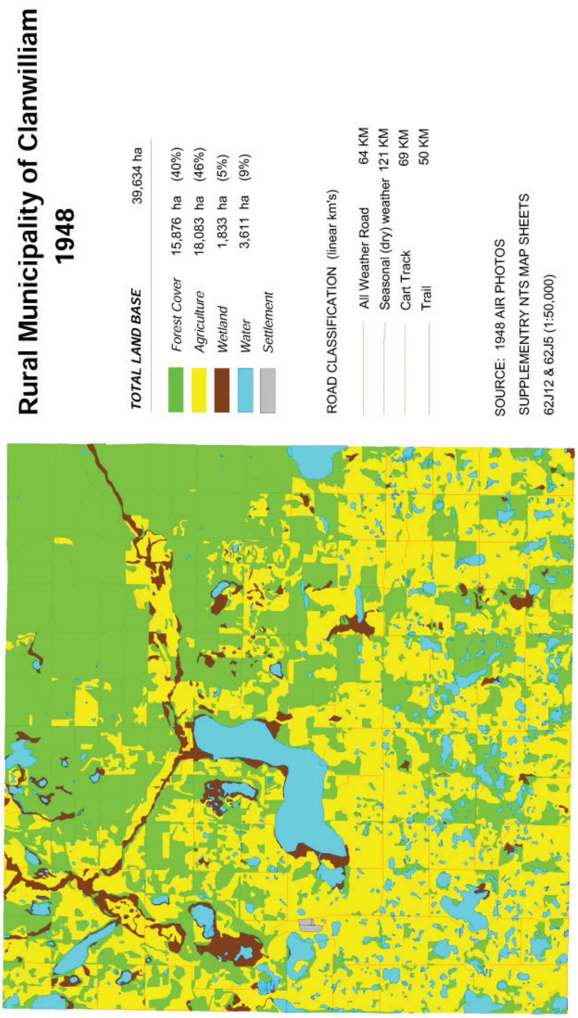

FIGURE 11
Land Cover of the Rural Municipality of Clanwilliam, Manitoba, Canada 1948. (Source: Sobkowich, 1998).

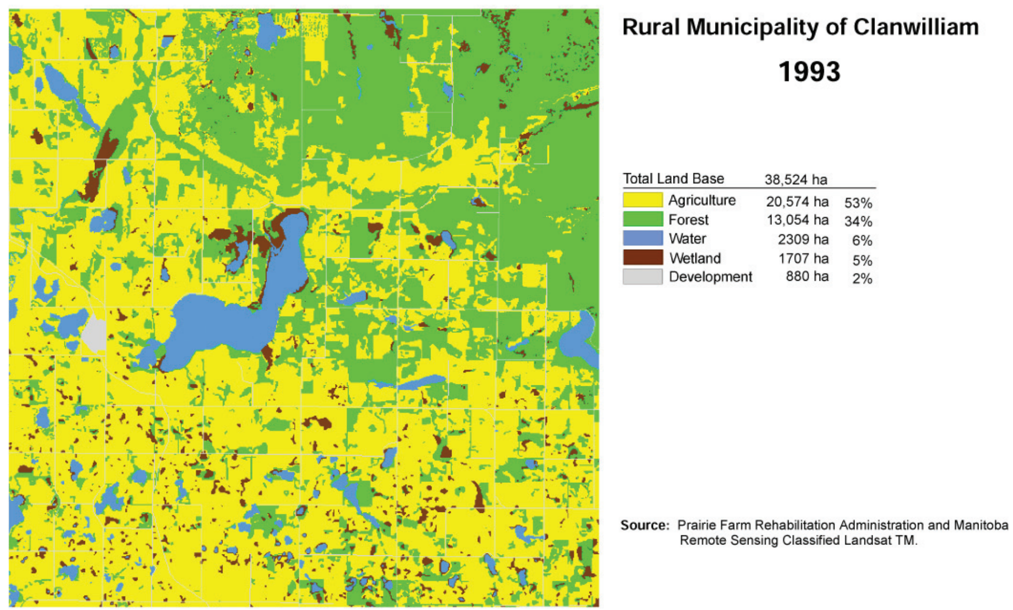

FIGURE 12
Land Cover of the Rural Municipality of Clanwilliam, Manitoba, Canada 1993.
(Source: Sobkowich, 1998).

5.6 Mont St. Hilaire Biosphere Reserve

The total forested area of the study region changed significantly from 1761 to 1993 (see Figures 13, 14, 15 and 16) as a result of human activity causing deforestation (Uhde, 1998) - a transformation of the use of land from forested land to agricultural land, road or dwelling construction. The situation in 1761 serves as the point of departure when the territory was virtually untouched by European civilisation: the approximate 160 km^2 study zone then contains almost 100 km^2 of uninterrupted forest. By 1815, the forest cover had decreased by half (Cobban and Lithgow, 1952). Agricultural land occupied most of the northern half of the study region; five road segments were constructed, along the interior bank of the two rivers and on the deforested area in the North; dwellings were regularly spaced on the North-South roads. The railway that cuts through the study region was constructed by 1867 and more road segments were constructed. The density of dwellings in the southern portion of the territory has increased significantly, particularly immediately south of the mount. These 28 years of fast development caused the limits of the large forest covering Mont St. Hilaire to recede considerably and this forest patch, now distinctly bigger than any other, becomes tightly shaped around the mountain at a contour of about 125 meters. Generally, the forested landscape became much more fragmented by 1867: everywhere south of Mont St. Hilaire is patchy; up to then, the north-eastern forest had become more fragmented and the position of the forest has changed. From 1932 on, the forest area continued to shrink. By 1932, straight lines have appeared in the forested landscape. This period marks the end of the economic crisis, when the steady decline in rural population stopped. Where the railway meets the road boarding the Richelieu River, a housing agglomeration has developed. From then on, deforestation does not remove huge tracts of forest like it did between 1839 and 1867, but rather causes the creation of new forest patches and the slow shrinkage of existing ones. In 1963, the housing development located south-west of Mont St. Hilaire on the east bank of the Richelieu has evolved into a town easily occupying twice as much land as thirty years earlier. The pattern of progressive reduction of forest patch area continued until 1963; the patch of Mont St. Hilaire is then completely detached from the southern forested landscape.

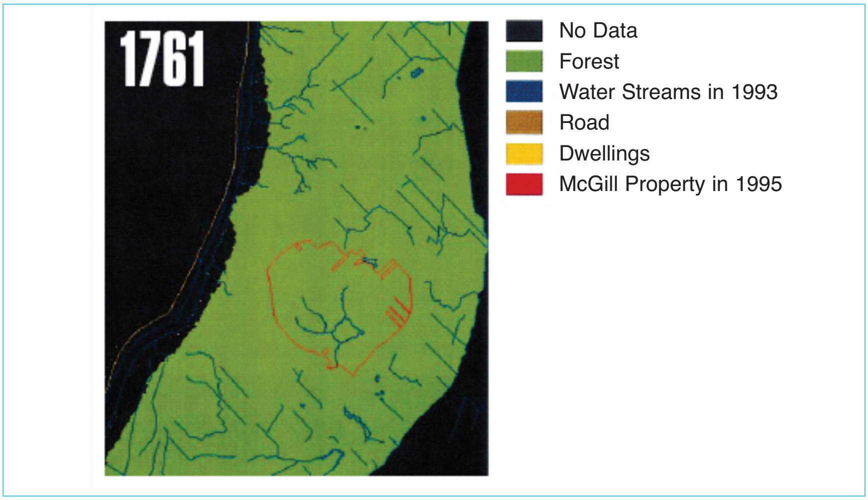

FIGURE 13
Land Cover at Mont St. Hilaire Biosphere Reserve, Quebec, Canada 1761.
(Source: Uhde, 1998).

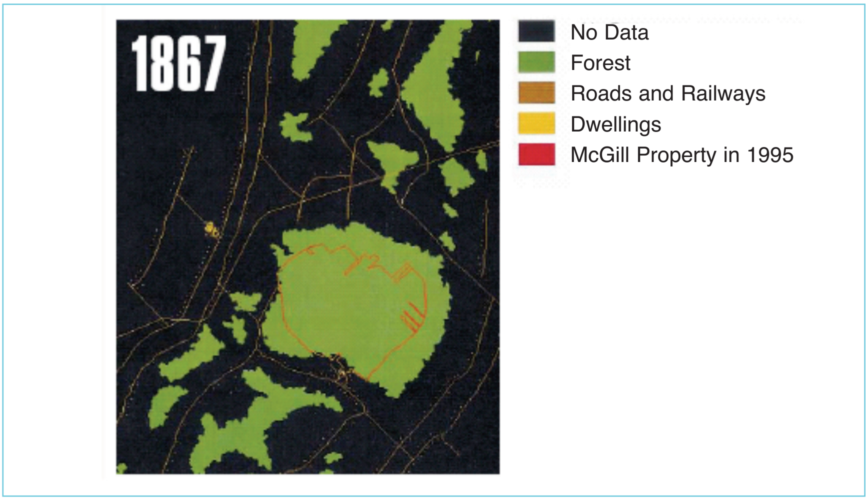

FIGURE 14
Land Cover at Mont St. Hilaire Biosphere Reserve, Quebec, Canada 1867.
(Source: Uhde, 1998).

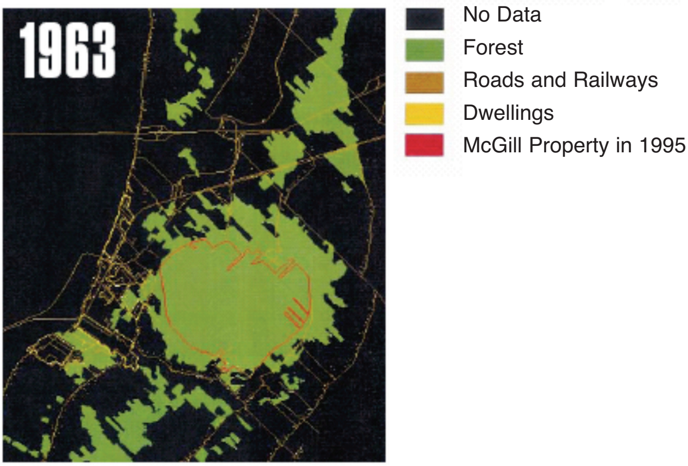

FIGURE 15
Land Cover at Mont St. Hilaire Biosphere Reserve, Quebec, Canada 1963.
(Source: Uhde, 1998).

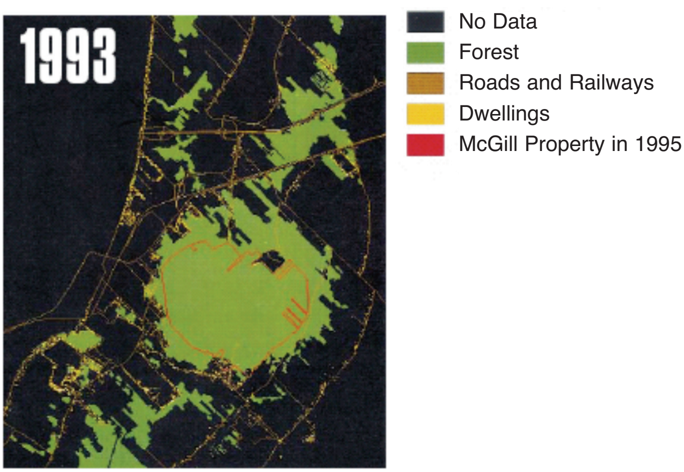

FIGURE 16
Land Cover at Mont St. Hilaire Biosphere Reserve, Quebec, Canada 1993.
(Source: Uhde, 1998).

6. Next Steps and Conclusions

The partners of this project will use the results and lessons learned from the study in different ways. Maps generated from this study have been shared at events of Biosphere Reserves and partners. Riding Mountain and Mont St. Hilaire Biosphere Reserves are planning to import this information into local management agencies to guide decision-making towards sustainability consistent with a community's sense of place. Each Biosphere Reserve plans to expand and build upon the initial work done as part of this study. The EMAN Coordinating Office, Environment Canada will be using the study and lessons learned to develop a landscape change indicator for use at other EMAN sites as part of an early warning system of ecological changes across Canada. The Ontario Ministry of the Environment will be sharing the protocols and lessons learned with their clients and partners including municipalities, non-government organizations and Conservation Authorities.

The Biosphere Reserve Landscape Change Project demonstrated significant insights about the changes that humans have brought on the landscape since European settlement may be documented from existing landscape data and information. These studies have provided a view of the changing natural environment in and around Biosphere Reserves and have provided information to Biosphere Reserve communities to help refine their "sense of place". Further application of the combined techniques from all of these studies is recommended to continue adding to the picture of landscape and associated ecological changes at Biosphere Reserves and elsewhere in Canada.

7. Acknowledgements

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Note: For a copy of the complete document titled "Landscape Changes at Canada's Biosphere Reserves: Summary of Six Canadian Biosphere Reserve Studies", visit **www.eman-rese.ca/eman/reports/publications/2001_cbra_acrb/brochure.pdf**

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PART

III

SOCIAL CHANGE

PAPER 9

EXPLORING EMERGING ENVIRONMENTAL ISSUES: THE RESULTS OF TWO CANADIAN SURVEYS

PETER TIMMERMAN[1], ADAM FENECH[2], AMAR WAHAB[3] AND ERIK SPARLING[4]

[1] York University, Toronto, Ontario, Canada
[2] Environment Canada, Toronto, Ontario, Canada
[3] University of Toronto, Toronto, Ontario, Canada
[4] Round Table on Environment and Economy, Ottawa, Ontario, Canada

ABSTRACT: 'Emerging issues' has emerged as an important theme in recent years, partly as an element in a diverse mix of 'strategic thinking' approaches. Emerging issues can be defined as those issues (both positive and negative) that are not generally or immediately recognized but which will have significant impact on human and/or ecosystem health in the 21st century. This paper details the results of two studies attempting to identify emerging environmental issues in Canada, as well as internationally in the field of atmospheric and climate sciences. Emerging issues of climate change and biodiversity in Canada - and severe weather and climate change detection in the atmospheric and climate sciences - are identified using both written surveys and key actor interviews. Some next steps are identified in the future study of emerging environmental issues.

Keywords: emerging issues; environment; sustainable development; atmosphere; climate; Canada

1. Introduction

'Emerging issues' has emerged as an important theme in recent years, partly as an element in a diverse mix of 'strategic thinking' approaches, including scenario modelling, forecasting, foresight exercises, future scanning, and so on. The Government of Canada explicitly gestures in this direction in *A Framework for Science and Technology Advice: Principles and Guidance for the Effective Use of Science and Technology Advice in Government Decision-Making* (Environment Canada, 2000) when, in the first section of Principles, under 'Early Issue Identification' it states:

1.1. Decision-makers should cast a wide net - consulting internal, external, and international sources - to assist in the early identification of issues requiring science advice;

1.2. Decision-makers, policy advisors and scientists should communicate emerging issues requiring advice, and improve the connections between research and potential policy or regulatory issues.

However, 'emerging issues' are about more than just science advice. One of the non-governmental interviewees for this Project said that "emerging issues raise all the basic questions: trust, competence, can we cope?" Other interviewees, in different ways, agreed that agencies like Environment Canada are in a complex position with regard to the whole trajectory of modern society. Discussions of emerging issues trigger these complexities.

The obvious motivations in considering emerging issues often include the hope that early identification of emerging issues will assist in:

- developing an overall strategic plan for a ministry, corporation, etc.;
- designing research priorities for the midterm (5-20 years); and
- providing an 'early warning' for policy responses that might be undertaken before an issue has become a serious threat.

This paper considers these, but in addition proposes that responding to 'emerging issues' must engage a wider set of purposes.

The study of emerging environmental issues has become a growth industry in the last few years. Recent works have included a global perspective produced by SCOPE (Scientific Committee on Problems of the Environment) for UNEP (United Nations Environment Programme) (Munn *et al.*, 1999); a study of emerging environmental issues in the province of Ontario, Canada (Munn, 1999); a special emerging issues workshop for the U.S. state of California (California Environmental Protection Agency Office of Environmental Health Hazard Assessment, 1998); a national survey in the United Kingdom of technology and environmental futures (Loveridge *et al.*, 1995); and a local study of future environmental risks facing the Houston area (Mitchell Center for Sustainable Development, 1996), used both for municipal priority setting and for public education.

This paper is a joint project of the Institute for Environmental Studies at the University of Toronto, and Environment Canada. The project has involved the mailing of detailed questionnaires: in the first study to representative scientists and experts across Canada inquiring as to their expectations regarding possible emerging issues of concern for Canada in the 21st century; and in the second study to representative scientists and experts around the world inquiring as to their expectations regarding possible emerging issues of concern in the atmospheric and climate sciences.

For the purposes of the study, emerging issues were defined as those issues (both positive and negative) that are not generally or immediately recognized but which will have significant impact on human and/or ecosystem health in the 21st century. Emerging issues can have impacts globally or regionally and can include local issues that occur in many parts of the globe. The boundaries of emerging issues for the first study were confined to those specific to the Canadian landscape; while for the second study, emerging issues in the atmospheric and climate sciences were considered globally.

Figure 1 gives some sense of the complex web of elements that contribute to the formation of emerging environmental issues; and also sketches a possible phasing of arrival and response.

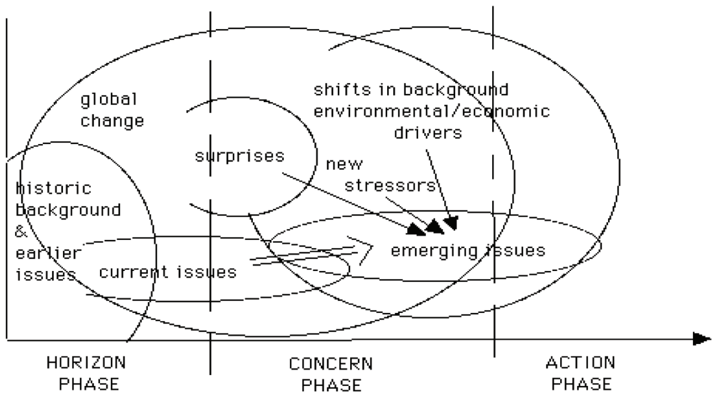

FIGURE 1
Phases of Emerging Environmental Issues.

2. First Study – Emerging Environmental Issues in Canada

2.1 The Questionnaire

For the first study, questionnaires were submitted to 106 scientists or science managers in the environmental sciences from across Canada representing various jurisdictions including federal government departments, provincial and territorial agencies, municipal governments, non-governmental organizations, and a few journalists. See Figure 2 for a regional distribution of the survey across Canadian regions (North), provinces and cities (National Capital Region).

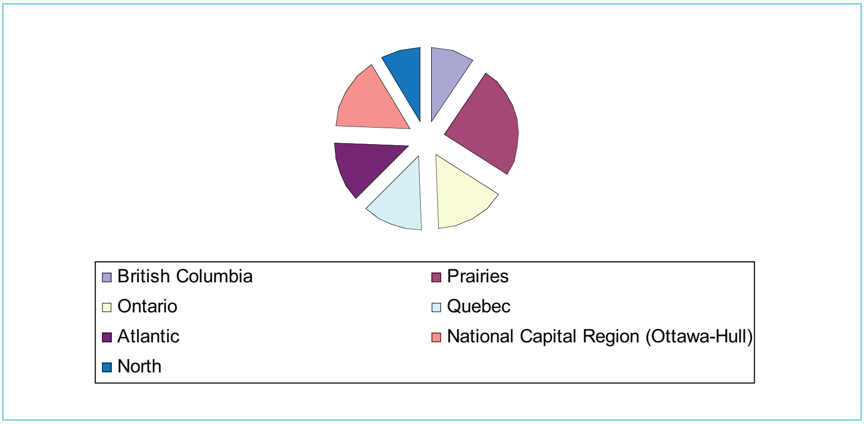

FIGURE 2
Recipients of First Study Questionnaire, by Region in Canada.

There was a 20 percent response rate to the questionnaire, with returns balanced across the regions. This was further supplemented by a handful of key actor interviews carried out through the winter 2000-2001 with representatives from Environment Canada, an NGO leader, and a leading member of the environmental academic community.

The respondents of the first study identified 7 Current Priority Environmental Issues of Concern for Canada as shown in Table 1.

TABLE 1

7 Current Priority Environmental Issues of Concern Identified (descending frequency of mentions)

1. Climate Change
2. Resource exploitation including land-use
3. Threats to biological diversity including invasive species, modified organisms
4. Management of knowledge and data, responsibility, monitoring, coordination
5. LRTAP, air quality especially mercury (Hg)
6. Impacts of environment on human health
7. Water issues: quality and quantity

The respondents of the first study identified 7 Current Priority Environmental Issues of Concern for Canada as shown in Table 1.

TABLE 2

4 Main Environmental Issues Identified as Emerging in the Near Future (descending frequency of mentions)

1. Threats to biological diversity
2. Climate change
3. Air Quality, LRTAP
4. Water issues: quality and quantity

Of note are the following results:

- a large number of respondents did not identify any emerging issues;
- the lack of positive emerging issues in the environmental field;
- the focus on Canada's North and mid-North as an emerging area of environmental concern as resource extraction issues come to the fore; and
- a continuing potential for stronger environmental consciousness among the Canadian public, including a wider and more powerful definition of 'environment' and 'sustainability', including a much clearer connection between the importance of environmental issues to everyday life and overall welfare.

Among the major obstacles cited to responding to these emerging environmental issues were: a lack of current public support; Canada's materialistic society and lifestyle; a lack of government initiative; and the scientific uncertainties.

The need for leadership was a constant theme in the responses. Respondents put the primary responsibility for handling the four main emerging environmental issues identified in Table 2 clearly in the hands of the federal government, and more specifically Environment Canada. The provinces are seen as responsible as well, but not to the same degree as the federal government. The federal government is seen as having the responsibility for thinking broadly and deeply about the longer term. Surprisingly, few respondents identified a coalition of jurisdictional groups as working together to handle any of the emerging issues.

When speaking about Canada's overall capacity to deal with emerging issues in general, the respondents were not optimistic; over half described the capacity as 'poor', and with those who described it as 'good' adding numerous caveats. The respondents who identified Canada's capacity as 'good' were referring to the scientific capacity. 'Bad' responses generally referred to government's unwillingness to take leadership and address the issues.

When asked how to improve personal, group or organizational capacity to manage emerging issues in Canada, respondents focused on funding, and leadership from the federal government (especially Environment Canada) to develop a long-term vision for the environment and partnerships to get all groups involved in addressing the issues.

2.2 Interviews with Key Actors

Characteristic of key actor interviewing is being able to capture specialist expertise and wide-ranging knowledge on the subject in question. It is not a sample from which larger extrapolations or calculations can be made. In academic terms, it is a subset of the 'structured interview' (see, Berg, 1998, for a broader discussion). Among its other virtues is that it can assist in developing what anthropologists refer to as 'thick descriptions' of the field of study.

The identification of key actors to interview usually focuses on pivotal ('key') people who are decision-makers or decision-influencers. Unlike standard questionnaires, key actor interviews involve open-ended questions and only semi-directed structures. Among the difficulties of key actor interviewing is that a similar level of expertise or familiarity with the subject is usually required of the interviewer. The Principal Investigator in this Project was able to carry out the interviews in person.

The interviewees were given a version of the larger questionnaire in advance, and were ensured of confidentiality in their remarks (all subsequent references to content below have been scanned to ensure that identification is difficult). In addition, they were given the opportunity to add questions, or return to the interviewer at a later date to clarify points made.

Virtually all the key actors that were interviewed agreed that 'emerging issues' provided a real challenge to governments, for a variety of reasons. These included:

- The primary commitment to short-term responses to problems faced by governments;
- The related difficulty in finding short-term or incremental steps to the solution of systemic issues, i.e. issues that require a holistic or full-scale intervention to match the potential seriousness of the issue; and
- The lack of funding for some of the key elements in any long-range scanning for emerging issues, including base-line data, monitoring networks, and staff that can be partly or wholly dedicated to focusing on issues that are not of immediate concern.

A number of the key actors articulated their views about how issues got onto the political agenda, and stayed there. Among the complexities were:

- Issues became characterized very early according to incidents, or initial reports that defined their nature and responsible agencies - and this happened often in ways that were not ultimately beneficial to the outcome of the issue. There are major problems with the definition of who does what with each issue in government, university, and industry. One often has to spend disproportionate amounts of time reframing an issue that has already 'set'.
- Many issues needed a champion with scientific credibility or political power or (what one actor referred to as) "the bureaucratic patience of an ox."
- There are different standards of evidence and credibility required for different issues; standards which are not a function of science, but a function of "how the game is played." In this context, reference was made to emission standards and health risks (and their relationships) as well as public indices, that are - as one respondent remarked - "as much of an art as a science".

It was noted that many of the institutions in the environmental system had been put in place to deal with previous emerging issues, and that they had lifecycles as well that were not matched with the needs of the new issue. One respondent noted that a major long-term management issue was how to have staff that were generalist enough or adaptive enough to translate and transform the existing teams and mandates into new territories. There was concern about whether the next generation of managers would have this capacity.

An emerging issue that was raised by a number of the key actors was the Arctic as a whole. It was considered to be a convergence point for concerns over climate change, biodiversity, the long-range transport of air pollutants (LRTAP), and so on, but it also had great potential because of the arrival of new governance systems both nationally and internationally. One key actor went so far as to say that "the Arctic is a key laboratory for emerging issues."

Questions of capacity were often raised in discussion. Institutionally, a major problem noted was that the existing scientific and policy units were very species and issue specific, which makes it difficult to spot larger or 'meta-level' emerging issues, and to respond to them collectively. There were major gaps in environmental monitoring systems, and fundamental gaps in ecological knowledge.

Key actors were asked about how they obtained information about emerging issues, and how they weighed their credibility. Virtually none of them had the time to rely on primary documents, and scanned the newspaper, TV, and radio like anyone else. They relied very much on personal contacts, conferences, and in-house scientists to weigh the seriousness and credibility of an emerging issue. They found that if they could assimilate the new concern to an already existing issue, that the management response was usually clear. Respondents considered the most troubling issues those that challenge basic scientific norms, or for which there was only one information source or expert.

3. Second Study – Emerging Issues in the Atmospheric and Climate Sciences

After the first study identified that climate change was the number one current priority issue of concern to Canadian scientists, and that climate change and other atmospheric issues are some of the most prominent emerging issues of concern, a second study was undertaken to focus on the mid-term prospects for scientific research in the climate and atmospheric sciences.

For the second study, questionnaires were submitted to scientists from around the world who are editors of major international journals in the atmospheric and climate sciences (see table 3); to scientists from across Canada who were successful in receiving a research grant from Canada's Natural Sciences and Engineering Research Council (NSERC); and to scientists from across Canada who were successful in receiving research grants from the Canadian Foundation for Climate and Atmospheric Sciences (CFCAS) (a distribution is shown in Figure 3). There was a 15 percent response rate to the questionnaire, with returns from Canada doubling those internationally.

The respondents of the second study identified the state of the earth's climate and atmosphere in the next 5 to 25 years as including:

1. Increased air pollution;
2. Increased frequency and magnitude of weather extremes including heat, drought, flooding, freezing rain, tornadoes, hurricanes; and
3. A dissipating cryosphere (ice, permafrost, glaciers, snow).

It is interesting to note that 15 percent of the respondents thought that the atmosphere would not change much in the next 5 to 25 years.

TABLE 3

International Journals in the Atmospheric and Climate Sciences Canvassed for 2nd Survey

1. Atmospheric Environment
2. Atmospheric Research
3. Boundary Layer Meteorology
4. Climatic Change
5. Climate Dynamics
6. Dynamics of Atmosphere and Ocean
7. International Journal of Climatology
8. Journal of Air and Waste Management Association
9. Journal of Applied Meteorology
10. Journal of Atmospheric and Oceanic Technology
11. Journal of Atmospheric and Solar Terrestrial Physics
12. Journal of Atmospheric Chemistry
13. Journal of Atmospheric Science
14. Journal of Climate
15. Meteorology and Atmospheric Physics
16. Nature
17. Quarterly Journal of the Royal Meteorological Society
18. Theoretical and Applied Climatology
19. Weather and Forecasting

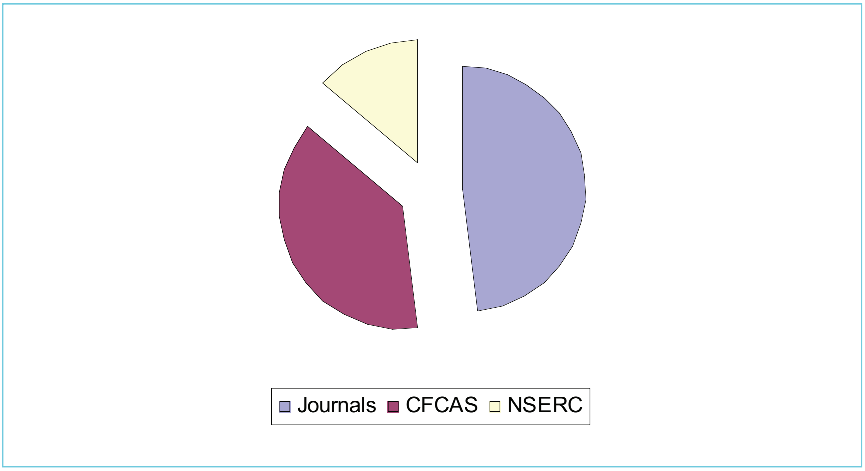

FIGURE 3
Recipients of Second Study Questionnaire, by Focus.

The respondents of the second study managed to zero in on only two priorities for research and development (R&D) in the atmospheric and climate sciences – severe weather and climate data analysis. Eleven other R&D priorities were identified by the respondents, but these reflected a ranking of their own area of research (see Table 4 for the top 10).

TABLE 4

Top 10 Emerging R&D Priorities in the Atmospheric and Climate Sciences (descending frequency of mentions)

1. Detection and prediction of severe weather
2. Climate data analysis
3. Numerical weather prediction
4. Data assimilation
5. Finer resolution climate models
6. Integrated environmental modelling
7. Cryospheric applications of remote sensing
8. Atmospheric chemical characterization and speciation
9. Air quality prediction for smog advisories
10. Land-climate and ocean-climate interactions

These priorities for R&D in the atmospheric and climate sciences were identified as such by the respondents because of:

- the availability of new technologies;
- a rapidly developing science;
- its urgency to society (linked to human health)
- the natural progression of science; and
- its links to developing policy.

Capacity is the main obstacle to addressing these priorities in the atmospheric and climate sciences. Funding is seen as the number one obstacle, with the dearth of trained personnel coming second.

Responses to who should respond to these R&D priorities in the atmospheric and climate sciences focus on national governments, academic research centres and international organizations to bring together important resources and build – what one respondent calls – an epistemic community.

Roles of the various players in this challenge are clear. The public is seen as needing to become more educated about issues, and apply pressure on governments to ensure that research is conducted. The academic community is seen as responsible for leading research. And the private sector is seen as developing the technologies and methods for addressing these priorities.

4. Conclusions

This paper detailed the results of two studies attempting to identify emerging environmental issues in Canada, as well as internationally in the field of atmospheric and climate sciences. Emerging issues of climate change and biodiversity in Canada - and severe weather and climate change detection in the atmospheric and climate sciences - were identified using both written surveys and key actor interviews. Some next steps for future study in the area of emerging environmental issues include:

- The study of emerging issues in a specific geographic area, such as the Far or Near North in Canada.
- An effort to determine ways of enhancing the capacity for identifying, exploring, and responding to emerging issues on the part of government, industry, and the public and private sectors generally.
- The exploration of ways of engaging the wider public in discussions over emerging issues.

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PAPER 10

SOCIAL LEARNING IN THE MANAGEMENT OF GLOBAL ATMOSPHERIC RISKS: A CANADIAN EXAMPLE OF ISSUE IDENTIFICATION

ADAM FENECH[1]

[1] Environment Canada, Toronto, Ontario, Canada

ABSTRACT: Social learning is how humans, as individuals and groups, adopt and spread new concepts, knowledge and skills. There was a clear recognition during the late 1980s of the need for a better understanding of how human societies perceive and respond to global environmental change. Applying this "social learning" framework to the identification of global atmospheric risks, this paper traces the evolution of efforts of individuals and agencies in Canada to address the issues of stratospheric ozone depletion and climate change focusing on how an issue became an issue, how it was framed and how it received attention. Four conclusions are drawn from this study: One obvious observation is that scientists "learned" from other scientists, although Canadian scientists usually "learned" from scientists from countries other than Canada. Another obvious observation is that media attention to a scientific issue acted as a "teacher" of the Canadian public (the "learner") creating a controversy that sparked scientific investigation and government action, although the surprise here is that the media attention was American in origin. A third conclusion was that the common stable of atmospheric scientists in Canada (the Meteorological Service) allowed for cross-issue learning in the areas of atmospheric monitoring, research and modelling. And finally, the study concludes that the time period for an idea of global change growing into an accepted issue can be quite long, even decades.

Keywords: social learning; history; stratospheric ozone depletion; climate change; Canada

1. Introduction

Simply put, social learning is how humans, as individuals and groups, adopt and spread new concepts, knowledge and skills. There was a clear recognition during the late 1980s of the need for a better understanding of how human societies perceive and respond to global environmental change. Most of our understanding reflected the perspectives of a very narrow range of countries and groups, and was focused on key scientific discoveries and decisions with little attention to the historic connections between them. There was little critical discussion of what might be appropriately "learned" from the experience of dealing with other environmental problems, and from the experience of dealing with them in other places or countries.

A study was developed under the leadership of William C. Clark, Harvard University and funded by the John D. and Catherine T. MacArthur Foundation to garner a better understanding of how human societies "learned" from earlier responses and other countries and organizations in the management of global atmospheric risks. The study examined a period extending from an organization of global environmental science known as the International Geophysical Year (IGY) of 1957 to the celebration of international environmental politics that was the UN Conference on Environment and Development (UNCED) of 1992.

The study asked the questions: (1) Who (individual, organization, country) learned? Was the learning from within the social group, among social groups or from another country? Who was the teacher? Who was the learner? (2) What was learned? What knowledge, experience, or norm was learned? How did this knowledge, experience or norm fit or redefine existing practices, models and decision-making processes? (3) How did the learning occur? *Who* brought new information to bear on the existing issue? *Where* did the new information come from? *How long* did the new information take to formulate into an issue?

This paper traces the evolution of efforts of individuals and agencies in Canada (Note: While this paper addresses only Canada, the overall study included a comparative exploration of the development of global issues across a range of national and international settings consisting of Japan, the United States of America, Mexico, the United Kingdom, the Netherlands, Germany, the former Soviet Union, Hungary, the European Union and the family of international environmental organizations) to address the issues stratospheric ozone depletion and climate change (The overall study also included the issue of acid rain) focusing on how an issue became an issue, how it was framed and how it received attention.

2. Identifying the Stratospheric Ozone Depletion Issue in Canada

The concept of humans polluting the upper limits of the Earth's atmosphere was considered astounding in the early 1960s. This was a time of many deplorable examples of human pollution of local and regional environments, but the idea that humans could pollute the far reaches of human travel remained astonishing. Given the sheer magnitude of the Earth and its atmosphere, few individuals even considered the possibility that humans could change things on a worldwide scale. A Canadian was one of those few individuals.

John Hampson working at the Canadian Armament Research and Development Establishment (CARDE) in Val Cartier, Quebec in the early 1960s provides the first statement of concern that human activities could harm the stratospheric ozone layer. Hampson was looking for radiative early-warning signals of incoming missiles, focusing on water vapour from both high-flying aircraft and rockets, arguing that hydrogen species arising from the photochemical dissociation of water could catalyze ozone destruction. His work appeared only in CARDE technical reports which, though widely circulated among both Canadian and American atmospheric and defence research communities, were never taken seriously. (Hampson's colleagues report that his highly eccentric temperament, his weaknesses in both written and oral communication, and the messianic fervour with which he warned of the risk of ozone depletion, all contributed to his not being regarded seriously).

These and other reports on the concern over stratospheric harm from water vapour emissions of high-flying aircraft circulated informally in the United States through the late 1960s, becoming salient enough in the early 1970s as the controversy surrounding the effects of high flying aircraft, or super sonic transports (SSTs) as they were then known, on stratospheric ozone heated up that the US Commerce Department sponsored a scientific meeting to consider the problem at Boulder, Colorado in March 1971. Canadian chemist Harold Schiff was invited because of his laboratory work on ozone chemical reactions. At this meeting, James McDonald presented his calculations of estimated increases in skin cancer, based on Hampson's photochemical calculations, and Harold Johnston challenged the participants with his contention that nitrogen emissions posed a much more serious ozone depletion risk than water. After heated discussion at the meeting left the question unresolved, Johnston sought to raise an alarm by quoting his estimates to an American newspaper, the New York Times, in an article that raise considerable public attention.

Johnston's claim came to the attention of the Canadian Prime Minister's Office which asked the Canadian Cabinet's Science Advisor for a note on the effects of SSTs on stratospheric ozone. Schiff prepared the note, who despite personal misgivings over the possibility of a catastrophic risk, supported the cautious consensus conclusion of the Boulder meeting - that the risk was significant but unproven, and that only further research was warranted. As Schiff reported to the Globe and Mail, Canada's National Newspaper - "It's on two levels: what if Johnston is right? I am worried for my children, not for myself. The other level is the credibility of science."

Only in 1973, after concerned scientists had briefed Environment Canada's Management Committee, and the chair of the US Climatic Impact Assessment Program (CIAP) had formally solicited a Canadian response to CIAP (at the prodding of Canadian scientists), did two significant responses from the Canadian executive occur. First, a jointly sponsored Environment Canada and Transport Canada funding proposal was approved by the Canadian Cabinet for a Canadian stratospheric pollution research programme including monitoring, modeling and laboratory chemistry. Second, an Advisory Committee on Stratospheric Pollution, made up of scientists from several government departments and universities, was established in April 1973 to coordinate Canadian research and advise the government on its policy implications.

Though the Committee was established to address the stratospheric risk posed by SSTs, this job became less urgent during the long delay that attended the Committee's formation. By the time of the first Committee meeting in May 1973, the US SST program had been stopped and the Concorde's introduction delayed so that estimates of 1975 SST operations had dropped from 17,000 to 4,500 flights per year. The Committee recognized a strong need for continued stratospheric research, however, arguing that: "there is no excuse for ignorance of a region (the stratosphere) so close and important to man … regardless of the immediate concern over SST operations".

By 1974, the first suggestions that chlorine could threaten stratospheric ozone appeared in the Molina and Rowlands' paper published in Nature which developed the mechanism for chlorine catalysis of ozone, and identified chlorofluorocarbons (CFCs) as the largest potential source of stratospheric chlorine. In Canada, the Advisory Committee on Stratospheric Pollution met to assess the state of knowledge on the "freon-ozone problem" (The ozone-depleting compounds that we know today as chlorofluorocarbons or CFCs were then referred to as the Dupont firm's brand-name of "freons" or chlorofluoromethanes (CFMs)). Schiff had just returned from being appointed to the US National Academy of Science (NAS) Panel on Ozone Depletion and informed the Committee that the NAS would now be treating chlorine as the primary issue, which the Committee agreed should now be the priority for Canadian research.

The Committee noted US activity on CFCs including state legislation banning aerosols in New York and Florida, a consumers' union lawsuit against the US Environmental Protection Agency (EPA) and a US Senate committee's recommendation for increased research into the chlorine-stratospheric ozone connection. The Canadian Advisory Committee Chair Barney Boville suggested that restrictive legislation could appear soon in Canada. Boville took the Committee's deliberations before the public in late 1974 stressing that he was not advocating an immediate ban on spray cans, but merely a slowing in their rate of growth. Canadian aerosol producers, represented by the Canadian Manufacturers of Chemical Specialties Association responded that a moratorium on spray cans would have grave economic implications. H. Crawford of Dupont Canada, the primary CFC producer in Canada, said that industry wanted a research program to gather data on what was actually happening in the upper atmosphere.

Calls for immediate regulatory action continued. Attending a 1975 seminar at York University in Toronto, Ontario, Sherry Rowland called for an immediate phase-out of CFCs 11 and 12. He suggested that it was increasingly unlikely that a major flaw would appear in the scientific calculations indicating that CFCs have serious environmental effects. Industry repeated its objections to a ban, arguing that predictions of environmental effects were based on speculations that lacked evidence.

When briefing the Official Canadian Government Opposition Critic in September 1976, Boville expressed with “full confidence (95 percent)” that ultimate stratospheric ozone loss from continued 1973 CFC emissions would be from 2 to 20 percent - levels that his own scientists’ models were showing, and levels that international scientific committees were predicting. Boville expressed his personal support for a Canadian aerosol ban but carefully delimited the scientist’s role in policy-making - to identify and quantify potential problems and communicate the conclusions, leaving the public and politicians to balance the risk of increased skin cancer from stratospheric ozone depletion against the benefit of air conditioning and underarm deodorants.

In its 1976 assessment report, the Advisory Committee on Stratospheric Pollution concluded that the scientific evidence was strong enough to warrant a response, and stated that if scientific evidence was the only consideration, they would recommend immediate regulations to achieve a significant reduction in CFC releases. Immediately after receiving the report, the Canadian executive through the Environment Minister announced it would regulate the non-essential uses of CFC aerosols in the following year.

3. Identifying the Climate Change Issue in Canada

Throughout the world and in Canada, there have been early indications of concern about the human influence on the world’s climate. In the 1950s, the question of climate change was entrenched in the Canadian climatology community through its development as a topic at university courses and meteorological training courses, as well as a subject on the weekly radio broadcasts to the Canadian public called *Meet Your Weatherman*. The general topic of unusual weather patterns was continually debated with fears of nuclear testing being the major cause, yet there was continued scientific agreement that the burning of fossil fuels were increasing atmospheric carbon dioxide concentrations which could lead to a changing climate.

Even with the potential environmental consequences of human activities on the climate, there was an initial ambivalent response from the executive of the Canadian government, Environment Minister Jack Davis: "If we burned up all the coal, oil and natural gas in the Earth's crust, we still would not bring the carbon dioxide content of the atmosphere up to one tenth of one percent. As the carbon dioxide content of the earth's atmosphere rises, it is taken up by plants at an increasing rate. About half of all the carbon dioxide released into the atmosphere by the burning of fossil fuels has already disappeared. Our earthly biosphere tends to counteract our every action."

Greater concern was placed on climate variability or even climate cooling during a time of food security concerns in the early 1970s. A hostile climate was seen as a serious threat to future world food supplies at the 1975 UN Conference on Food. This conference deliberated the idea for the first World Climate Conference held in Geneva in February 1979 where the issue going into the conference was climate variability, the issue coming out of the conference was carbon dioxide identified as the major culprit in global warming.

In recognition of the impact of climate and climatic fluctuations on society, the Canadian government established a Canadian Climate Program to integrate efforts of the various federal and provincial agencies as well as universities and the private sector in the field of climatology. An important aspect of the early program was the holding of workshops in 1979 across the country designed to examine important impacts of climate on several key resource and economic sectors in Canada's energy, agriculture, forestry, water, oceans and fisheries, recreation and tourism, and transportation. The workshops were designed as an information dissemination tool to examine the impacts of climate change and variability, to apply climate knowledge to Canadian resource and environmental management, and as a way to increase the member participation in the Canadian Climate Program. Gathering together the top Canadian meteorologists of the day, the workshops concluded publicly that "society has about 15 years to address the urgent questions before the onset of possibly catastrophic global climate changes".

Both events in 1979 helped advance recognition of the climate change issue to the executive levels of the Canadian government. At the 1979 Economic Commission for Europe's (of which Canada is a member country) Meeting on Protection of the Environment, Canadian Environment Minister John Fraser stated that "combustion of fossil fuel on a world-wide basis is known to be producing a global increase in atmospheric carbon dioxide concentrations which may influence the earth's heating balance and cause climate changes with far-reaching consequences."

While climate warming was being discussed between scientists and pronounced by politicians, the climate itself remained variable giving rise to an obvious confusion in the media. In 1981 and 1982, there were two articles written at the same time of the year (winter) in the same Canadian newspaper (Vancouver Province) separated by one year - one indicating a potential climate warming and one indicating a potential climate cooling.

In 1981, the Canadian government supported the Canadian Climate Centre with an large increase in funding and approval to purchase a supercomputer (shared with the main national weather forecasting centre) to develop an advanced climate model to provide predictions of climate scenarios for impact studies. During the early and mid-1980s, the Canadian Climate Centre's climate models consistently supported a 1.5 to 4.5 degree Celsius temperature change from a doubling of carbon dioxide concentrations.

Three international climate conferences held in the mid-1980s established climate change as an issue in its own right among the scientific community. At Villach, Austria in October 1985, a joint UNEP/WMO/ICSU conference was convened to assess the role of the increased carbon dioxide and other greenhouse gases on climate changes and associated impacts. The concern in this case was how future climates might affect the decisions being made on long-term irrigation and hydro-electric projects. The conference concluded that it was a matter of urgency to refine estimates of future climate conditions to improve this decision-making. Two workshops at Villach and Bellagio, Italy in late 1987 followed the 1985 Villach conference, forwarding the scientific consensus that international action to curb escalating levels of atmospheric greenhouse gases was "inevitable".

The single moment galvanizing the climate warming issue in Canada was the 1988 conference on Our Changing Atmosphere: Implications for Global Security held in Toronto. The Toronto Conference firmly established global warming as an international issue. As Canadian climatologist Henry Hengeveld stated about the conference, the media response "together with political leaders from a number of industrialized countries who pledged to push for further action within the international political community, gives reason for optimism that the conference was not just a one-conference wonder, but a major step towards global action to protect the atmosphere".

It is not surprising that public interest in the climate change issue peaked at the time of the 1988 Toronto Conference. First, there was a high degree of scientific consensus at the conference as to the future direction of global temperatures and the likely social and economic disruptions that might result. This consensus was consistent with the testimony of James Hansen of NASA on June 22, 1988 before the US Senate Committee on Energy and Natural Resources, just four days prior to the Toronto Conference. The second factor that gave credibility to the mounting public concern about climate change was the fact that the conference was held during a continent-wide heat wave and drought, a sequel to severe droughts experienced in preceding years. Temperatures in Toronto for example, exceeded 35 degrees Celsius on six occasions in the month of July 1988, at the time the greatest number for that month since measurements began in 1846.

The Toronto Conference called for governments and industry to "reduce carbon dioxide emissions by approximately 20 percent of 1988 levels by the year 2005 as an initial global goal" as an attempt to combat climate change. The Toronto Conference target was incorrectly identified as a Canadian commitment to carbon dioxide reductions, where in fact, the Canadian government proceeded more cautiously.

4. Conclusions: So who learned what from whom?

The two stories above provide the history behind the development of the issues of stratospheric ozone depletion and climate change in Canada. Applying our "social learning" framework to investigating these histories provide several conclusions about social learning in Canada.

4.1 Scientists-to-Scientists Learning

One obvious observation is that scientists "learned" from other scientists. What was not so obvious was that the cadre of Canadian scientists from Environment Canada who inform and advise the Canadian government to action usually "learned" from scientists from countries other than Canada about issues, even if scientists from Canada were "teaching" the same message. For example, Hampson raised the concern of ozone depletion from increased air traffic in the atmosphere yet the Canadian government did not take action until the issue was raised in response to an American research program investigating the issue of SSTs.

The avenue for "learning" from scientists-to-scientists places an importance on the "teachings" being in person, either by sending a Canadian scientist to an international gathering to act as the messenger bringing the "teachings" back to Canada such as Schiff and the Boulder meeting, or by bringing the "teacher" directly to Canada such as Rowland's visit to York University.

The "teaching" was not blindly accepted by the "learners" as Canada required its own monitoring, modeling and science to confirm for Canada the implications and necessity for response. For example, Boville relied on his own modelers results of predicted stratospheric ozone depletion from chlorine before he took his message public and recommended regulatory actions. Also, Canadian government officials relied on the Canadian Climate Centre's climate model runs as confirmation of predictions of temperature changes under a regime of climate change.

Canadian scientists have now "learned" the lessons above and take their scientific findings to international gatherings to gain legitimacy so they can be brought back to Canada through an "acceptable" community of international scientists.

4.2 US Media-to-Canadian Public Learning

Another obvious observation is that media attention to a scientific issue acted as a "teacher" of the Canadian public (the "learner") creating a controversy that sparked scientific investigation and government action. The surprise here is that the media attention was American in origin, thus making the US media a "teacher" and the Canadian public and Canadian media "learners". For example, the New York Times article of US scientist Johnston's concern about SSTs sparked an immediate response from the Canadian government for an information note. Also, media coverage of the US Senate Committee hearings of NASA scientist Hansen's concern with the climate change issue, sparked Canada's own media (the "learner") to report on the "consensus" of scientists that climate change was a real concern.

4.3 Cross-Issue Learning

Most atmospheric scientists in Canada are federal civil servants, mostly employed in one organization, Environment Canada's Meteorological Service of Canada (formerly known as the Canadian Meteorological Service and the Atmospheric Environment Service). The expertise of this organization was applied to both issues of climate change and stratospheric ozone depletion. The scientists, for the most part, were one and the same. This allowed for cross-issue learning in the areas of atmospheric monitoring, research and modelling. The atmospheric science community that developed was stable, bureaucratic and conservative in character, bringing several important advantages. It provided secure support for the kind of careful, long-term, unglamorous monitoring and observational work that is essential for the development of baseline data and the identification of long-term trends. It also reliably provided resources to support extended participation in international research and coordination activities. The remarkable involvement of the Canadians in the activities of the UNEP, WMO and other international bodies in part reflected the value their government employers placed on such activity and their ability to support it.

4.4 Learning takes its own sweet time

The time period for an idea of global change growing into an accepted issue can be quite long. In the case of stratospheric ozone depletion, the idea of humans causing damage to the upper atmosphere was discussed in the 1960s, but it did not become a salient issue in Canada until the mid-1970s. As for climate change, the idea of human-caused carbon dioxide emissions influencing the global climate was around since the 19th century, but it did not become an issue until the 1988 Toronto Conference.

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