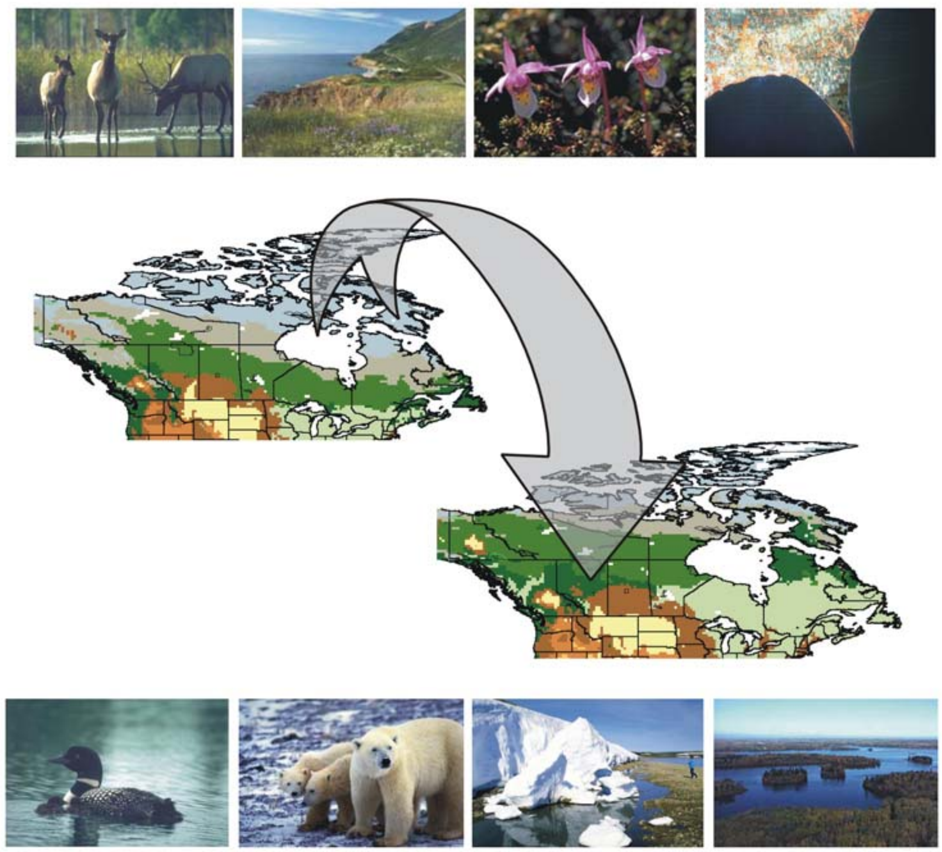
Vegetation Response to Climate Change: Implications for Canada's Conservation Lands



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Réaction de la végétation au changement climatique: conséquences pour les terres protégées du Canada

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List of Acronyms

AIRG	Adaptation and Impacts Research Group, Environment Canada
CBD	Convention on Biological Diversity
CBS	Canadian Biodiversity Strategy
CCAD	Canadian Conservation Areas Database
CCC GCM	Canadian Climate Centre general circulation model
CCEA	Canadian Council on Ecological Areas
CCELC	Canada Committee On Ecological Land Classification
CCIS	Canadian Climate Impacts and Scenarios project
CCVM	Canadian Climate-Vegetation Model
CGCM1	Canadian Global Coupled Model, first version
COP	Convention on Biological Diversity Conference of the Parties
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CWS	Canadian Wildlife Service
DGVM	Dynamic Global Vegetation Model
FAR	IPCC First Assessment Report
FPPC	Federal Provincial Parks Council
GCM	Global Circulation Model
GFDL	Geophysical Fluid Dynamics Laboratory, USA
GIS	Geographic Information Systems
GISS	Goddard Institute for Space Studies, USA
GVM	Global Vegetation Model
HadCM2	Second Hadley Centre Coupled Ocean-Atmosphere GCM
HadCM3	Third Hadley Centre Coupled Ocean-Atmosphere GCM
IUCN	The World Conservation Union
IPCC	Intergovernmental Panel on Climate Change
MAB	UNESCO's Man and Biosphere Programme
MAPSS	Mapped-Atmosphere-Plant-Soil System
MBS	Migratory Bird Sanctuary
MPI	Max Planck Institute for Meteorology
NRCAN	Natural Resources Canada
NWA	National Wildlife Area
SAR	IPCC Second Assessment Report
TAR	IPCC Third Assessment Report
UKMO	United Kingdom Meteorological Office
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WCPA	World Commission on Protected Areas

Executive Summary

Climate change has been recognised as a global concern by the Intergovernmental Panel on Climate Change (IPCC) and by the 185 nations that have ratified the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC (1997-Article 2) articulated the critical linkage between climate change and biodiversity when it indicated that, "The ultimate objective of this convention is to achieve stabilization of greenhouse gas concentrations in the atmosphere at such a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change..." The IPCC also commissioned a special technical paper on climate change and biodiversity, which recognized climate change as a key threat to global biodiversity and noted evidence of ecological change as a result of climate change that occurred over the last century.

At the fourth World Congress on National Parks and Protected Areas, the International Union for the Conservation of Nature (IUCN 1993) concluded, "Climatic change represents a critical and urgent threat to all ecosystems … (and that) Existing … protected areas may not provide adequate future safeguards for the continued survival of existing ecosystems and species in a changing world." However, comparatively few climate change assessments have applied projections of biophysical impacts to existing protected area systems and even fewer have examined the implications for policy, planning and management within existing institutional frameworks.

Paleoecolgoical and observational evidence indicate that the distribution of terrestrial ecosystems is primarily determined by climatic factors. Climate-vegetation modelling studies examining the impacts of climate change on terrestrial vegetation in Canada have consistently projected major shifts in vegetation types over much of the country.

This report examines the potential impacts of landscape level alterations in vegetation distribution resulting from projected climate change, for biome representation in Canada's broad network of conservation lands (including provincial parks, Migratory Bird Sanctuaries, National Wildlife Areas, Ramsar sites, ecological reserves, and wilderness and wildlife protected areas) and the national park system in particular. This is the first study to explicitly apply the results of equilibrium Global Vegetation Models (GVMs) to the network of protected areas in any country. The results of the Mapped-Atmosphere-Plant-Soil System (MAPSS) and BIOME3 equilibrium GVMs run with five climate change scenarios derived from General Circulation Models (GCMs) are examined. The report then explores some of the challenges that landscape level vegetation changes might pose for the policy and planning frameworks of the federal and provincial agencies responsible for Canada's network of protected areas.

The vegetation change scenarios for this analysis were based on modelling results developed for the IPCC-Working Group 2. The more detailed vegetation classifications of MAPSS and BIOME3 (45 and 18 vegetation classes respectively) were aggregated into ten common biome classifications so that the results of the two GVMs would be comparable. The structural differences in GVMs and their different response sensitivities to climate change in previous

inter-comparison studies necessitated the use of two GVMs to better represent the range of assumptions and scientific uncertainties related to vegetation response to climate change. Consistent with IPCC recommendations, multiple climate change scenarios were used in combination with the vegetation models to represent a range of plausible climate futures.

The report presents the results of two distinct analyses. The Geographic Information System (GIS) methodology used to assess vegetation change in Canada's broader network of conservation lands differed slightly from the more detailed analysis of the national parks system. GIS boundary files were not available for all conservation lands in Canada and in order to apply a consistent methodology across the nation, geocentroids were used to represent the 2,979 conservation lands in the GIS analysis. The availability of national park boundary files from Parks Canada facilitated a more detailed area-based analysis for the national parks. All terrestrial conservation lands that had some degree of ecological importance were included in the broader conservation lands analysis. Conservation lands excluded were historical sites and marine protected areas. All of the 39 designated terrestrial national parks and national park reserves were originally included in the national park system analysis, but in three of the national parks (Pacific Rim, Gwaii Haanas, Quttinirpaaq) where the majority of the vegetation grid cells in the GIS were classified as water or glacier, the park was excluded from the analysis. All of the conservation lands and national parks were superimposed on vegetation distribution layers in a GIS (current vegetation and all climate change scenarios) and vegetation change for each conservation land was examined. The study also investigated how biome representation was projected to change within each conservation land designation and the national park system. In the broader conservation lands analysis this was determined as a function of the number of conservation lands containing each biome type, and as a function of area (km^2) in the national parks analysis.

The vegetation modeling results for Canada's broader network of conservation lands revealed the potential for significant change under each of the climate change scenarios. The vegetation change analysis for each GVM is summarized separately below.

Using the MAPSS GVM, 28% to 48% of the 2,979 conservation lands analyzed were projected to experience a change in biome type under the four climate change scenarios. The United Kingdom Meteorological Office (UKMO) scenario (which is the warmest climate change scenario used in this analysis) projected the greatest overall vegetation change, with nearly half (48%) of all conservation lands projected to experience a change in biome type. At the opposite end of the impact range, the Hadley Centre Coupled Ocean-Atmosphere (HadCM2) scenario projected that only 28% of Canada's total conservation lands could experience a change in biome type.

There were also notable variations in the proportionate change in each conservation land designation. Under all four MAPSS scenarios, Canada's national parks were consistently projected to experience the greatest change in biome type, ranging from 47% in the HadCM2 scenario to 61% in the UKMO scenario. Migratory Bird Sanctuaries slightly edged out National Wildlife Areas as the conservation land designation projected to experience the least change in modeled biome type. System wide, between 17% (HadCM2 scenario) and 50% (Geophysical

Fluid Dynamics Laboratory [GFDL] scenario) of Migratory Bird Sanctuaries were projected to experience a biome type change.

The BIOME3 modeling results showed similar differences between GVMs and among conservation land designations. Approximately 37% (Max Planck Institute for Meteorology [MPI] scenario) to 48% (HadCM2) of the 2,979 conservation lands analyzed were projected to experience a change in biome type under the two BIOME3 scenarios. Provincial parks were projected to experience the greatest change in biome type under the BIOME3 scenarios, with the HadCM2 scenario projecting 70% change and the MPI projecting 54% change. National Wildlife Areas were projected to experience the least biome type change under the BIOME3 scenarios (18% - HadCM2 and 30% - MPI).

In terms of potential changes in the representation of the biome classifications in Canada's network of conservation lands, more northern biomes (tundra, taiga/tundra and boreal conifer forest) were projected to decrease as a result of the overall contraction of these biomes in Canada. For example, the loss of tundra representation was projected under all four MAPSS scenarios and ranged from 38% (HadCM2) to 79% (UKMO) fewer conservation lands. In contrast, representation of more southern biomes was generally projected to increase in the network of conservation lands under MAPSS climate change scenarios. The results for the temperate evergreen forest projected a 3% (GFDL) to 46% (Goddard Institute for Space Studies [GISS]) increase in the number of conservation lands.

BIOME3 modeling results displayed similar changes in biome representation among Canada's network of conservation lands, with the more northern biome type classifications (tundra, taiga/tundra and boreal conifer forest) projected to experience decreased representation under both HadCM2 and MPI scenarios. Both scenarios projected over a 50% reduction in the number of conservation lands representing each of the three northern biomes (tundra: HadCM2 –67%, MPI –72%; taiga/tundra: HadCM2 –57%, MPI –53%; boreal conifer forest – HadCM2 -78%, MPI –54%).

Regardless of the GVM and climate change scenario used, the vegetation modeling results showed the potential for substantial change in biome representation in Canada's national park system. All four MAPSS-based scenarios resulted in at least one new biome type appearing in most of national parks (55-61% of parks); the BIOME3 results showed slightly fewer parks with a new biome appearing (39-50% of parks). When a second important metric of potential vegetation change was examined; namely, the proportion of grid boxes that changed from one biome to another, the results were equally notable. Under all of the MAPSS scenarios, changes were projected in greater than half of all vegetation grid boxes in the majority of national parks (18 to 21 of the 36 parks analyzed). The BIOME3 results also projected changes, but to a lesser degree; only 15 to 17 of 36 parks analyzed displaying biome change in greater than half of their grid boxes.

Across the entire national park system, there was general agreement among the six climate change scenarios with respect to the nature of the biome representation change. All six climate change scenarios projected a decline in representation of tundra. The taiga/ tundra biome, which was only modeled with the MAPSS GVM, also showed a consistent decline. Results for boreal representation were mixed when examined separately in the four MAPSS scenarios, with two scenarios projecting no change (UKMO) to a slight decline in proportional representation (from 27% to 26% [GISS] of area) and two scenarios projecting increased representation (from 27% to 30% [HadCM2] and 34% [GFDL] of area). The proportional representation of temperate forests increased in all MAPSS scenarios, while savanna/woodland increased in two scenarios and remained the same in two others. The relative proportion of both temperate mixed forest and savanna/woodland increased substantially in the BIOME3 scenarios as well, but unlike the MAPSS results, temperate evergreen forest was projected to decline slightly (from 4% to 1% [HadCM2] to 2% [MPI] of area).

It must be emphasized that although the results of the equilibrium GVMs used in this analysis indicate the potential for substantial biome change in Canada's national parks and broader conservation lands, these results should be considered suggestive of the potential magnitude of vegetation change rather than predictive of the eventual distribution and composition of biomes in Canada. Equilibrium GVMs do not model the transient response of vegetation to climate change and but rather simulate a fully equilibrated vegetation distribution for a given scenario of future climate which would likely occur over 200-500 years. GVMs model potential natural vegetation and do not take into account human land use patterns or the many other human-induced environmental stresses that might hinder natural vegetation migration and other natural adaptation processes. Considering the limitations of equilibrium GVMs, the actual vegetation composition and distribution found under the changed climatic conditions of the late 21st century may be different than the potential vegetation modelled in this analysis. Nonetheless, the magnitude of biome change in Canada's conservation lands projected in each scenario should be considered indicative of the risk posed by climate change and the inherent uncertainty in GVM scenarios should not be misinterpreted to mean that a 'no-change' scenario is a potential outcome of climate change. A number of international research teams are working on a new generation of Dynamic Global Vegetation Models (DGVMs) to address some of the limitations of equilibrium GVMs, but DGVMs remain in various stages of development and have not yet been validated and run in Canada.

On November 25, 1992, the Canadian Parks Ministers Council met jointly with the Canadian Council of Ministers of the Environment and the Wildlife Ministers Council of Canada in Aylmer, Quebec. At the meeting, each Council signed *A Statement of Commitment to Complete Canada's Networks of Protected Areas*. Most jurisdictions in Canada have adopted some type of ecoregion or biogeoclimatic land classification framework as the main system-planning tool for their terrestrial protected area system. These system plans were developed with the assumptions of climatic and biogeographic stability. These assumptions are tenuous under climate change and the idea of planning and management of a steady-state protected area system therefore requires reconsideration.

Although significant knowledge gaps related to ecosystem response to climate change remain, the preceding analysis illustrated that the biome composition of Canada's existing conservation lands and national parks could differ substantially under the climate change scenarios examined. New ecological communities will not equilibriate quickly and the latter part of this next century is therefore likely to be characterized by ecological communities in transitionary stages. The IPCC compiled evidence from a wide range of studies that indicate physical systems and some species are already responding to on-going climate change. In a changing climate, conservation planning based on protecting representative samples of natural areas will have to address the fundamental problem of defining what is to be considered a 'representative natural area' in an era characterized by transitory ecosystems.

Policy and planning sensitivities also exist for the management of individual protected areas. For example, each of Canada's national parks is responsible for protecting ecosystems representative of the natural region within which they are located. The management plan of each individual park defines the purpose of the park. For example, the stated purpose of Riding Mountain National Park (RMNP) is to, "Protect for all time the ecological integrity of a natural area … representative of the boreal plains and mid-boreal uplands." All six vegetation modelling scenarios in this analysis projected the eventual loss of boreal forest in this park, suggesting that the park's mandate could be untenable in the long-term. A review of approved management plans from several national parks revealed additional climate change sensitivities at the individual park level. These included wildfire fire management strategies, individual species management plans and contingencies for species at risk, non-native species management programs, and species reintroduction programs.

These policy and planning sensitivities highlight fundamental questions regarding the role of protected areas in an era of climate change. Are protected areas to continue to protect a representative sample of current ecosystems, or will the conservation agencies become dedicated to the function of assisting ecosystems to adapt to climate change (or could both approaches be integrated into a coherent response strategy)?

Climate change represents an unprecedented challenge for the agencies responsible for the planning and management of Canada's conservation lands. If Canada's system of conservation lands continues to be managed without contingencies for climatic change, the intergenerational conservation legacy of the parks system could be diminished. The issues related to the strategic response of conservation agencies to the challenge of climate change are very complex and deserve further elaboration than that provided here. There is a strong need for participatory dialogue among conservation stakeholders on the implications of climate change and the development of adaptation strategies.

Sommaire

Le Groupe intergouvernemental d'experts sur l'évolution du climat (GIEC) et les 185 États signataires de la Convention-cadre des Nations Unies sur les changements climatiques (CCNUCC) reconnaissent que le changement climatique est une préoccupation mondiale. L'article 2 de la CCNUCC, 1997, traduisait le lien critique entre le changement climatique et la biodiversité en ces termes : « L'objectif ultime de la présente Convention… est de stabiliser les concentrations de gaz à effet de serre dans l'atmosphère à un niveau qui empêche toute perturbation anthropique dangereuse du système climatique. Il conviendra d'atteindre ce niveau dans un délai suffisant pour que les écosystèmes puissent s'adapter naturellement aux changements climatiques… ». Le GIEC a également commandé un document technique spécial sur le changement climatique et la biodiversité, qui indiquait que le changement climatique constituait une menace importante pour la biodiversité de la planète et apportait des preuves de variation écologique découlant du changement climatique survenu au cours du siècle dernier.

Au 4[e] Congrès mondial sur les parcs nationaux et les aires protégées, l'Union mondiale pour la nature (UICN 1993) concluait en disant que le changement climatique représente une menace importante et pressante pour tous les écosystèmes et que les aires protégées existantes ne pourront peut-être pas assurer de façon adéquate la survie des espèces et des écosystèmes existants dans un monde en mutation. Toutefois, relativement peu d'évaluations de changement climatique ont appliqué les projections des répercussions biophysiques aux réseaux existants d'aires protégées et un nombre encore moins grand en ont examiné les répercussions sur la politique, la planification et la gestion dans les cadres institutionnels existants.

Des données paléoécologiques et des données d'observation révèlent que la distribution des écosystèmes terrestres est avant tout déterminée par les facteurs climatiques. Les études de modélisation climat-végétation qui examinent les répercussions du changement climatique sur la végétation terrestre au Canada ont toujours prévu d'importants changements des types de végétation dans une grande partie du pays.

Le présent rapport examine les répercussions potentielles des altérations du paysage sur la distribution de la végétation à la suite du changement climatique prévu au chapitre de la représentation des biomes dans le grand réseau des terres protégées du Canada (qui comprend les parcs provinciaux, les refuges d'oiseaux migrateurs, les réserves nationales de faune, les sites Ramsar, les réserves écologiques, les aires de nature sauvage et les zones de protection de la faune) et dans le réseau des parcs nationaux en particulier. C'est la première étude qui applique formellement les résultats des modèles de végétation mondiale (MVM) d'équilibre au réseau des aires protégées d'un pays. L'étude examine ensuite les résultats des MVM d'équilibre BIOME3 et MAPSS (Mapped – Atmosphere – Plant – Soil System) conjugués à cinq scénarios de changement climatique découlant des modèles de circulation générale (MCG). Le rapport traite en outre de certains défis que les répercussions des changements de paysage sur la végétation peuvent poser aux cadres d'action et de planification des organismes fédéraux et provinciaux responsables du réseau des aires protégées du Canada.

Les scénarios de changement de la végétation aux fins de la présente analyse reposaient sur les résultats de la modélisation obtenus pour le Groupe de travail 2 du GIEC. Les catégories de végétation plus détaillées du MAPSS et du BIOME3 (45 et 18 catégories de végétation respectivement) ont été regroupées en 10 catégories de biome de façon à ce qu'on puisse comparer les résultats des deux MVM. Les différences de structure des MVM et leur réaction différente au changement climatique dans des études comparatives antérieures ont nécessité l'utilisation de deux MVM pour mieux représenter l'éventail des hypothèses et des incertitudes scientifiques ayant trait à la réaction de la végétation face au changement climatique. Conformément aux recommandations du GIEC, de nombreux scénarios de changement climatique ont été utilisés conjointement avec les modèles de végétation pour représenter un éventail de situations climatiques futures plausibles.

Le rapport présente les résultats de deux analyses distinctes. La méthode du système d'information géographique (SIG) utilisée pour évaluer le changement de la végétation dans le grand réseau des terres protégées du Canada différait légèrement de l'analyse plus détaillée du réseau des parcs nationaux. Il n'y avait pas de fichiers des limites SIG pour l'ensemble des terres protégées au Canada et, pour assurer l'utilisation d'une méthode uniforme dans l'ensemble du pays, on a eu recours à des géocentroïdes pour représenter 2 979 terres protégées dans l'analyse SIG. Les fichiers des limites des parcs nationaux fournis par Parcs Canada ont permis de faire une analyse par secteur plus détaillée des parcs nationaux. Toutes les terres protégées qui avaient une certaine importance écologique ont été incluses dans la grande analyse des terres protégées. Les lieux historiques et les aires marines protégées ont toutefois été exclus. Au départ, les 39 parcs nationaux et réserves de parc national désignés faisaient partie de l'analyse du réseau des parcs nationaux, mais trois d'entre eux (Pacific Rim, Gwaii Haanas, Quttinirpaaq), où la majorité des cellules de la grille de végétation correspondaient à de l'eau ou à des glaciers, ont été exclus de l'analyse. Toutes les terres protégées et les parcs nationaux ont été superposés à des couches de distribution de la végétation dans un SIG (végétation actuelle et tous les scénarios de changement climatique), puis le changement de végétation de chaque terre protégée a été examiné. L'étude a également examiné comment la représentation des biomes allait changer dans chaque désignation de terre protégée et dans le réseau des parcs nationaux. Dans la grande analyse des terres protégées, cela a été établi comme étant une fonction du nombre de terres protégées renfermant chaque type de biome et dans l'analyse des parcs nationaux, comme une fonction de la superficie (km^2).

Les résultats de la modélisation de la végétation pour le grand réseau des terres protégées du Canada ont révélé dans chacun des scénarios de changement climatique qu'un changement important pouvait survenir. L'analyse du changement de la végétation pour chaque MVM est résumée séparément ci-après.

L'utilisation du MVM du MAPSS a permis de prévoir qu'entre 28 et 48 p. 100 des 2 979 terres protégées analysées connaîtraient un changement de type de biome d'après les quatre scénarios de changement climatique. Le scénario du United Kingdom Meteorological Office (UKMO) (qui est le scénario de changement climatique le plus chaud utilisé dans le cadre de l'analyse) prévoyait le plus grand changement de végétation global où près de la moitié (48 %) des terres protégées devraient connaître un changement de type de biome. À l'autre extrémité de la gamme des répercussions, le deuxième scénario couplé océan-atmosphère du Hadley Centre (HadCM2) prévoyait que seulement 28 p. 100 de toutes les terres protégées du Canada pourraient connaître un changement de type de biome.

Il y avait également des écarts notables dans le changement relatif dans chaque désignation de terre protégée. Selon les quatre scénarios du MAPSS, les parcs nationaux du Canada devraient tous connaître le plus grand changement de type de biome, soit 47 p. 100 pour le scénario HadCM2 et 61 p. 100 pour le scénario du UKMO. Les refuges d'oiseaux migrateurs supplantaient légèrement les réserves nationales de faune pour ce qui est du plus petit changement de type de biome que devraient connaître les terres protégées. Dans l'ensemble du réseau, on prévoyait qu'entre 17 p. 100 (scénario HadCM2) et 50 p. 100 (scénario du Geophysical Fluid Dynamics Laboratory [GFDL]) des refuges d'oiseaux migrateurs connaîtraient un changement de type de biome.

Les résultats de la modélisation BIOME3 présentaient des différences similaires entre les MVM et dans les désignations de terre protégée. Entre 37 p. 100 (scénario du Max Planck Institute for Meteorology [MPI]) et 48 p. 100 (HadCM2) environ des 2 979 terres protégées analysées devraient connaître un changement de type de biome selon les deux scénarios BIOME3. Les parcs provinciaux devraient connaître le plus grand changement de type de biome selon les scénarios BIOME3, le scénario HadCM2 prévoyant un changement de 70 p. 100 et le scénario MPI, un changement de 54 p. 100. Ce sont les réserves nationales de faune qui devraient connaître le changement de type de biome le moins important selon les scénarios BIOME3 (18 % - HadCM2 et 30 % - MPI).

En ce qui a trait aux changements possibles de la représentation des catégories de biome dans le réseau des terres protégées du Canada, les biomes plus au nord (toundra, taïga/toundra et forêt boréale de conifères) devraient diminuer en raison de leur rétrécissement global au Canada. Par exemple, les quatre scénarios du MAPSS prévoient une diminution de la représentation de la toundra et une diminution des terres protégées variant de 38 p. 100 (HadCM2) à 79 p. 100 (UKMO). Par contre, la représentation des biomes plus au sud devrait en général augmenter dans le réseau des terres protégées selon les scénarios de changement climatique du MAPSS. Quant à la forêt tempérée de résineux, elle devrait connaître une augmentation allant de 3 p. 100 (GFDL) à 46 p. 100 (Goddard Institute for Space Studies [GISS]) dans le nombre des terres protégées.

Les résultats de la modélisation BIOME3 indiquaient des changements similaires au chapitre de la représentation des biomes dans le réseau des terres protégées du Canada, les biomes les plus au nord (toundra, taïga/toundra et forêt boréale de conifères) devant connaître une représentation moindre selon les scénarios HadCM2 et MPI. Les deux scénarios prévoyaient une diminution supérieure à 50 p. 100 du nombre de terres protégées représentant chacun des trois biomes boréaux (toundra : HadCM2 – 67 %, MPI – 72 %; taïga/toundra : HadCM2 – 57 %, MPI – 53 %; forêt boréale de conifères – HadCM2 – 78 %, MPI – 54 %).

Quel que soit le scénario de changement climatique et le MVM utilisé, les résultats de la modélisation de la végétation ont révélé la possibilité que la représentation des biomes dans le réseau des parcs nationaux du Canada connaisse un changement important. Les quatre scénarios reposant sur le MAPSS ont révélé l'apparition d'au moins un nouveau type de biome dans la plupart des parcs nationaux (55 à 61 % des parcs); quant aux résultats du BIOME3, ils ont révélé l'apparition d'un nouveau biome dans un nombre légèrement moins élevé de parcs (39 à 50 % des parcs). L'examen d'une deuxième mesure importante du changement de végétation possible, notamment la proportion de cubes de la grille variant d'un biome à l'autre, donnait des résultats tout aussi remarquables. Selon tous les scénarios du MAPSS, des changements étaient prévus dans plus de la moitié des cubes de la grille de végétation dans la majorité des parcs nationaux (entre 18 et 21 des 36 parcs analysés). Les résultats du BIOME3 prévoyaient également des changements, mais dans une mesure moindre. En effet, entre 15 et 17 parcs seulement sur les 36 analysés présentaient un changement de biome dans plus de la moitié des cubes de la grille.

Dans l'ensemble du réseau des parcs nationaux, les six scénarios de changement climatique concordaient quant à la nature du changement de représentation des biomes. En effet, les six scénarios de changement climatique prévoyaient une diminution de la représentation de la toundra. Le biome taïga/toundra, qui a été modélisé uniquement avec le MVM du MAPSS, présentait lui aussi une diminution régulière. Les résultats concernant la représentation de la forêt boréale étaient variables lorsqu'on les examinait séparément d'après les quatre scénarios du MAPSS : un scénario ne prévoyait aucun changement (UKMO), un autre prévoyait une légère diminution de la représentation proportionnelle (de 27 à 26 % de la région [GISS]) et deux scénarios prévoyaient une augmentation de la représentation (de 27 % à 30 % [HadCM2] et à 34 % [GFDL] de la région). La représentation proportionnelle des forêts tempérées augmentait dans tous les scénarios du MAPSS alors que celle de la savane/forêt-parc augmentait dans deux scénarios et demeurait la même dans les deux autres. La proportion relative de la forêt mixte tempérée et de la savane/forêt-parc augmentait considérablement dans les scénarios BIOME3 également, mais contrairement aux résultats du MAPSS, la forêt tempérée de résineux connaissait une légère diminution (de 4 % à 1 % [HadCM2] et à 2 % [MPI] de la région).

Il importe de souligner que même si les résultats des MVM d'équilibre utilisés dans la présente analyse indiquent la possibilité d'un changement important de biome dans les parcs nationaux du Canada et dans l'ensemble des terres protégées, on doit les considérer comme étant indicatifs de l'importance possible du changement de végétation plutôt que prédictifs de la distribution et de la composition éventuelles des biomes au Canada. Les MVM d'équilibre ne représentent pas la réaction transitoire de la végétation au changement climatique, mais simulent plutôt une distribution de végétation entièrement équilibrée pour un scénario donné de climat qui marquerait les 200 à 500 ans à venir. Les MVM représentent la végétation naturelle potentielle et ne tiennent pas compte des modèles d'aménagement du territoire par les humains ou des nombreux autres stress environnementaux causés par les humains qui pourraient entraver la migration de la végétation naturelle et d'autres processus d'adaptation naturels. Compte tenu des limites des MVM d'équilibre, la composition et la distribution réelles de la végétation suivant le changement des conditions climatiques de la fin du XXI[e] siècle peuvent être différentes de la végétation potentielle modelée dans la présente analyse. Néanmoins, l'importance du changement des biomes dans les terres protégées du Canada prévu dans chaque scénario devrait être considérée comme étant une indication du risque que pose le changement climatique, et l'incertitude inhérente des scénarios de MVM ne devrait pas être interprétée à tort comme une possibilité que le changement climatique n'entraîne aucune modification. Un certain nombre de groupes de recherche internationaux cherchent à produire une nouvelle génération de modèles de végétation mondiale dynamique (MVMD) pour trouver une solution à certaines des limites des

MVM d'équilibre, mais les MVMD en sont à divers stades d'élaboration et n'ont pas encore été validés ni utilisés au Canada.

Le 25 novembre 1992, le Conseil canadien des ministres des Parcs s'est réuni avec le Conseil des ministres de l'Environnement et le Conseil des ministres de la Faune du Canada à Aylmer (Québec). Chaque conseil a alors signé un *Engagement formel de compléter le réseau canadien des aires protégées*. La plupart des gouvernements au Canada ont adopté un certain type de cadre de classification biogéoclimatique des terres ou par écorégion comme outil principal de planification de leur réseau d'aires protégées terrestres. Ces plans de réseau ont été élaborés en supposant une stabilité climatique et biogéographique. Ces hypothèses sont fragiles en raison du changement climatique et l'idée de planifier et de gérer un réseau d'aires protégées stable mérite donc d'être revue.

Bien qu'il manque encore beaucoup de données concernant la réaction des écosystèmes au changement climatique, l'analyse qui précède a montré que la composition des biomes des terres protégées du Canada et des parcs nationaux pouvait varier considérablement selon les scénarios de changement climatique examinés. Les nouvelles biocénoses n'atteindront pas rapidement l'équilibre et la dernière partie du présent siècle est donc susceptible de se caractériser par des biocénoses se trouvant à des étapes de transition. Le GIEC a rassemblé des preuves tirées d'un large éventail d'études qui indiquent que les systèmes physiques et certaines espèces réagissent déjà au changement climatique en cours. Avec l'évolution du climat, la planification de la conservation axée sur la protection d'exemples représentatifs des aires naturelles devra aborder le problème fondamental de la définition « d'aire naturelle représentative » à une époque caractérisée par des écosystèmes en transition.

Il existe également des questions délicates concernant la politique et la planification de gestion de certaines aires protégées. Par exemple, chacun des parcs nationaux du Canada doit protéger des écosystèmes représentatifs de la région naturelle où ils se trouvent. Le plan directeur de chaque parc définit le mandat du parc. Par exemple, le parc national du Mont-Riding a pour mandat « de protéger à jamais l'intégrité écologique… de la région naturelle des plaines et des plateaux boréaux. » Les six scénarios de modélisation de la végétation mentionnés dans la présente analyse ont prévu la perte éventuelle d'une forêt boréale dans ce parc, laissant croire que le mandat du parc ne pourra être réalisé à long terme. Un examen des plans directeurs approuvés de plusieurs parcs nationaux a révélé d'autres éléments sensibles au changement climatique dans chaque parc. Citons notamment les stratégies de lutte contre les incendies de forêt, les plans de gestion de différentes espèces et les mesures d'urgence pour les espèces en péril, les programmes de gestion des espèces exotiques et les programmes de réintroduction des espèces.

Ces points sensibles de la politique et de la planification mettent en lumière des questions fondamentales concernant le rôle des aires protégées à une époque de changement climatique. Les aires protégées continueront-elles de protéger un exemple représentatif des écosystèmes actuels ou les organismes de conservation devront-ils aider les écosystèmes à s'adapter au changement climatique? Peut-être que ces deux fonctions pourraient être intégrées dans une stratégie harmonieuse d'adaptation au changement climatique.

Le changement climatique pose un défi sans précédent aux agences responsables de la planification et de la gestion des terres protégées du Canada. Si le réseau des terres protégées du Canada continue d'être gérées sans qu'on tienne compte du changement climatique, la conservation du réseau des parcs pour les générations à venir pourrait en souffrir. Les problèmes liés à l'intervention stratégique des agences de conservation face au défi du changement climatique sont très complexes et méritent qu'on y réfléchisse davantage qu'on ne le fait ici. Les intervenants en conservation doivent absolument amorcer un dialogue concerté sur les répercussions du changement climatique et l'élaboration de stratégies d'adaptation.

1.0 Introduction

Global climate change is likely to be one of the most significant environmental issues during the 21^{st} century. It has been recognised as a global concern by the Intergovernmental Panel on Climate Change (IPCC) and by the 185 nations that have ratified the United Nations Framework Convention on Climate Change (UNFCCC). The IPCC Third Assessment Report (TAR) (IPCC 2001a) has projected global annual mean temperatures to increase by 1.4 to 5.8^0C over the period of 1990 to 2100. Warming is expected to be more pronounced at northern high latitudes. In Canada for example, twenty-five (warm start coupled) General Circulation Model scenarios projected annual mean temperature increases in the 2080s of 2.7 – 7.4^0C in the central interior of the country and 4.6 – 10.9^0C in the Arctic (Canadian Climate Impacts Scenarios Project 2002).

The international community has recognized the significance of global climate change for ecosystem change and biodiversity. The UNFCCC (1997-Article 2) articulated the critical linkage between the magnitude and rate of climate change and the natural capacity of ecosystems to adapt: "The ultimate objective of this convention is to achieve stabilization of greenhouse gas concentrations in the atmosphere at such a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change..." However, the international community has yet to identify and agree upon an upper limit for greenhouse gas concentrations that would avoid irreversible biological change. The IPCC also commissioned a special technical paper on climate change and biodiversity (IPCC 2002), which recognized climate change as a key threat to global biodiversity and noted evidence of ecological change as a result of climate change that occurred in the 20^{th} century.

For more than a decade, climate change has been identified as an important emerging issue for protected areas. Peters and Darling (1985), Graham (1988), and Peters and Lovejoy (1992) were among the first to examine the implications of climate change for conservation. At the fourth World Congress on National Parks and Protected Areas, the International Union for the Conservation of Nature (IUCN 1993:28) concluded, "Climatic change represents a critical and urgent threat to all ecosystems … (and that) Existing … protected areas may not provide adequate future safeguards for the continued survival of existing ecosystems and species in a changing world."

Nonetheless, comparatively few climate change assessments have applied biophysical impact projections to existing protected area systems (Halpin 1997; Viller-Ruiz and Trejo-Vazques 1998; and Scott and Suffling 2000 are some exceptions); even fewer (see Scott and Suffling 2000, and Scott et al. 2002) have explicitly examined the implications of climate change for policy implementation and practical management within existing institutional contexts. While our understanding of the potential impacts of climate change on biophysical systems and biodiversity continues to improve, few linkages with conservation practitioners are being made. An understanding of the vulnerabilities of existing protected area conservation policies and planning frameworks is essential to advancing practical development of climate change adaptation strategies.

Paleoecolgoical and observational evidence indicate that the distribution of terrestrial ecosystems is primarily determined by climatic factors, particularly temperature and precipitation (Woodward 1987). As climatic zones change, so too does the distribution and composition of ecosystems. In order to explore the potential impact of climate change on ecosystem distribution and biodiversity, both the IPCC Second Assessment (Neilson 1998) and the US National Assessment on Climate Change (National Assessment Synthesis Team 2000) utilized Global Vegetation Models (GVMs) to model potential changes in the distribution of major vegetation types (biomes[1]). These process-based vegetation models are essential for assessments of potential future vegetation distribution in North America because the climate change scenarios for the 21st century are distinct from the climate of the past 18,000 years and therefore appropriate vegetation analogues are not available (Overpeck et al. 1992).

Similar climate-vegetation modelling efforts to examine the impacts of climate change on terrestrial vegetation in Canada have consistently projected major shifts in vegetation types over much of the country. Rizzo and Wiken (1992) used a climate-vegetation classification model to examine spatial shifts in ten ecoclimatic provinces under two doubled-CO_2 scenarios and found that the boreal forest was reduced from 28.9% of the land area to 14.9% and was displaced northward by an average of 500 km. Similarly, the arctic and subarctic provinces were diminished from 26.1% and 20% of Canada, to 20.2% and 7.8% respective, including the displacement of subarctic in Quebec and Labrador by boreal forest. Cool temperate forests expanded over much of eastern Canada south of James Bay, with total land area increasing from 4% to 15.2%. Grasslands expanded throughout the Prairie region (an increase of 6.9% in land area) and a semi-desert zone emerged in southern Saskatchewan and Alberta.

A regional analysis of climate change implications for forests in Western Canada (Hogg and Hurdle 1995) revealed that 50% of the boreal forest in Alberta-Saskatchewan-Manitoba could experience a drier climate regime similar to that of the current Aspen Parkland in the region. As a result, much of the lowland boreal forest was projected to degrade into mixed forest remnants and grassland. Subsequent analysis by Henderson et al. (2003) concluded that the valuable island forests of the Prairies are at significant risk to climate change.

Using a similar type of vegetation change analysis based on climate-pollen response surfaces, Overpeck et al. (1991) found that some vegetation ranges and abundance maxima in Eastern North America could shift as much as 500-1000km in the next 200-500 years. They also concluded that potential vegetation change in the next 200-500 years could exceed the total

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[1] The IPCC (IPCC 2002: 76) defined a biome as ‘a grouping of similar plant and animal communities into broad landscape units that occur under similar environmental conditions.’ Biomes (also referred to as ecozones) are at the top of the ecological hierarchy and represent large-scale and very generalized climatic and physiographic features. Each biome is subdivided into a number of ecoprovinces, which are characterized by a unique combination of landforms, soil types, climate, vegetation and animal communities. Ecoprovinces are further divided into ecoregions (also called natural regions), ecosections and biogeoclimatic zones (Demarchi, 1996). The biogeoclimatic zone system, developed initially to serve forestry, defines zones, subzones and variants based on the biological communities that can develop within the constraints of climate and geography (Meidinger 1997).

vegetation change that occurred over the past 10,000 years during the glacial-interglacial transition.

Lenihan and Neilson (1995) used their Canadian Climate-Vegetation Model (CCVM) to investigate the potential response of natural vegetation to two doubled-CO_2 climate scenarios. The vegetation formations generated under the GISS and GFDL climatic scenarios exhibited broad agreement for some vegetation formations and disagreement for others. Under both scenarios, CCVM predicted reductions in the extent of the tundra and subarctic woodland formations, a northward shift and some expansion in the distributions of boreal and temperate forest, and an expansion of the dry woodland and prairie formations. Conversely, where the GFDL scenario projected a northward shift and expansion of the boreal forest, the GISS scenario projected negligible expansion of boreal forests and sizable expansions of temperature forests.

Malcolm and Markham (2000) used the results of 14 combinations of seven GCM experiments and two equilibrium global vegetation models (BIOME3 and MAPSS) generated by the IPCC (Neilson 1998) to examine global vegetation distribution under doubled-CO_2 conditions. Canada's high-latitude land area was more vulnerable to vegetation change than most other nations. Averaged across the 14 scenarios, 46.3% of Canada's map cells were projected to experience a biome change. Six provinces and one territory were projected to experience biome change in excess of 50% (Yukon Territory – 64.1%, Newfoundland and Labrador – 63.6%, British Columbia – 60.4%, Ontario – 61.4%, Quebec – 59.5%, Alberta – 56.4%, and the Manitoba – 52.9%). With the exception of the Northwest Territories (33% biome change), the Atlantic Provinces were consistently projected to experience the least biome change among provinces (PEI – 0%, Nova Scotia – 34.2%, New Brunswick – 44.7%).

This report examines the potential impacts of large-scale climate change related alterations in biome distribution for biome representation in Canada's broad network of conservation lands (including provincial parks, Migratory Bird Sanctuaries, National Wildlife Areas, Ramsar sites, ecological reserves, and wilderness and wildlife protected areas) and the national park system in particular. This is the first study to explicitly apply GVM outputs to the network of protected areas in any country. Using the results of two GVMs run with five climate change scenarios that were derived from General Circulation Models, the report explores some of the challenges that landscape level vegetation changes might pose for the policy and planning frameworks of the federal and provincial agencies responsible for Canada's network of protected areas.

2.0 Methodology

2.1 Methodological Overview

The vegetation change scenarios for our analysis were based on modelling results developed for the IPCC-Working Group 2 (Neilson 1998) and Malcolm and Markham (2000). The two GVMs used were BIOME3 (Haxeltine and Prentice 1996) and MAPSS (Neilson 1995). Both are equilibrium process-based models that simulate the potential distribution of generalized types of natural vegetation on the basis of the physiological properties of plants, average seasonal climate and hydrological conditions. Equilibrium GVMs do not simulate the transitional response of vegetation to climate changes, but rather depict vegetation distributions once vegetation has stabilized under changed climate conditions (in this case doubled-CO_2 scenarios). A concise comparison of the vegetation discrimination criteria and ecophysiological processes modeled by BIOME3 and MAPSS is provided in Peng (2000: 43). The GVM results used here all included the direct physiological effects of elevated CO_2 (increased water use efficiency by plants).

Although BIOME3 and MAPSS models are capable of more detailed representation of vegetation types (18 and 45 vegetation classifications respectively), for the purposes of both the analysis of biome change in Canada's broader conservation lands and the national parks specific analysis, vegetation classifications were aggregated into common biome classifications so that the results of the two GVMs would be comparable. The nine vegetation classifications used in this analysis are described in Table 2.1. Further, where a biome change was projected it would signify a major ecological change in the region that would have substantive implications for the conservation of current biodiversity.

It is important to note that the vegetation classifications used in the analysis of Canada's broader conservation lands differed slightly from the more detailed national parks assessment. The analysis of Canada's broader network of conservation lands used the vegetation classification scheme developed by Malcolm and Markham (2000) for their analysis of vegetation change across Canada's entire land area. In their vegetation classification for the BIOME3 model, Malcolm and Markham (2000: 22) differentiated between the two biomes by including boreal deciduous forest/woodland for the taiga/tundra biome and boreal evergreen forest for the boreal conifer forest biome. The national park assessment was designed to be consistent with IPCC Working Group 2 assessment (Neilson 1998) and included the taiga/tundra classification in the boreal conifer forest for the BIOME3 model (Table 2.1).

Table 2.1 - Aggregated Vegetation Classifications Used in the GVM Analysis

Tundra
Tundra is defined as the treeless vegetation which extends beyond the tree line at high latitudes and altitudes regardless of whether it is dominated by dwarf shrubs or herbaceous plants. *BIOME3:* Arctic/alpine tundra, Polar desert *MAPSS:* Tundra, Ice

Taiga/Tundra
Taiga/Tundra is the broad 'ecotonal' region of open woodland, which occurs at higher latitudes or elevations beyond the 'closed' Boreal Forest. This type of vegetation classification is not explicitly simulated by BIOME3, but rather is included in Boreal Conifer Forest. Conservation Lands Analysis *BIOME3:* Boreal deciduous forest/woodland *MAPSS:* Taiga/Tundra National Parks Analysis *BIOME3*: no Taiga/Tundra classification *MAPSS:* Taiga/Tundra
Boreal Conifer Forest
Boreal Conifer Forest is the Taiga proper, i.e., relatively dense forest composed mainly of needle-leaved trees and occurring in cold-winter climates. Conservation Lands Analysis *BIOME3:* Boreal evergreen forest/woodland *MAPSS:* Forest Evergreen Needle Taiga National Parks Analysis *BIOME3*: Boreal evergreen and deciduous forest/woodland *MAPSS:* Forest Evergreen Needle Taiga
Temperate Evergreen Forest
Temperate Evergreen Forest encompasses the wet temperate and subtropical conifer forests of the Northwest in North America. *BIOME3:* Temperate/boreal mixed forest *MAPSS:* Forest Mixed Warm, Forest Evergreen Needle Maritime, Forest Evergreen Needle Continental
Temperate Mixed Forest
Temperate Mixed Forest includes pure temperate broadleaf forests, such as oak hickory, or beech-maple. It also includes mixtures of broadleaf and temperate evergreen types, such as the cool-mixed pine/fir and hardwood forests of the Northeast or the warm-mixed pine/hardwood forests of the Southeastern U.S. *BIOME3:* Temperate conifer forest, Temperate deciduous forest *MAPSS:* Forest Deciduous Broadleaf, Forest Mixed Warm, Forest Mixed Cool, Forest Hardwood Cool

Savanna/Woodlands
Savanna/Woodlands encompass all 'open' tree vegetation from high to low latitudes and elevations. The tropical dry savannas and drought deciduous forests are contained within this classification. So too are the temperate pine savannas and 'pygmy' forests and the aspen woodlands adjacent to the Boreal Forest. Fire can play an important role in maintaining the open nature of these woodlands; while, grazing can increase the density of woody vegetation at the expense of grass. *BIOME3:* Temperate broad-leaved evergreen forest, Tropical deciduous forest, Moist savannas, Tall grassland, Xeric woodlands/scrub *MAPSS:* Forest Seasonal Tropical, Forest Savannah Dry Tropical, Tree Savanna Deciduous Broadleaf, Tree Savanna Mixed Warm, Tree Savanna Mixed Cool, Tree Savanna Evergreen Needle Maritime, Tree Savanna Evergreen Continental, Tree Savanna PJ Continental, Tree Savanna PJ Maritime, Tree Savanna PJ Xeric Continental
Shrub/Woodlands
Shrub/Woodlands are distinguished from the Savanna/Woodlands by their lower biomass and shorter stature. This is a drier vegetation type than the Savanna/Woodlands and encompasses most semi-arid vegetation types from Chaparral to mesquite woodlands to cold, semi-desert sage shrublands. The actual vegetation associated with this type is very susceptible to variation depending on soils, topography, fire, grazing and land-use history. Distinctions between shrubsteppe and grassland are sometimes difficult to quantify, given that each usually contains elements of both grass and woody vegetation. The relative abundance of the two functional types is considerable in determining the classification, but there are no generally accepted rules to indicate how much woody vegetation is sufficient to label a region a shrubland, or conversely how much grass is required to label it a grassland. *BIOME3:* Short Grassland *MAPSS:* Chaparral, Open Shrubland No Grass, Broadleaf, Shrub Savanna Mixed Warm, Shrub Savanna Mixed Cool, Shrub Savanna Evergreen Micro, Shrub Savanna SubTropical Mixed, Shrubland SubTropical, (Mediteranean: Shrubland Temperate Conifer, Shrubland Temperate Xeromorphic Conifer, Grass Semi-desert C3, Grass Semi-desert C3/C4

Grasslands
Grasslands include both C3 and C4 grassland types in both temperate and tropical regions. Much of the grassland type is a 'fire climax' type that would be populated by shrubs either with the absence of fire, or with extensive grazing. *BIOME3:* Dry savannas, Arid shrubland/steppe *MAPSS:* Grassland Semi Desert, Grass Northern Mixed Tall C3, Grass Prairie Tall C4, Grass Northern Mixed Mid C3, Grass Southern Mixed Mid C4, Grass Dry Mixed Short C3, Grass Prairie Short C4, Grass Northern Tall C3, Grass Northern Mid C3, Grass Dry Short C3, Grass Tall C3, Grass Mid C3, Grass Short C3, Grass Tall C3/C4, Grass Mid C3/C4, Grass Short C3/C4, Grass Tall C4, Grass Mid C4, Grass Short C4
Arid Lands
Arid Lands encompass all regions drier than Grasslands, from hyper-arid to semiarid. The regions could be more or less 'grassy or 'shrubby' depending on disturbance and land-use history. *BIOME3:* Desert *MAPSS:* Shrub Savanna Tropical, Shrub Savanna Mixed Warm, Grass Semi-desert C4, Desert Boreal, Desert Temperate, Desert Subtropical, Desert Tropical, Desert Extreme

It is also noteworthy that when Malcolm et al. (2002) conducted a sensitivity analysis by examining both coarse vegetation classifications (see Table 2.1) and the original more detailed vegetation classifications (18 in BIOME3 and 45 in MAPSS), the latter revealed more pervasive vegetation change. The vegetation changes using the more detailed classification were however more subtle in nature (i.e., from a boreal evergreen to boreal deciduous forest/woodland rather than from a boreal forest to a grassland). Consequently, if the more detailed vegetation classes were applied to this analysis, we would anticipate projected vegetation change in Canada's protected areas to increase as well.

A comparison of BIOME2 and MAPSS over the coterminous United States (VEMAP Members 1995) determined that they were able to simulate current vegetation patterns with roughly equal success. The IPCC analysis (Neilson 1998: 447) found that at a global level BIOME3 and MAPSS performed similarly under current climate conditions, although each was better calibrated to their 'home' continents (Europe and North America respectively). The structural differences in the two GVMs and their different response sensitivities to climate change in previous inter-comparison studies (VEMAP Members 1995 and Neilson 1998), necessitated the use of the two GVMs to better represent the range of assumptions and scientific uncertainties related to vegetation response to climate change.

Consistent with IPCC recommendations, multiple climate change scenarios were used in combination with the vegetation models. Three equilibrium doubled-CO_2 GCM scenarios from the IPCC First Assessment Report (IPCC 1990: UKMO, GFDL-R30, and GISS) and two transient GCM scenarios from the IPCC Second Assessment Report (IPCC 1995: HadCM2-ghg and MPI-T106) were used in the analysis. The climate change scenarios, control climate, and interpolation procedures (to a 0.5^0 latitude-longitude resolution) are described in Neilson (1998).

In general, the transient GCMs used in the IPCC vegetation modelling analysis (Neilson 1998) projected less climate change than other GCMs in the IPCC Second Assessment Report (SAR). The GCM comparison in Table 2.2 illustrates that the global climate change projected by the HadCM2 scenario used in this analysis is conservative relative to the four other transient GCM scenarios provided in the lower portion of Table 2.2. The more recent IPCC Special Report on Emission Scenarios (SRES) further extended the upper bounds of greenhouse gas emissions and the range of projected global climate change (from 1.0 to 3.5^0C in SAR to 1.4 to 5.8^0C in TAR) (IPCC 2001a). Because the older equilibrium GCMs scenarios generally projected greater climate change (see UKMO in Table 2.2), they were retained in this analysis as illustrative of the magnitude of vegetation change that may result from the upper range of the newly available SRES-based climate change projections (i.e., A1F1, A1B or A2 scenarios in IPCC, 2001a).

Table 2.2 - General Circulation Model Comparison

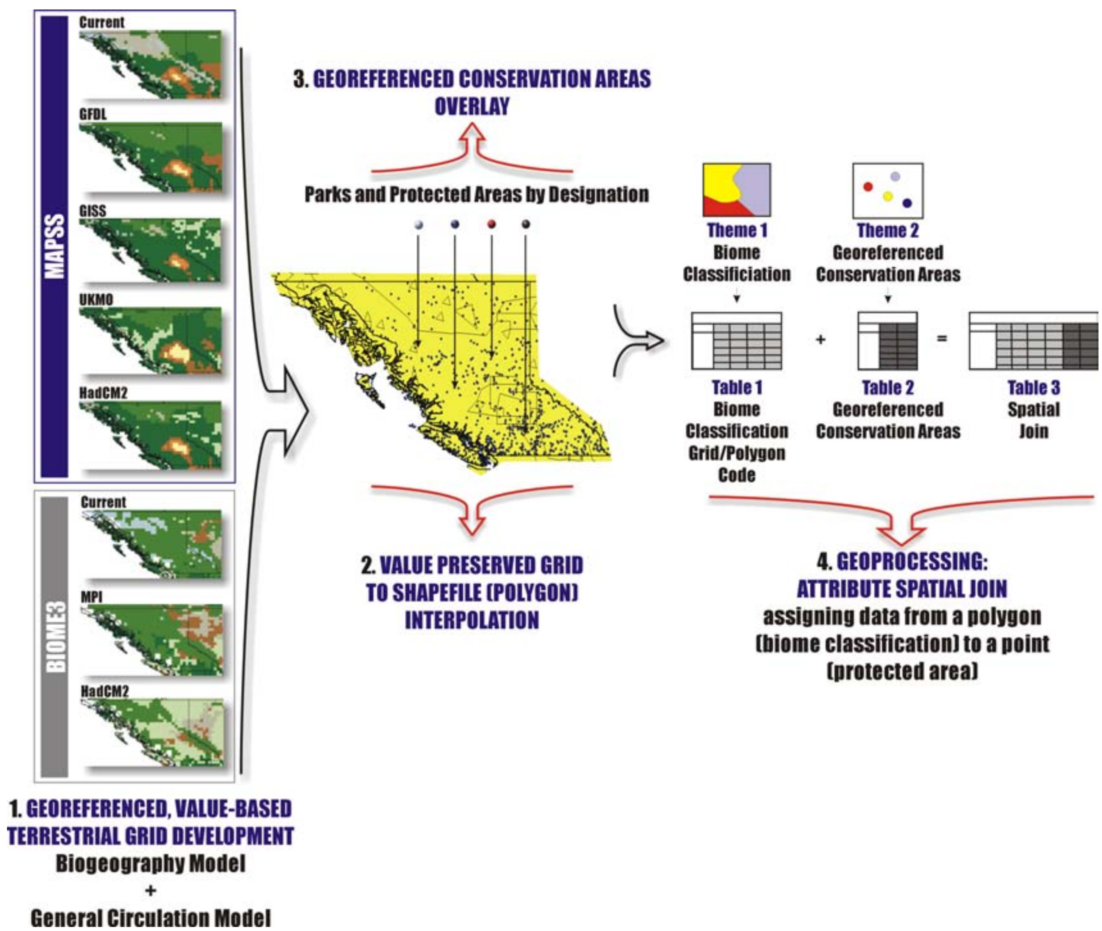
GCM	Characteristics *(see notes below)*	Projected Warming (^{0}C) Global	Canada [3]	Source
Climate Scenarios Used in this Analysis				
UKMO	E, ghg,	5.2^0C [1]	na	IPCC 1998 - Annex C
HadCM2	T, ghg	1.7^0C [1]	na	IPCC 1998 - Annex C
Climate Scenarios Not Used in this Analysis				
CGCM1	T, ga, X	3.8^0C [2]	5.6^0C [2]	CCIS 2002
HadCM2	T, ga, X	2.5^0C [2]	3.7^0C [2]	CCIS 2002
CCRS98	T, ga	na	6.8^0C [2]	CCIS 2002
CSIRvOMk2b	T, ga	2.7^0C [2]	4.9^0C [2]	CCIS 2002

E = Equilibrium, T = Transient, ghg = includes the forcing of greenhouse gases only, ga = includes the forcing of greenhouse gases and atmospheric aerosols, X = ensemble average (consists of a number of climate change scenarios undertaken with identical forcing scenarios, but slightly different initial starting conditions in the atmosphere and oceans),
1 – projected climate change at $2xCO_2$ levels
2 – projected climate change during 2070-99 time slice
3 – projected climate change over Canada's land area

2.2 Methodology for Canada's Conservation Lands Analysis

Figure 2.1 graphically summarizes the methodological framework developed for the broader conservation lands GIS analysis. GIS park boundary files were not available for all conservation lands; consequently park geocentroids were used to represent the 2,979 conservation lands so that a consistent methodology could be applied across Canada. Some protected areas in Canada are large enough to contain more than one grid cell at the spatial resolution utilized (0.5° latitude/longitude) for the vegetation modelling and therefore, the potential exists for more than one biome type to be present or for there to be only partial vegetation change under climate change scenarios (i.e., only 1 of 3 grid cells changes vegetation type). The availability of park boundary files for national parks facilitated more detailed area-based calculations for the national parks only. Thus, the national parks results presented in the broader conservation lands analysis

Figure 2.1 - Methodological Framework for Canada's Conservation Lands



(Source: Lemieux 2002)

is included mainly for comparative reasons and may be slightly dissimilar to those in the more detailed national parks boundary analysis which used area (defined by grid cells within park boundaries) to assess vegetation change in national parks.

Centroids for Canada's network of conservation lands were extracted from the Canadian Conservation Areas Database (CCAD). Natural Resource Canada's (NRCAN) GeoAccess Division and the Canadian Council on Ecological Areas (CCEA) developed the database in collaboration with the Canadian Wildlife Service's (CWS) Habitat Division and Parks Canada. This database was found to be partially incomplete with a number of protected areas, especially in British Columbia and Ontario (the two provinces with the greatest number of protected areas), missing. To conduct an analysis that was national in scope and as current as possible, government agencies were contacted to fill in data gaps on the conservation network[2]. Data obtained from these agencies was also forwarded to NRCAN to update the central database.

All conservation lands that had some degree of ecological importance were included in the analysis. Conservation lands not considered for this terrestrial vegetation analysis included historical sites and marine protected areas. Conservation land size and IUCN classification were not used as a basis for inclusion or exclusion, though this strategy may be useful for subsequent studies. The conservation land database was organized into specific designations (e.g., national parks, provincial parks, Migratory Bird Sanctuaries, National Wildlife Areas, Ramsar sites, ecological reserves, and wilderness and wildlife protected areas). Because provincial jurisdictions across Canada do not designate protected areas utilizing consistent terms, this analysis has combined designations based on like attributes such as legislation [the main piece(s) of authorizing legislation for the protected area(s)] and jurisdiction (managing authority). In the context of this analysis, Ecological Reserves refer to all ecological, biosphere and wildlife reserves, ecological/nature reserves, Man and Biosphere (MAB) reserves, conservation reserves, and representative area reserves, where applicable. Provincial Parks include all provincial wildlife areas and wildland provincial parks, where applicable. Finally, Wilderness and Wildlife Protected Areas refer to all wildlife refuges, wildlife protection areas, wildlife mitigation lands, wildlife management areas, wildlife reserves, wildlife parks, wildlife habitat protection lands, wilderness reserves, wilderness parks, wildlife development fund lands and wilderness areas, where applicable.

The terrestrial grids of each GVM were converted to value-preserved shape files (polygons) in order to utilize ESRI's Arcview Geoprocessing extension. This process of interpolation was essential due to the large number of conservation lands used in the analysis (2,979). Conservation land geocentroids were then superimposed on the five MAPSS and three BIOME3 vegetation scenario layers in Arcview. Protected area location and vegetation type attributes (protected area geocentroid and biome value) were spatially joined in order to determine vegetation type under current climatic conditions and climate change scenarios.

[2] Significant data gaps existed for several of Ontario's conservation areas, including Conservation Niagara, Essex Region Conservation Authority, Trenton Region Conservation Authority and Hamilton Conservation Authority. Similarly, British Columbia's protected areas network was incomplete in the CCAD. Respective conservation authorities and BC Parks were contacted for park centroids.

2.3 Methodology for Canada's National Parks Analysis

The GIS boundary files for Canada's 39 national parks were obtained from Parks Canada. National park boundaries were superimposed onto the vegetation distribution layers in the GIS. All of the vegetation grid boxes (0.5^0 latitude/longitude resolution) where a national park covered more than 50% of the grid box were included in the analysis. The majority of the grid cells in three of the national parks (Pacific Rim, Gwaii Haanas, Quttinirpaaq) were classified as water or glacier and they were subsequently excluded from the analysis. Of the remaining 36 parks, 24 were entirely within a single grid box and therefore would have results identical to the centroid based analysis (described in section 2.3). For the proportional representation analysis for the entire national park system, the area of the grid boxes was converted to square kilometres to account for the latitudinal difference in grid box area.

3.0 Vegetation Change Modeling Results

3.1 Assessment of Vegetation Change in Canada's Conservation Lands

3.1.1 Vegetation Change in Individual Conservation Lands

Table 3.1 summarizes the results of the vegetation change analysis for each designated type of conservation lands for both MAPSS and BIOME3 models. The modeling results for each GVM are discussed separately below.

Of the 2,979 conservation lands analyzed, 28% to 48% were projected to experience a change in biome type under the four MAPSS scenarios. Considerable variations were found among the climate change scenarios. The UKMO scenario (which is the warmest climate change scenario used in this analysis – see Table 2.2) projected the greatest overall change, with nearly half (48%) of all conservation lands projected to experience biome type change. The GFDL scenario also projected a significant change (46% of all conservation lands). At the other end of the range, the HadCM2 scenario only projected that 28% of Canada's conservation lands could experience a change in biome type.

Under all four MAPSS scenarios (Table 3.1), Canada's national parks consistently experienced the greatest change in biome type compared to the other six conservation land designations. The greatest change (61% of the national parks were projected to experience a change in biome) was projected under the UKMO climate change scenario. Alternately, the HadCM2 scenario projected the least change (47%). The GFDL and GISS scenarios simulated equal biome type changes of 58%.

Migratory Bird Sanctuaries slightly edged out National Wildlife Areas as the conservation land designation experiencing the least change in modeled biome type. System wide, Migratory Bird Sanctuaries experienced a biome type change between 17% (HadCM2) and 50% GFDL. Similar results were found for National Wildlife Areas, where simulated biome changes ranged from 15% (HadCM2) to 45% (GFDL). The vegetation modeling results for Ramsar sites showed a similar range. System-wide 18% (HadCM2) to 48% (UKMO) of Ramsar sites were projected to experience a change in biome type.

Results for ecological reserve designation under the four MAPSS projections showed a narrow range of projected biome change, with the UKMO scenario projecting 52% of ecological reserves would experience a biome change and the HadCM2 projecting 34% would change. Similar results were found for provincial parks. (31% - GFDL to 49% - UKMO) and wilderness and wildlife protected areas (39% - UKMO to 44% - GFDL).

Table 3.1 - Projected Biome Change in Canada's Network Conservation Lands

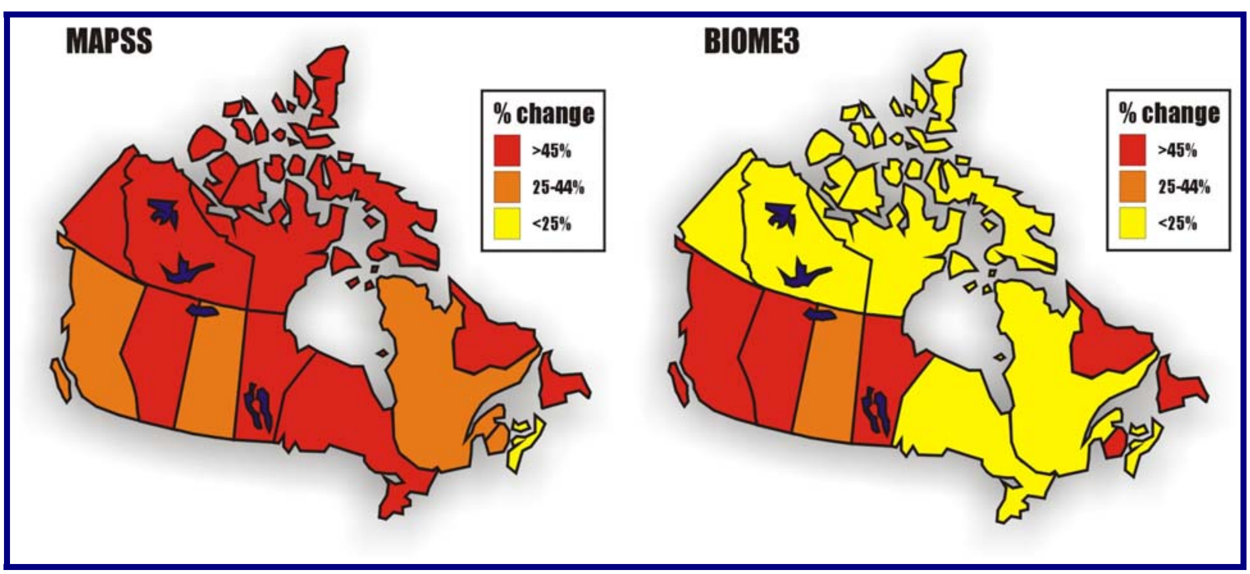
Protected Areas Designation	Current	MAPSS				BIOME3	
		UKMO	GFDL	GISS	HadCM2	HadCM2	MPI
NATIONAL PARKS							
total	**38**						
total change		**23**	**22**	**22**	**18**	**16**	**15**
total change (%)		**61%**	**58%**	**58%**	**47%**	**42%**	**39%**
RAMSAR SITES							
total	**44**						
total change		**21**	**19**	**16**	**8**	**15**	**15**
total change (%)		**48%**	**43%**	**36%**	**18%**	**34%**	**34%**
MIGRATORY BIRD SANCTUARIES							
total	**66**						
total change		**22**	**33**	**20**	**11**	**24**	**23**
total change (%)		**33%**	**50%**	**30%**	**17%**	**36%**	**35%**
NATIONAL WILDLIFE AREAS							
total	**40**						
total change		**16**	**18**	**10**	**6**	**12**	**7**
total change (%)		**40%**	**45%**	**25%**	**15%**	**30%**	**18%**
ECOLOGICAL RESERVES							
total	**464**						
total change		**239**	**206**	**194**	**159**	**257**	**204**
total change (%)		**52%**	**44%**	**42%**	**34%**	**55%**	**44%**
PROVINCIAL PARKS							
total	**946**						
total change		**467**	**293**	**360**	**326**	**663**	**511**
total change (%)		**49%**	**31%**	**38%**	**34%**	**71%**	**54%**
WILDERNESS and WILDLIFE PROTECTED AREAS							
total	**234**						
total change		**90**	**104**	**95**	**89**	**131**	**73**
total change (%)		**38%**	**44%**	**41%**	**38%**	**56%**	**31%**
	Current	UKMO	GFDL	GISS	HadCM2	HadCM2	MPI
Total Number of Protected Ares	**2979**	**1426**	**1371**	**1168**	**832**	**1418**	**1093**
Total Change Change %		**48%**	**46%**	**39%**	**28%**	**48%**	**37%**

As illustrated in Table 3.1, of the 2,979 conservation lands analyzed, approximately 37-48% were projected to experience a change in biome type under the two BIOME3 scenarios. Provincial parks are projected to experience the greatest change in biome type under BIOME3, with the HadCM2 scenario projecting 70% change and the MPI projecting just over half (54%) of Canada's provincial parks could experience a change in biome type. Ecological reserves also appear to be particularly sensitive to biome shifts under BIOME3 modeling scenarios. Once again, the HadCM2 projected a greater change (55%) the MPI scenario (44%). National Wildlife Areas are projected to experience the least biome type change under the BIOME3 scenarios (18% - HadCM2 and 30% - MPI).

The HadCM2 scenario of BIOME3 projected that 42% of Canada's national parks could experience a change in biome type, slightly greater than the MPI scenario (40%). A slightly wider range was found for Canada's wilderness and wildlife protected areas (31% - MPI to 56% - HadCM2). Slightly lower magnitudes of change were projected for Ramsar sites and Migratory Bird Sanctuaries. Ramsar sites were projected to experience a 34% change in biome type representation (both HadCM2 and MPI scenarios), while 35% (HadCM2) to 36% (MPI) of Migratory Bird Sanctuaries were projected to change biome type under BIOME3.

A breakdown of biome type change in the conservation lands within each province and territory is presented in Figure 3.1. In general, the HadCM2 driven BIOME3 scenario consistently projected greater biome type change compared to the HadCM2 driven MAPSS scenario. By conservation land designation (Table 3.1), MAPSS projected that 832 (28%) of Canada's conservation lands would experience a change in biome type. BIOME3 projected that a significantly greater number of parks and protected areas would change biome type (1,418 or 48%).

Figure 3.1 - Projected Biome Type Change by Province and Territory



Examining the results of the only common climate change scenario available for the two GVMs, regional differences in the HadCM2 results for MAPSS and BIOME3 was due to the greater expansion of the temperate mixed forest into Canada's western provinces and territories. The heavy concentration of southerly-located provincial parks and biosphere reserves in British Columbia account for the majority of the discrepancy between the HadCM2 results for MAPSS and BIOME3. British Columbia contains over half of Canada's provincial parks (511) and the HadCM2 driven BIOME3 scenario projected that 79% of the province's provincial parks could change biome type (as opposed to only 27% under the HadCM2 driven MAPSS scenario).

Overall, MAPSS projected greater biome type change for conservation lands in the central interior of the country (Manitoba, Ontario and Quebec) and the north (Yukon Territory, Northwest Territories and Nunavut), while BIOME3 projected greater changes in the west (British Columbia, Alberta and Saskatchewan) and the east coast (New Brunswick and Nova Scotia/Labrador).

3.1.2 Biome Representation Change in Canada's Conservation Lands

Table 3.2 summarizes the projected change in the representation of the nine biomes in the network of conservation lands analyzed under the MAPSS scenarios. The representation of the more northern biome type classifications (tundra, taiga/tundra and boreal conifer forest) is projected to decrease as a result of the overall contraction of these biomes in Canada. A loss of tundra representation is projected under all four MAPSS scenarios (ranging from 38% to 79% fewer conservation lands). All four MAPSS scenarios also projected a large decline in the representation of the taiga/tundra biome (81% to 87%). Considerable variation was found in the MAPSS results for the boreal conifer forest. The GISS and UKMO scenarios projected a 75% and 74% decrease in the number of conservation lands boreal conifer forest, while the GFDL model projected a decrease of only 22%.

Table 3.2 - Biome Representation Change in Canada's Conservation Lands (MAPSS)

Biome	Current Number of Protected Areas	UKMO % Change	GFDL % Change	GISS % Change	HadCM2 % Change
Tundra	39	-79%	-64%	-59%	-38%
Taiga-Tundra	124	-87%	-82%	-81%	-87%
Boreal Conifer Forest	419	-74%	-22%	-75%	-61%
Temperate Evergreen Forest	684	-7%	-3%	+46%	+34%
Temperate Mixed Forest					
Savanna/Woodland	1081	+1%	-29%	+6%	+31%
Shrub/Woodland	580	+78%	+90%	+11%	-32%
Grassland	24	-29%	+13%	+17%	+4%
Arid Lands	27	+141%	+89%	-41%	-15%
	0	na	na	na	na
Total	2979				

In contrast, representation of more southern biomes was generally projected to increase in the network of conservation lands under MAPSS climate change scenarios. The results for the temperate evergreen forest were divided under MAPSS. The HadCM2 and GISS scenarios projected that the number of conservation lands representing temperate evergreen forest could experience 34% and 46% respectively. However, the GFDL and UKMO scenarios projected nominal decreases in temperate evergreen forest representation (3% and 7%).

The results for the grasslands were also divided, but the variation between models was greater than that of the temperate evergreen forest. Two models (UKMO and GFDL) projected substantial increases in the number of conservation land containing grasslands (141% and 89%). However, the HadCM2 and GISS scenarios projected decreases of 15% and 41%.

Like the results for temperate evergreen forest and grasslands, MAPSS showed disparate representational scenarios for the savanna/woodland biome. The GFDL and UKMO scenarios projected the number of conservation lands that would represent savanna/woodland to increase 90% and 78% respectively. Conversely, the HadCM2 scenario projected a 32% decrease in the number of conservation land representing savanna/woodland.

Three of the four scenarios under MAPSS projected increases in the number of conservation lands representing the shrub/woodland biome. The HadCM2, GFDL and GISS scenarios projected that representation of the shrub/woodland biome would experience increase 4%, 13% and 17% respectively, while the UKMO scenario projected a decrease in representation of 29%.

The temperate mixed forest was the most highly represented biome in the conservation lands network under current climate conditions. Only one climate change scenario (GFDL) projected that this biome could experience a decrease in representation (-29%). All three other models project a range of increases in the number of conservation lands with temperate mixed forest (1% - UKMO, 6% - GISS, 31% - HadCM2). The GISS scenario projected a +increase in biome representation. With the exception of the GFDL model, the temperate mixed forest biome is projected to remain the most highly represented biome in Canada network of conservation lands under MAPSS scenarios.

Table 3.3 summarizes the current and projected numbers of conservation lands representing each of the nine biomes under the two BIOME3 scenarios. Similar to the results of MAPSS, the more northern biome type classifications (tundra, taiga/tundra and boreal conifer forest) are expected to experience decreases representation under both HadCM2 and MPI scenarios. Both scenarios projected over a 50% decline in the number of conservation lands representing each of the three northern biomes (tundra: HadCM2 –67%, MPI –72%; taiga/tundra: HadCM2 –57%, MPI –53%; boreal conifer forest – HadCM2 -78%, MPI –54%).

Under the HadCM2 scenario, eight of the nine biome classifications were projected to experience decreased representation in the current conservation lands network. The lone projected to increase in terms of representation was the temperate mixed forest, which doubled in terms of the number of conservation lands if was found in.

Table 3.3 - Biome Representation Change in Canada's Conservation Lands (BIOME3)

Biome	Current Number of Protected Areas	HadCM2 % Change	MPI % Change
Tundra	79	-67%	-72%
Taiga-Tundra	161	-57%	-53%
Boreal Conifer Forest	797	-78%	-54%
Temperate Evergreen Forest	335	-73%	-34%
Temperate Mixed Forest			
Savanna/Woodland	1184	+93%	+47%
Shrub/Woodland	346	-17%	+35%
Grassland	76	-43%	+9%
Arid Lands	1	-100%	-100%
	0	na	na
Total	2979		

The MPI scenario projected divided results for the BIOME3 model. The more northern biome classifications were projected to experience decreased representation, whereas the more southern biomes (shrub/woodland, savanna/woodland, and temperate mixed forest) were all projected to experience moderate to substantial increases (9%, 34%, 47%).

The finding that MAPSS generally projected greater biome type change is consistent with previous GVM inter-comparison studies (VEMAP Members 1995; Neilson 1998; Malcolm and Markham 2000). In this analysis greater vegetation change anticipated with MAPSS in part because three of the four scenarios were driven by older 'warmer' GCMs [three of the four MAPSS driven scenarios were from the IPCC FAR (1990)] whereas BIOME3 was run under two newer GCM scenarios that project less warming (see Table 2.1 for more details).

3.2 Assessment of Vegetation Change in Canada's National Park System

Regardless of the GVM and climate change scenario used, the vegetation modeling results showed the potential for substantial change in biome representation in Canada's national park system (Figures 3.2 to 3.5[3]). All four MAPSS-based scenarios resulted in at least one new biome type appearing in the majority of national parks (55-61% of parks; Table 3.4). The BIOME3 results showed slightly fewer parks with a new biome appearing (39-50% of parks). When a second important metric of potential vegetation change was examined; namely, the proportion of grid boxes that changed from one biome to another, the results were equally notable. Under all of the MAPSS scenarios, changes were projected in greater than half of all vegetation grid boxes in the majority of national parks (18 to 21 of the 36 parks analyzed) (Table 3.4). The BIOME3 results again projected less change, with only 15 to 17 of 36 parks analyzed displaying biome change in greater than half of their grid boxes. The finding that MAPSS generally projected greater biome change is consistent with previous GVM inter-comparison studies (VEMAP Members 1995; Neilson 1998; Malcolm and Markham 2000) that found MAPSS had a more sensitive response to water stress and elevated CO_2 levels.

[3] The MAPSS vegetation modelling maps for the GISS and HadCM2 climate change scenarios are not shown.

Table 3.4 – Projected Biome Change in Canada's National Parks

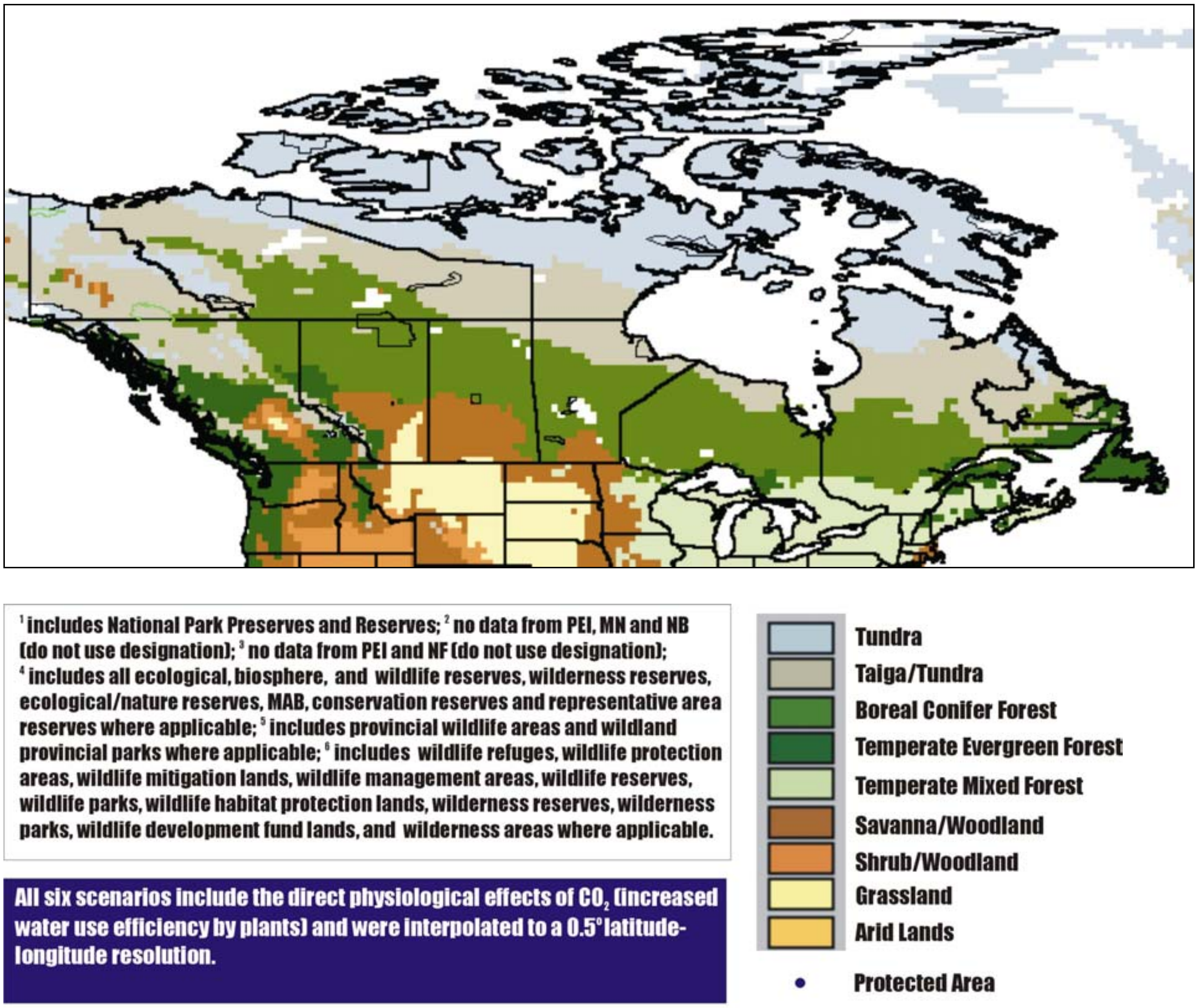
	MAPSS				BIOME3	
	GFDL	GISS	UKMO	HadCM2	HadCM2	MPI
Novel Biome Appears (number of parks)	21	20	22	20	18	14
Biome Change in >50% of Grid Cells	21	19	21	18	17	15

Table 3.5 presents the modeled proportional distribution of the biome types in Canada's national park system (as a % of area) under the current climate and each of the climate change scenarios. The MAPSS modelling results have been analyzed both with the boreal and taiga/ tundra biomes separated and, to provide results that are comparable with BIOME3, with the boreal and taiga/ tundra biomes combined.

Table 3.5 – Proportional Biome Representation in Canada's National Park System (based on km^2)

Biome Type	MAPSS					BIOME3		
	Current	GFDL	GISS	UKMO	Had CM2	Current	Had CM2	MPI
Tundra	**35%**	28%	26%	20%	30%	**37%**	22%	23%
Boreal + Taiga/Tundra	**46%**	48%	43%	45%	43%	**47%**	39%	49%
Taiga/Tundra	*19%*	*14%*	*17%*	*18%*	*13%*			
Boreal	*27%*	*34%*	*26%*	*27%*	*30%*			
Temperate Evergreen Forest	**8%**	7%	14%	15%	19%	**4%**	1%	2%
Temperate Mixed Forest	**8%**	12%	14%	14%	16%	**7%**	26%	18%
Savanna / Woodland	**2%**	5%	2%	5%	2%	**4%**	11%	5%
Shrub / Woodland	**0%**	0%	0%	0%	0%	**1%**	1%	2%
Grassland	**1%**	1%	1%	1%	0%	**0%**	0%	0%
Arid Lands	**0%**	0%	0%	0%	0%	**0%**	0%	0%

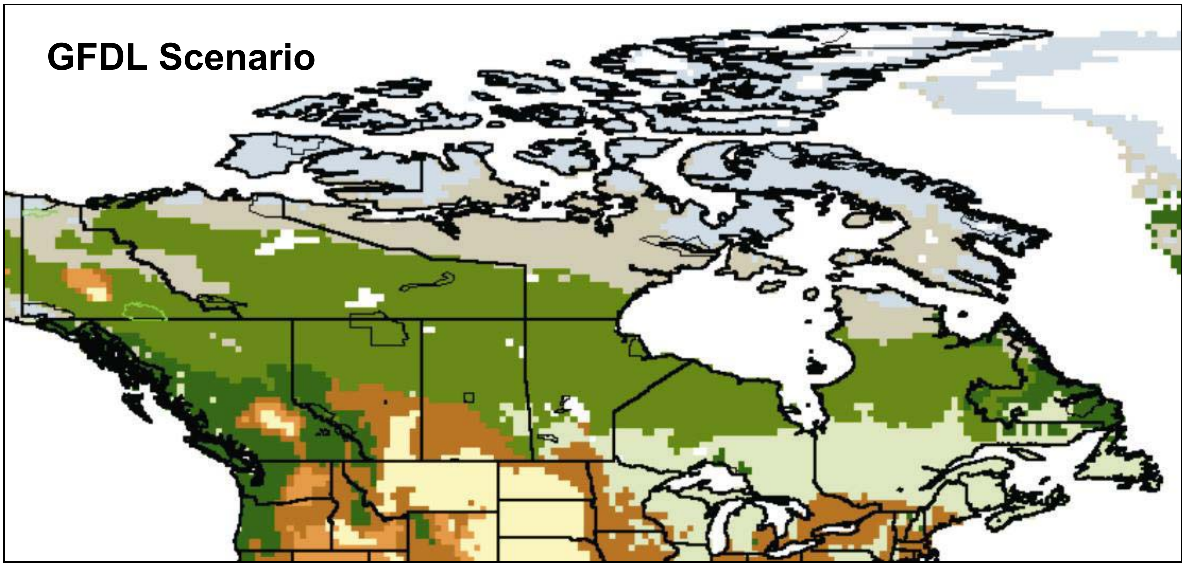
Figure 3.2 - Current MAPSS Vegetation Distribution in Canada's National Parks



The proportional distribution of biomes by MAPSS and BIOME3 under the current climate was very similar (within 3% of area for each biome) when boreal and taiga/ tundra biomes were combined in MAPSS (Table 3.5). Under both GVMs tundra and the combined boreal and tundra/taiga biome were dominant in the national park system, largely because of several very large parks in these biomes (e.g., Wood Buffalo National Park = 44,802 km^2).

Across the entire national park system, there was general agreement among the six climate change scenarios with respect to the nature of the biome change (Table 3.5). All six climate change scenarios projected a decline in representation of tundra. The taiga/ tundra biome, which was particular to MAPSS, also showed a consistent decline. Results for boreal representation were mixed when examined separately in the four MAPSS scenarios, with two scenarios projecting no change to a slight decline in proportional representation (from 27% to 26% of area) and two scenarios projecting increased representation (from 27% to 30% and 34% of area - Table 3.5).

Figure 3.3 - Projected MAPSS Vegetation Distribution in Canada's National Parks



[1] includes National Park Preserves and Reserves; [2] no data from PEI, MN and NB (do not use designation); [3] no data from PEI and NF (do not use designation); [4] includes all ecological, biosphere, and wildlife reserves, wilderness reserves, ecological/nature reserves, MAB, conservation reserves and representative area reserves where applicable; [5] includes provincial wildlife areas and wildland provincial parks where applicable; [6] includes wildlife refuges, wildlife protection areas, wildlife mitigation lands, wildlife management areas, wildlife reserves, wildlife parks, wildlife habitat protection lands, wilderness reserves, wilderness parks, wildlife development fund lands, and wilderness areas where applicable.

All six scenarios include the direct physiological effects of CO_2 (increased water use efficiency by plants) and were interpolated to a 0.5° latitude-longitude resolution.

- Tundra
- Taiga/Tundra
- Boreal Conifer Forest
- Temperate Evergreen Forest
- Temperate Mixed Forest
- Savanna/Woodland
- Shrub/Woodland
- Grassland
- Arid Lands
- • Protected Area

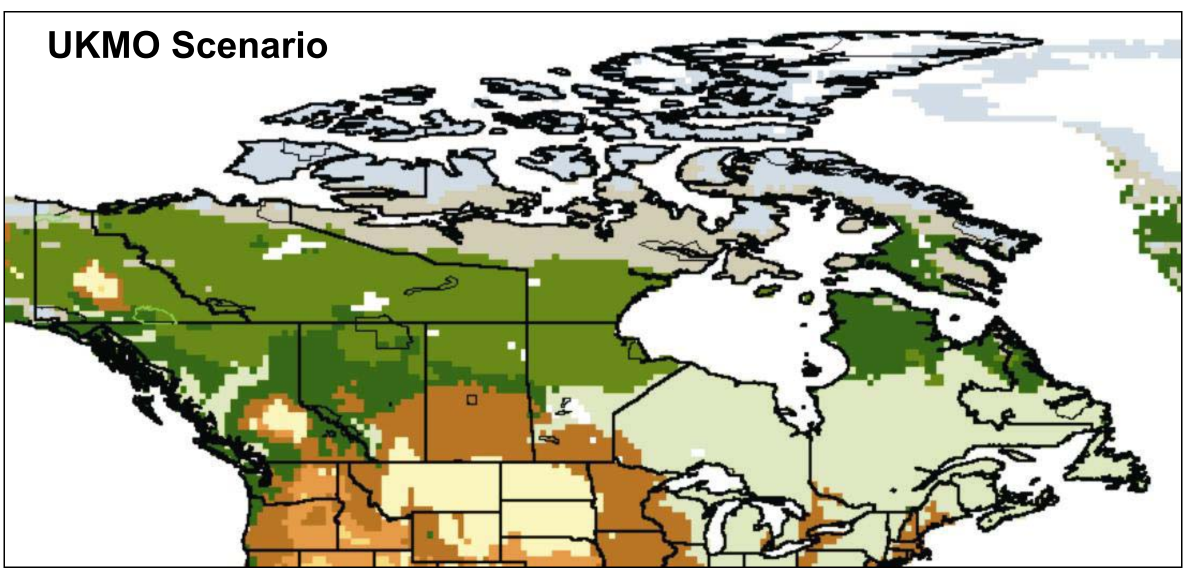
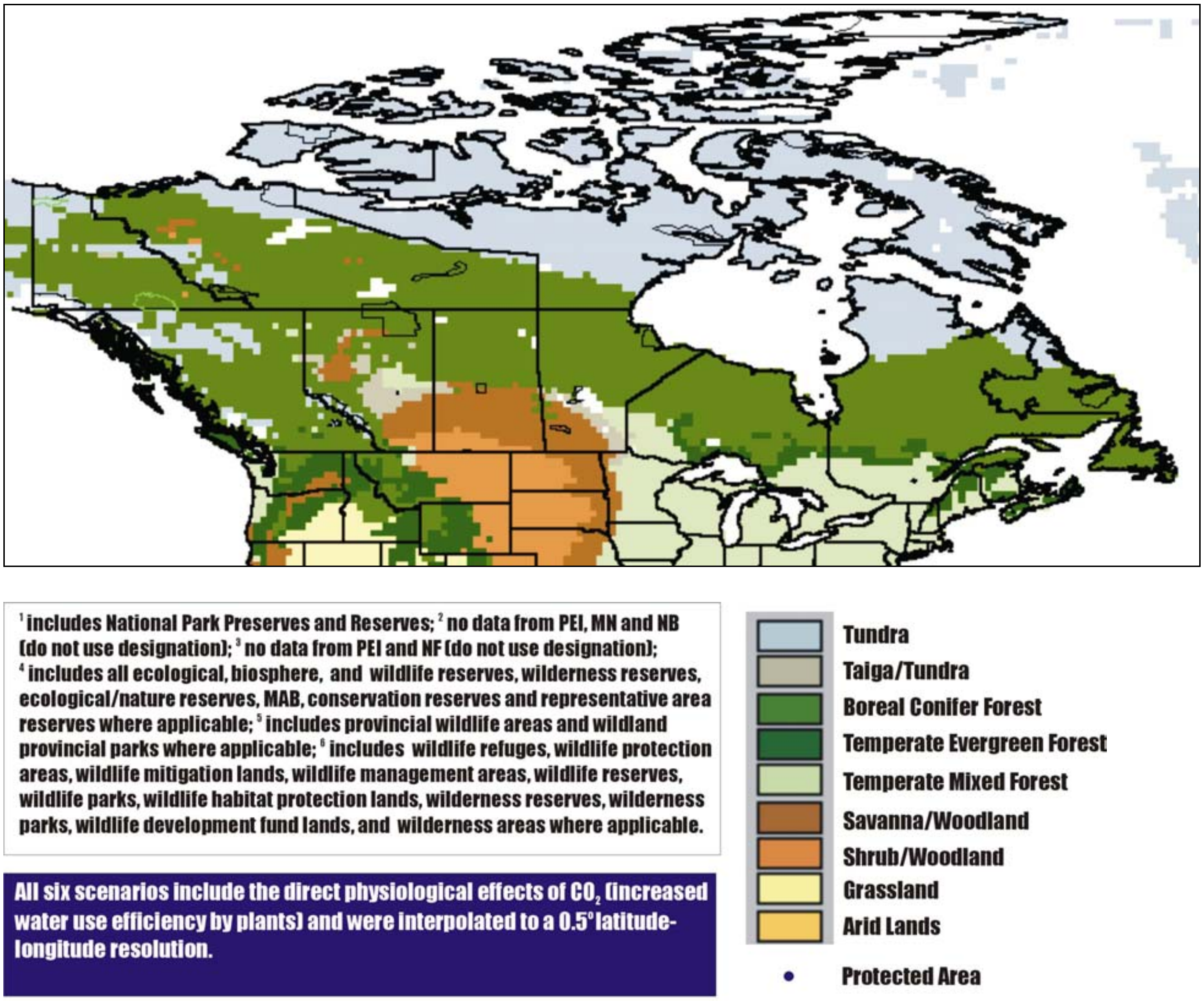
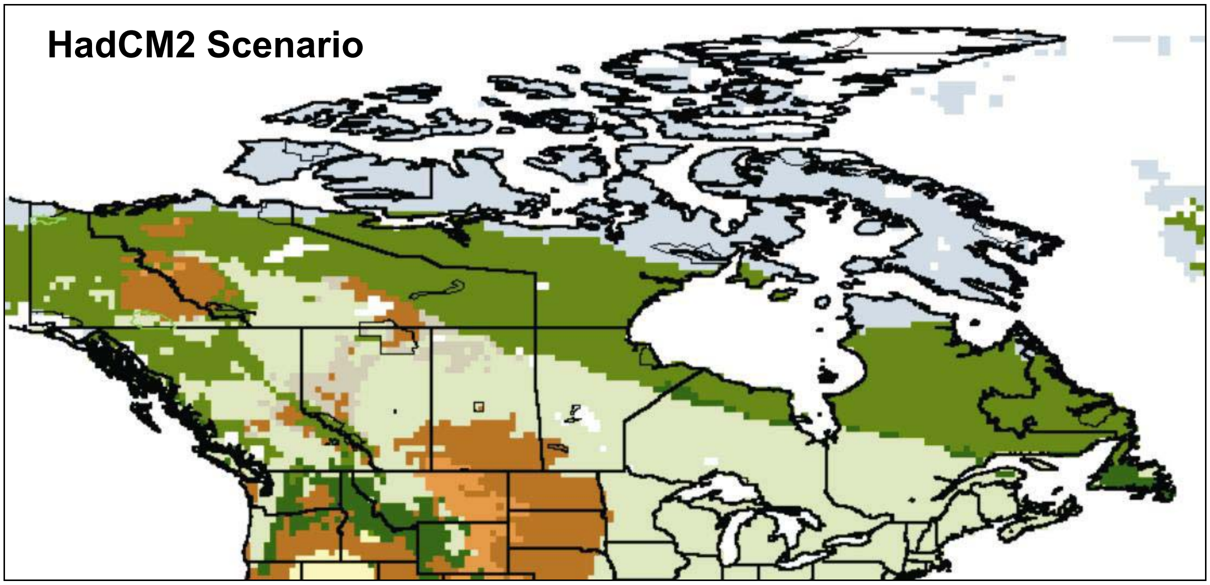


Figure 3.4 - Current BIOME3 Vegetation Distribution in Canada's National Parks



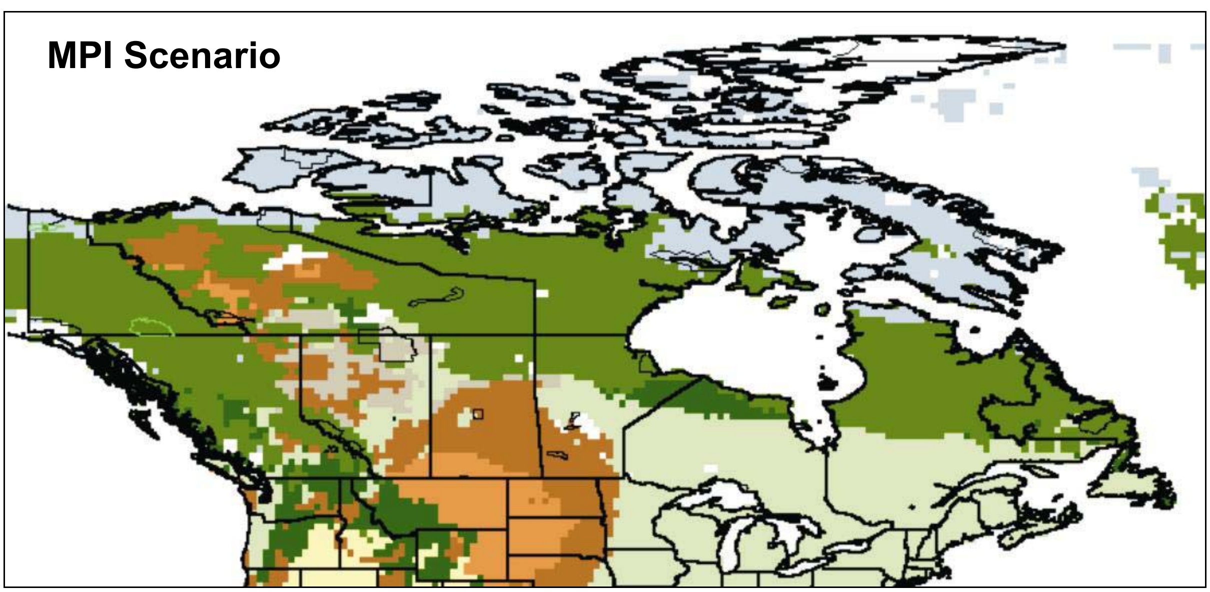
The boreal-taiga/tundra biome in BIOME3 also showed divergent projections, with one scenario indicating a decrease in area and the other an increase (from 47% to 39% and 49% respectively). The proportional representation of temperate forests increased in all MAPSS scenarios, while savanna/woodland increased in two scenarios and remained the same in two others. The relative proportion of both temperate mixed forest and savanna/woodland increased substantially in the BIOME3 scenarios as well, but unlike the MAPSS results, temperate evergreen forest was projected to decline slightly (from 4% to 1-2% of area).

Figure 3.5 - Projected BIOME3 Vegetation Distribution in Canada's National Parks



[1] includes National Park Preserves and Reserves; [2] no data from PEI, MN and NB (do not use designation); [3] no data from PEI and NF (do not use designation); [4] includes all ecological, biosphere, and wildlife reserves, wilderness reserves, ecological/nature reserves, MAB, conservation reserves and representative area reserves where applicable; [5] includes provincial wildlife areas and wildland provincial parks where applicable; [6] includes wildlife refuges, wildlife protection areas, wildlife mitigation lands, wildlife management areas, wildlife reserves, wildlife parks, wildlife habitat protection lands, wilderness reserves, wilderness parks, wildlife development fund lands, and wilderness areas where applicable.

All six scenarios include the direct physiological effects of CO_2 (increased water use efficiency by plants) and were interpolated to a 0.5° latitude-longitude resolution.



3.3 Limitations of Equilibrium Global Vegetation Model Analysis

It must be emphasized that although the results of the equilibrium GVMs used in this analysis indicate the potential for substantial biome change in Canada's national parks and broader conservation lands, these results should be considered suggestive of the potential magnitude of vegetation change rather than predictive of the eventual distribution and composition of biomes in Canada. Equilibrium GVMs do not model the transient response of vegetation to climate change and do not incorporate many important factors influencing the complexities of vegetation change (e.g., species migration rates, altered competitive relationships, and changes in disturbance regimes – insect, disease, fire, extreme climate events like drought and wind) (see also Woodward and Beerling 1997). Equilibrium GVMs simulate a fully equilibrated vegetation distribution for a given scenario of future climate and as Overpeck et al. (1991) this is would likely occur over 200-500 years. GVMs model potential natural vegetation and do not take into account human land use patterns or the many other human-induced environmental stresses that might hinder natural vegetation migration and other natural adaptation processes. Considering the limitations of equilibrium GVMs, the actual vegetation composition and distribution found under the changed climatic conditions of the late 21st century may be different than the potential vegetation modelled in this analysis. Nonetheless, the magnitude of biome change in Canada's conservation lands projected in each scenario should be considered indicative of the risk posed by climate change and the inherent uncertainty in GVM scenarios should not be misinterpreted to mean that a 'no-change' scenario is a potential outcome of climate change.

A number of international research teams are developing a new generation of Dynamic Global Vegetation Models (DGVMs) to address some of the limitations of equilibrium GVMs and produce more realistic predictions of the transient response of vegetation to climatic change (Cramer et al. 2001). The development of models to assess the transient response of ecosystems and known feedback processes was a research priority identified by the IPCC special technical report on climate change and biodiversity (IPCC 2002). The integration of DGVMs with actual and potential land use surfaces (as opposed to natural vegetation only) will enable a much more robust analysis of the cumulative stress of climate change on fragmented landscapes and represent a vital scientific advance for climate change impacts and adaptation research in this field. DGVMs remain in various stages of development. At the time of writing this report, DGVMs had not yet been validated and run in Canada, however Parks Canada is collaborating with the Adaptation and Impacts Research Group of Environment Canada, the Northern Forestry Centre of the Canadian Forest Service and various international partners to provide state-of-the-art high resolution DGVM modelling across Canada by 2005.

4.0 Policy and Planning Implications

In order to advance practical debate about climate change adaptation strategies in Canada's network of conservation lands, it is essential to investigate the various ways in which the policies and planning frameworks of the agencies responsible for protected areas are sensitive to climate change. This section explores conservation policy and management implications at both the system and individual protected area levels, using examples from the conservation land designations examined in this report.

Most jurisdictions in Canada have adopted some type of ecoregion or biogeoclimatic land classification framework as the main system-planning tool for their terrestrial protected area system. Table 4.1 summarizes the ecoregion or biogeoclimatic classification systems utilized in each of the provinces and territories, with the exception of Nunavut, which is currently in the process of developing a strategy. The national park system plan was developed by Parks Canada using 39 natural regions (defined by vegetation classification and physiological features) deemed representative of landscapes across Canada, to provide a long-term framework for park selection.

On November 25, 1992, the Canadian Parks Ministers Council met jointly with the Canadian Council of Ministers of the Environment and the Wildlife Ministers Council of Canada in Aylmer, Quebec. At the meeting, each Council signed *A Statement of Commitment to Complete Canada's Networks of Protected Areas*. In so doing, the key commitment for Parks Ministers was to "make every effort to complete Canada's networks of protected areas representative of Canada's land-based natural regions by the year 2000 and accelerate the protection of areas representative of Canada's marine natural regions." (FPPC 2000: 5).

Like protected area systems around the world, the park and protected area systems in Canada were developed to protect specific natural features, species and communities *in-situ,* with the assumptions of climatic and biogeographic stability. These assumptions are tenuous under climate change. Species assemblages with no current analogue are an important feature of North American paleoecology (Overpeck et al. 1992). Although significant knowledge gaps related to ecosystem response to climate change remain, our current understanding suggests that climate change will significantly alter the spatial extent and composition of current ecological communities. Tables 3.1 through 3.5 illustrated that the biome composition of Canada's existing conservation lands and national parks could differ substantially under the climate change scenarios examined. The implication is that projected climate change would produce new species assemblages that also have no current analogue. New ecological communities will not equilibriate quickly, as the time frame for disassociation and resorting in response to past climate change appears to have been in the order of centuries (Ritchie 1987; MacDonald et al. 1993). Added to this potential lag in ecological responses is the possibility of continuing human-induced climatic change. The latter part of this next century therefore is likely to witness ecological communities in transitionary stages. Indeed, Hughes (2000), IPCC (2001b), McCarty (2001), Root et al. (2003), and Parmesan and Yohe (2003) have compiled evidence from a wide range of studies that indicate physical systems and some species are already responding to on-going climate change.

Table 4.1 - Landscape Classifications Used for Protected Area System Planning

Province	Protected Areas Strategy	Protected Areas Establishment Fundamental Premise	Scale/Landscape Classification
British Columbia	Protected Areas Strategy (1992)	ecoregion representation biogeoclimatic classification framework	14 eco/biogeoclimatic zones 100 ecosections
Alberta	Special Places Plan (1995)	ecoregion representation	6 ecoregions 20 subregions
Saskatchewan	Saskatchewan Representative Areas Network (1997)	ecoregion representation based on enduring features	4 ecozones 11 ecoregions
Manitoba	A System Plan for Manitoba Provincial Parks (1998)	representative natural resources based on enduring features	18 natural regions and subregions
Ontario	Nature's Best: A Framework and Action Plan (1997) Living Legacy Land-Use Strategy (1999) Ontario Parks Legacy 2000 Natural Areas Protection Program (2000)	ecoregion representation	13 ecoregions 65 districts
Quebec	Action Plan for Parks: Nature's Heritage (1992) (Plan d'action sur les parcs: La nature en heritage)	natural region representation	43 natural regions
New Brunswick	Protected Areas Strategy (1999)	ecoregion representation	7 ecoregions
Newfoundland and Labrador	Wilderness and Ecological Reserves Program (1980)	ecoregion representation special species and habitat	9 ecoregions (NFLD) 21 subregions (NFLD) 10 ecoregions (LAB)
Nova Scotia	Protected Areas Strategy (1997)	natural landscape representation	80 natural landscapes
Prince Edward Island	Significant Areas Plan (1991)	habitat type representation	7 habitat types
Northwest Territories	Protected Areas Strategy- A Balanced Approach to Establishing Protected Areas in the Northwest Territories (1999)		9 ecozones 69 ecoregions

Nunavut	Nunavut Land Claim Agreement (1993) Nunavut Park Program (proposed) Parks and Conservation Areas System Plan (proposed)	ecoregion representation	n/a
Yukon Territory	Yukon Protected Areas Strategy (1998)	ecoregion representation special places protection ecological viability naturalness	23 ecoregions

In a changing climate, conservation planning based on protecting representative samples of natural areas, including those listed in Table 4.1 and Canada's national park system plan, will have to deal with two fundamental problems. First, steady-state representative conservation based on current species assemblages would exclude future non-analogue assemblages. Because possible non-analogue assemblages are unknown, comprehensive representation in a system of protected areas will become an increasingly impractical objective. Second, protected area system planners will have to grapple with attempting to 'hit a moving target' of ecological representativeness as climate change raises the fundamental question of 'What is to be considered a 'representative natural area' in an era characterized by transitory ecosystems?' These challenges should not be construed as an argument against efforts to protect the ecological integrity of current protected areas or against the conservation value of existing protected area systems. Rather, the point being made is that the policy of completing the current system plans without consideration for the effects of climate change should be reassessed so as optimize the limited resources available for ecological protection.

Parks Canada's management paradigm is guided by the principle of ecological integrity, which is defined in the National Parks Act (clause 2) (Parks Canada 2000) as, "with respect to a park, a condition that is determined to be characteristic of its natural region and likely to persist, including abiotic components and the composition and abundance of native species and biological communities, rates of change and supporting processes. With regard to the definition of ecological integrity, Parks Canada (1998: 24) also states, "Ecosystems are inherently dynamic and change does not necessarily mean a loss of integrity. A system with integrity may exist in several states, but the change occurs within *acceptable limits* (their emphasis)." The magnitude of climate change and associated changes in disturbance regimes are likely to accelerate ecosystem change beyond what science has observed to be the natural range in some regions. The compounded perturbations resulting from climate change (e.g., vegetation change, altered disturbance regimes, invasive species, increased extreme climate events) is also likely to heighten the occurrence of ecological surprises and non-linear responses by ecosystems (Paine et al. 1998). Consequently, it remains uncertain as to how ecosystem change 'within acceptable limits' is to be interpreted within the context of climate change.

Policy and planning sensitivities also exist for the management of individual protected areas. For example, each of Canada's national parks is responsible for protecting ecosystems representative of the natural region within which they are located. The management plan of each individual park defines the purpose of the park. For example, the stated purpose of Riding Mountain National Park (RMNP) is to, "Protect for all time the ecological integrity of a natural area … representative of the boreal plains and mid-boreal uplands." All six vegetation modelling scenarios in this analysis projected the eventual loss of boreal forest in this park, suggesting that the park's mandate could be untenable in the long-term. Commenting on vegetation change in Prairie island forests similar to Riding Mountain National Park, Henderson et al. (2003:10) stated that, 'Management that aims simply to retain existing vegetation, or restore historical vegetation distributions and ecosystems, will fail as the climate moves further away from recent and current norms.' Furthermore, the decision to reintroduce natural fire regimes in ecotonal parks like Riding Mountain National Park, where vegetation models project a shift from boreal forest to grasslands, could hasten the transition to grassland communities and therefore be ostensibly in conflict with the current park purpose. The reintroduction of natural fire regimes, while necessary to preserve current biodiversity, might also be in conflict with future government policy to maximize carbon storage in order to achieve Canada's international commitments under the Kyoto Protocol should it be ratified.

Like protected areas around the world, certain national parks in Canada were established with the specific intent of protecting highly valued individual species and their habitats. For example, Wapusk National Park located on the coast of Hudson Bay, was established in 1996 largely to protect the world's largest denning and gathering place for polar bears. The world's only maritime bear, polar bears require pack ice to hunt. Several studies offer evidence of declining Arctic sea ice extent and thickness (Vinnikov et al. 1999; Johannessen et al. 1999; Rothrock et al. 1999) and sea ice scenarios have projected 40-100% loss of summer sea ice by the end of the 21st century (National Assessment Synthesis Team 2000). The polar bear population in Wapusk National Park is near the southern limits of its range and may be extirpated from the park as a result of nutritional stress and/or reproductive failure related to projected declines in sea-ice cover. The reduction in female body weight index and average births of polar bears in Western Hudson Bay over the past 20 years may be an early indicator of climate-induced stress (Stirling et al. 1999). In this case, the ecological manifestations of climate change may be such that the established management objectives of the park are no longer viable.

A similar example at the provincial level is the protection of woodland caribou. Under Manitoba's Provincial Park System Plan, management plans are prepared for each provincial park. The stated park purpose for Nopiming Natural Park (1,429 km^2) is, "To preserve areas that are representative of the Lac Seul Upland portion of the Precambrian Boreal Forest Natural Region …." (Manitoba Department of Natural Resources 1998: 41) Moreover, the plan states that the park will "…preserve areas of woodland caribou habitat, notably caribou calving grounds." (Manitoba Department of Natural Resources 1998: 41) Similarly, Seager Wheeler Lake Representative Area's stated purpose is to represent Saskatchewan's Mid-Boreal Lowland, and is home to a variety of boreal wildlife, including woodland caribou and the great grey owl (SERM 1999). Under Ontario's *Living Legacy Land-use Strategy*, there has been a call for an extension of the Woodland Caribou Provincial Park management area, which protects a unique mix of southern boreal forest vegetation and is an important habitat and calving ground for woodland caribou (OMNR 2002).

All four MAPSS scenarios projected a northward migration of the boreal conifer forest with the replacement of less favourable woodland caribou habitat for all three of these protected areas (Figure 3.2), suggesting the stated park purposes to represent the boreal forest biome and protect woodland caribou populations could become increasingly difficult. Woodland caribou are an important component of Canada's boreal forest ecosystem, and the boreal population is listed as 'threatened' on COSEWIC's "Species at Risk" list in Ontario, Manitoba, Saskatchewan, Nunavut, British Columbia, Alberta, Québec and Newfoundland (COSEWIC 2002). The projected northward migration of the boreal conifer forest coupled with more immediate stresses such as fire, disease, insects and logging, could further place stress on the threatened woodland caribou as the boreal forest could move beyond the protected area boundaries originally positioned for the caribou.

A review of approved management plans from several national parks revealed additional climate change sensitivities at the individual park level. These included wildfire fire management strategies, individual species management plans and contingencies for species at risk, non-native species management programs, and species reintroduction programs.

These policy and planning sensitivities highlight fundamental questions regarding the role of protected areas in an era of climate change. Are protected areas to continue to protect a representative sample of current ecosystems, or will the conservation agencies become dedicated to the function of assisting ecosystems to adapt to climate change (or could both approaches be integrated into a coherent response strategy)? Scott and Suffling (2000) and Suffling and Scott (2002) describe the different policy directions that could be adopted and some of the challenges associated with each:

1) *Static management*: Continue to manage and protect current ecological communities within current protected area boundaries, using current goals.
2) *Passive management*: Accept the ecological response to climate change and allow evolutionary processes to take place unhindered;
3) *Adaptive management*: Maximise the capacity of species and ecological communities to adapt to climate change through active management (e.g., fire suppression, species translocation, invasive species suppression), either to slow the pace of ecological change or facilitate ecological change to a new climate adapted state;
4) *Hybrid management*: Some combination of the above

To pursue the first policy pathway, against evolutionary processes, is unsustainable in the long-term. A passive management approach is likely to be insufficient to prevent the loss of current biodiversity in many protected areas. It is also questionable whether Canadians would be willing to accept the consequences of a policy of laissez faire conservation management, when a valued or symbolic species was at risk (e.g., the decimation of polar bear populations in Wapusk National Park). A strong interventionist lobby is likely to emerge in such situations. The political pressure that drove the translocation of Plains Bison to Wood Buffalo National Park, despite the known risk of hybridization and introduction of tuberculosis to resident Wood Buffalo, may foreshadow the decision-making pressures that Parks Canada and other conservation agencies will increasingly face. Canadians are likely to place greater demands on the national parks system to protect species and ecosystems under stress from climate change.

Although an active management regime to augment the capacity of natural systems to adapt to climate change is warranted, it would nonetheless heighten scientific (and arguably ethical) dilemmas for protected area managers. Intervention strategies, for the most part, are likely to be species specific. With limited conservation resources, there will be critical questions regarding which species should receive assistance. Protected area managers will be placed in a position of having to determine whether the continued protection of a threatened species that may no longer have suitable habitat in a park or a role in the emerging ecological community is reasonable. Ultimately, conservation agencies are likely to be faced with difficult choices regarding which climate change impacts are tolerable. The level of scientific certainty required for active management strategies will also be difficult to assess, both in terms of determining when intervention is warranted and the probability of unanticipated consequences. Our limited understanding of the enormously complex dynamics of ecosystems indicates that ecosystem-level response to climate change may never be entirely predictable (Myers 1995). The information requirements for an adaptive management approach to climate change will be intensive at a time when conservation budgets are under increasing pressure.

Adaptation to climate change will be a complex process and is likely to vary by jurisdiction. Adaptation strategies that are appropriate in one jurisdiction may not be suitable in another because they are in conflict with existing policy and planning regulations. For example, some of the management recommendations that Henderson et al. (2003) put forward for maintaining forest cover on vulnerable and highly valuable Prairie island forests (including: ‘countering potentially catastrophic insect or vegetation disturbances by biological, chemical or physical controls’, ‘introduction of new or non-native species best adapted to new climates’, and ‘undertake forest harvest where appropriate’) may be possible in provincial forests, but cannot be in accord with existing Parks Canada policy. The non-availability of particular adaptation strategies in some jurisdictions may have important implications for determining the direction and magnitude of ecosystem change and the management objectives for individual protected areas.

5.0 Conclusions

Climate change represents an unprecedented challenge for the agencies responsible for the planning and management of Canada's conservation lands. Scott and Suffling (2000) identified a range of biophysical climate change impacts that would have implications for the integrity of conservation lands in each region of Canada. Their assessment and the vegetation modeling analysis presented here also identify a number of ways in which existing conservation policy and planning frameworks are sensitive to the impacts of climate change. If Canada's system of conservation lands continues to be managed without contingencies for climatic change, the intergenerational conservation legacy of the parks system could be diminished. The IPCC (2002: 41) came to a similar conclusion, stating that 'the placement and management of reserves and protected areas will need to take into account potential climate change in the reserve systems are to continue to achieved their full potential.'

The issues related to the strategic response of conservation agencies to the challenge of climate change are very complex and deserve further elaboration than that provided here. There is a strong need for participatory dialogue among conservation stakeholders on the implications of climate change and the development of adaptation strategies. Integrating climate change into existing institutional frameworks of conservation agencies will be both complex and challenging. Governments and conservation stakeholders cannot shy away from this challenge and must work collaboratively so that as the scientific community continues to advance understanding of the impacts of climate change on physical and biological systems, there exists the institutional capacity to develop and implement pragmatic conservation responses. For although climate change is a long-term issue, the research documenting observed ecological responses to on-going climate change (Hughes 2000, IPCC 2001b, McCarty 2001, Walther et al. 2002, Root et al. 2003, Parmesan and Yohe 2003) and the long-term planning horizons necessary for biodiversity conservation, emphasizes the need for conservation agencies to consider climate change in current policy and planning processes.

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