CCEA CANADIAN COUNCIL ON ECOLOGICAL AREAS
CCAE CONSEIL CANADIEN DES AIRES ÉCOLOGIQUES

WILDLIFE CONSERVATION, PROTECTED AREAS AND CLIMATE CHANGE IN CANADA:

Implications of Projected Species Range Shifts

Kathryn Lindsay, Jean-François Gobeil, Joshua L. Lawler, Carrie Schloss, Karen F. Beazley, and Thomas J. Beechey

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Front Cover:
Muskox (*Ovibus moshatus*), confronting more serious climate change impacts in the Arctic. Location: Fosheim Peninsula, Ellesmere Island, Nunavut (Photo Credit: Lisa Pirie).

Back Cover:
Burrowing Owl (*Athene cunicularia*), facing more extreme weather events on the Prairies. Location: Onefour Agricultural Station, Southern Alberta (Photo Credit: Gord Court).

Frontispiece:
Conservationists (*Homo sapiens*), creating more resilient protected areas to conserve biodiversity across Canada. Location: Cape-Wolstenholme National Park project, Quebec (Photo Credit: Alain Thibault).

CCEA 2020 VISION

...to enhance the representation and viability of native species and natural ecosystems in Canada's natural heritage estate through an expanded and more resilient network of protected areas for biodiversity conservation.

Building on Canada's international commitments....

... the United Nations *Convention on Biological Diversity* and its *Strategic Plan for Biodiversity 2011-2020* including the *Aichi BiodiversityTargets*

and

...the United Nations *Framework Convention on Climate Change* with the 2015 *Paris Agreement* on Climate Change

ABOUT CCEA

The Canadian Council on Ecological Areas (CCEA) is an independent national organization constituted in 1982 to encourage and to facilitate the selection, protection and stewardship of a comprehensive network of protected areas in Canada. In 1995, CCEA became a registered charitable organization. The Council draws its following and support from federal, provincial and territorial government agencies, non-governmental organizations, universities, industry, First Nations and Inuit peoples, and private citizens concerned with protected areas.

The goal of CCEA is to facilitate and to assist Canadians with the establishment, management and use of a comprehensive, viable network of protected areas that represents the diversity of terrestrial, marine and other aquatic ecosystems in Canada. To this end, the work of CCEA is centred on the following activities.

- Promoting the value of protected areas for conserving biodiversity and for helping to sustain ecosystems and species for the environmental, social and economic well being of all Canadians.
- Providing scientific advice and guidance on the design of a nation-wide network of protected areas incorporating both terrestrial and aquatic ecosystems and the selection of areas to complete it.
- Advancing sound ecological and science-based stewardship practices for protected areas including the management, restoration and use of them for conservation, science, education and heritage appreciation.
- Monitoring, reporting and disseminating information on initiatives and progress regarding the establishment, conservation, management and use of protected areas in Canada.
- Assisting in determining the administrative and institutional arrangements for the securement, protection, management and use of protected areas.
- Communicating and working with regional, national and international interests toward the achievement of Council's goals and objectives.
- Conducting other such work and activities as may be necessary to support these aims.

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FOREWORD

Successful conservation outcomes are predicated on pursuing clear goals, overcoming challenges, and exploiting opportunities. This formula marks the history of the protected areas movement in Canada. Beginning with the creation of Banff National Park in 1885, the incremental growth of Canada's network of protected areas was periodically punctuated with accelerated spurts in response to social, economic and environmental pressures coupled with opportunities for conservation action. Rapid expansion in the post-war era and especially the past two decades has generated unprecedented growth in Canada's network of protected areas, which now comprises more than 8% of the land and water base of the nation.

Against this backdrop, climate change now poses a serious, growing worldwide threat to biodiversity challenged by global warming and the protected areas dedicated to conserve it. Protected areas are vulnerable to shifts in climate regimes and the uncertainties that this poses for the persistence and distribution of species and ecosystems, and areas housing targeted assemblages of species, ecosystems and ecological functions today may not meet intended goals for biodiversity conservation under future climate scenarios. Strategies to confront this challenge must be based on sound projections of climate change and its impacts on biodiversity to guide initiatives that are nimble and responsive to emergent opportunities for conservation action.

This report provides an initial analysis of species turnover in Canada's existing network of federal, provincial and territorial protected areas implicated by climate change. It is based on a bioclimatic modelling approach using an Intergovernmental Panel on Climate Change (IPCC) mid- to high-range greenhouse gas (GHG) emissions scenario, combined with overlay digital mapping of protected areas and range distributions for native mammals, birds and amphibians. Temporal turnover scenarios are forecast for each taxa in three 30-year intervals up to 2100. The results are illuminating in many respects, notably with reference to the design criteria and spatial planning for protected areas:

- the core foundational construct of ecoregional representation based on "enduring features", first advanced in the Canadian Council on Ecological Areas (CCEA's) national framework for protected areas and adopted by most jurisdictions, has served as a sound blueprint for spatially planning protected areas and regional networks of sites that now capture very high proportions of Canada's mammalian, avian and amphibian fauna;
- the turnover of species in the targeted suite of protected areas that is ascribed to climate change over the forecast period, although necessarily of high concern, builds progressively with loading concentrated toward the end of the 21st century, thereby providing an extended timeframe to refine the spatial design and expand the layout of the existing network of protected areas; and,
- notwithstanding the granular resolution of this analysis, the findings already reveal potential hotspots in terms of species turnover and some geographical regions where this assessment can help to guide further study and inform necessary conservation actions.

In addition to the substantial analyses, results and conclusions presented in this report, this study offers a valuable science-based template for the assessment of other species assemblages. In particular, the assessment of native trees, other floristic groups, reptiles, marine and freshwater biota, species at risk, and others would provide additional insights on species, ecosystems and protected areas vulnerable to climate change. And finer-grain analyses of targeted species, protected areas and critical regions identified through these assessments could help to define spatial planning needs and adaptive management approaches that could lead efforts that help to mitigate the impacts of climate change.

The United Nations *Convention on Biological Diversity* and its *Strategic Plan for Biodiversity 2011-2020*, including Aichi Target 11 (reflected in Canada's Biodiversity Goals and Targets), commit Canada and other signatories to expand their systems of protected areas and other conservation sites to incorporate at least 17% of their land and inland waters and 10% of their coastal and marine waters by 2020. This commitment provides a significant opportunity to pursue the findings in this report. Confronting species turnover needs to be a primary goal in nation-wide efforts on protected areas and climate change that are designed to fulfill the commitment to Aichi Target 11 on three fronts:

1. completing work underway by CCEA to determine the full extent of the protected areas and other conserved lands and waters that contribute to Aichi Target 11;
2. identifying and establishing new protected areas, linkages and corridors to enhance representation and connectivity and strengthen ecological integrity and resilience of the protected areas system; and,
3. formulating and implementing plans for adaptive management to enhance species conservation that help to counter species turnover in specific protected areas and critical regions.

The United Nations 2015 *Paris Agreement* on Climate Change, stipulating zero net anthropogenic GHG emissions by the second half of the 21st century to keep global warming below 2°C (aiming for 1.5°C) in this century, now reinforces the commitment to Aichi Target 11. Protected areas provide many ecological functions and services that help to mitigate the impact of global warming, notably: conserving plants and animals in natural habitats; providing nodes and corridors to assist species' migration; helping to maintain critical environmental functions such as hydrological cycles; enhancing the resilience and integrity of regional ecosystems; purifying air and filtering water; sequestering carbon to help curb global warming; and, providing sites for research, environmental monitoring and education to provide insight and understanding about climate change and guide efforts on adaptive management. Accordingly, the vast Canadian network of protected areas is a significant global asset that is helping to combat climate change every day. Canada's commitment to curbing global warming under the *Paris Agreement* on Climate Change now presents another opportunity to enhance complementary efforts on protected areas and biodiversity conservation that will help to meet this goal.

This report is a worthy complement to earlier work by CCEA to provide guidance on the establishment and management of a comprehensive network of protected areas to represent Canada's ecological diversity. It validates the foundational approach for such a network first prescribed in CCEA's national framework. It reinforces CCEA's push for large protected areas in the North to maximize representation, ecological integrity and species persistence. It extends CCEA's national review on climate change and protected areas with timely guidance for spatial planning and conservation action. It invokes CCEA's interpretation of IUCN guidelines for protected areas including ongoing work to upgrade and manage the Conservation Areas Reporting and Tracking System (CARTS). And finally, it adds immediacy to CCEA's ongoing work to provide guidance on the recognition of those conserved lands and waters beyond formally recognized protected areas that contribute to biodiversity conservation and to lead efforts on spatial planning for new protected areas.

Clear goals, challenges and opportunities are forces that have regularly played out in the establishment and management of Canada's protected areas network since the creation of Banff National Park. Now confronted by climate change, Canada's commitments to protected areas, biodiversity conservation, the *Strategic Plan for Biodiversity 2011-2020*, and the *Paris Agreement* on Climate Change once again present a stage for conservation forces to perform with the hope that we can surmount the impending threats of global warming, including first and foremost the conservation of species on the edge. With this goal in mind, this report provides valuable insights into conservation needs, approaches and actions that can help to maintain species in protected areas and beyond that are vulnerable to climate change.

Karen Beazley and Tom Beechey
Associate Directors, Canadian Council on Ecological Areas

PRÉFACE

Des résultats positifs en conservation sont fondées sur la poursuite d'objectifs clairs, de défis à surmonter et d'exploitation des opportunités. Cette formule marque l'histoire du mouvement des aires protégées au Canada. En commençant par la création du parc national de Banff en 1885, la croissance progressive du réseau des aires protégées au Canada a été régulièrement ponctuée de poussées accélérées en réponse à des pressions sociales, économiques et environnementales associés à des possibilités d'action de conservation. L'expansion rapide suite à la période d'après guerre et surtout au cours des deux dernières décennies a résulté en une croissance sans précédent du réseau canadien des aires protégées, qui comprend maintenant plus de 8% de la superficie des terres et de l'eau de la nation.

Dans ce contexte, le changement climatique pose maintenant une menace mondiale croissante sérieuse pour la biodiversité, étant défiée par le réchauffement climatique et les aires protégées dédiées à la conserver. Les aires protégées sont vulnérables aux changements des régimes climatiques et les incertitudes que cela pose pour la persistance et la distribution des espèces et des écosystèmes, et les zones abritant des assemblages ciblées d'espèces, des écosystèmes et des fonctions écologiques, qui aujourd'hui risquent de ne pas atteindre les objectifs de conservation de la biodiversité dans le cadre des scénarios climatiques futurs. Les stratégies pour faire face à ce défi doivent être fondées sur des projections solides de changement climatique et de ses impacts sur la biodiversité pour guider les initiatives qui sont flexibles et sensibles aux opportunités émergentes en matière de conservation.

Ce rapport fournit une première analyse du changement des espèces dans le réseau canadien existant des aires protégées fédérales, provinciales et territoriales touchées par le changement climatique. Il est basé sur une approche de modélisation bioclimatique utilisant des scenarios de moyennes et de hautes émissions de gaz à effet de serre (GES) issus d'un groupe d'experts intergouvernemental sur l'évolution du climat (GIEC), le tout associé à une cartographie numérique superposée des aires protégées et à un éventail de distribution pour les mammifères, les oiseaux et les amphibiens. Des scénarios temporels sont prédits pour chaque taxon dans trois intervalles de 30 ans jusqu'à 2100. Les résultats sont révélateurs à bien des égards, notamment en référence aux critères de conception et d'aménagement du territoire pour les aires protégées:

- le principe de base de la représentation écorégionale, fondé sur des «caractéristiques durables», tel qu'initialement suggéré par le Conseil canadien des aires écologiques (CCAE) dans son cadre national pour les aires protégées et adopté par la plupart des entités gouvernementales, a servi de modèle solide pour la planification spatiale des aires protégées et des réseaux régionaux de sites qui incluent maintenant des proportions très élevées des mammifères, de la faune aviaire et des amphibiens du Canada;
- le changement des espèces dans la sélection ciblée des aires protégées qui est attribuée au changement climatique au cours de la période de prévision, bien que nécessairement très préoccupante, s'accentue progressivement avec une charge concentrée vers la fin du 21ème siècle, fournissant ainsi une période de temps prolongée pour affiner la conception spatiale et étendre la configuration du réseau existant des aires protégées; et,
- nonobstant la résolution granulaire de cette analyse, les résultats révèlent déjà les points chauds potentiels en termes de changement des espèces et certaines régions géographiques où cette évaluation peut aider à guider une étude plus approfondie et instruire les mesures de conservation nécessaires.

En plus des analyses, des résultats et des conclusions importantes présentées dans ce rapport, cette étude propose un modèle basé sur des données scientifiques précieuses pour l'évaluation d'autres assemblages d'espèces. En particulier, l'évaluation des arbres indigènes, d'autres groupes floristiques, les reptiles, les biotes marins et d'eau douce, les espèces en péril, et d'autres qui pourraient fournir des indications supplémentaires sur les espèces, les écosystèmes et les aires protégées vulnérables aux changements climatiques. Des analyses plus détaillées d'espèces ciblées, les aires protégées et les régions critiques identifiées par le biais de ces évaluations pourraient aussi aider à définir les besoins d'aménagement du territoire et des approches de gestion adaptative qui pourraient mener les efforts qui contribuent à atténuer les impacts du changement climatique.

La Convention sur la diversité biologique des Nations Unies et son *Plan stratégique pour la biodiversité 2011-2020*, dont l'Objectif 11 d'Aichi (reflété dans les buts et objectifs canadiens pour la biodiversité) engage le Canada et les autres signataires à étendre leurs systèmes d'aires protégées et d'autres sites efficaces de conservation pour y incorporer au moins 17% de leurs terres et eaux intérieures et 10% de leurs eaux côtières et marines d'ici à 2020. Cet engagement offre une occasion importante de poursuivre les conclusions de ce rapport. Face aux besoins que la rotation des espèces soit un objectif primordial dans les efforts à l'échelle nationale sur les aires protégées et le changement climatique, le respect de l'engagement à l'Objectif 11 d'Aichi est conçu sur trois fronts:

1. l'achèvement des travaux en cours par le CCAE pour déterminer l'étendue des aires protégées et d'autres terres et les eaux conservées qui contribuent à l'Objectif 11 d'Aichi;
2. l'identification et l'établissement de nouvelles aires protégées, de liens et de corridors pour améliorer la représentation et la connectivité, de renforcer l'intégrité écologique et la résilience du système des aires protégées; et,
3. la formulation et la mise en œuvre des plans de gestion adaptative pour améliorer la conservation des espèces qui aident à lutter contre le changement des espèces dans les aires protégées et des régions critiques.

L'Accord de Paris (2015) des Nations Unies sur les changements climatiques, stipulant des émissions nettes de zéro GES anthropiques d'ici la seconde moitié du 21e siècle pour maintenir le réchauffement climatique en dessous de 2° C (visant 1,5° C) dans ce siècle, renforce maintenant l'engagement à l'Objectif 11 d'Aichi . Les aires protégées offrent de nombreuses fonctions et services écologiques qui contribuent à atténuer l'impact du réchauffement climatique, notamment: la conservation des plantes et des animaux dans les habitats naturels; fournir des liens et des corridors pour faciliter la migration des espèces; aider à maintenir les fonctions critiques de l'environnement tels que les cycles hydrologiques; le renforcement de la résilience et de l'intégrité des écosystèmes régionaux; la purification de l'air et la filtration de l'eau; la séquestration du carbone pour aider à freiner le réchauffement climatique; et fournir des sites pour la recherche, la surveillance environnementale et de l'éducation afin d'augmenter notre compréhension du changement climatique et guider les efforts sur la gestion adaptative. Par conséquent, le vaste réseau canadien des aires protégées est un atout mondial important qui contribue à lutter contre le changement climatique chaque jour. L'engagement du Canada à la lutte contre le réchauffement climatique en vertu de *l'Accord de Paris* sur les changements climatiques présente maintenant une autre occasion de renforcer les efforts complémentaires sur les aires protégées et la conservation de la biodiversité qui aideront à atteindre cet objectif.

Ce rapport est un complément pertinent aux travaux antérieurs du CCAE qui vise à fournir des conseils sur la création et la gestion d'un réseau complet d'aires protégées pour représenter la diversité écologique du Canada. Il valide l'approche fondamentale pour un tel réseau prescrit dans le cadre national du CCAE. Il renforce les efforts du CCAE pour de grandes aires protégées dans le Nord afin de maximiser la représentation, l'intégrité écologique et la persistance des espèces. Il bonifie l'examen national du CCAE sur les changements climatiques et les aires protégées avec des conseils en temps opportun pour l'aménagement du territoire et à l'action de conservation. Il invoque l'interprétation du CCAE des lignes directrices de l'UICN pour les aires protégées, y compris les travaux en cours pour améliorer et gérer le Système de rapport et de suivi des aires de conservation (SRSAC). Enfin, il ajoute aux travaux en cours du CCAE en fournissant des conseils sur la reconnaissance des autres terres et des eaux conservées que celles des aires protégées officiellement reconnues qui contribuent à la conservation de la biodiversité et à diriger les efforts sur l'aménagement du territoire pour les nouvelles aires protégées.

Des objectifs clairs, des défis et des opportunités sont les forces qui ont régulièrement joué dans l'établissement et la gestion de la protection du réseau des aires protégées du Canada depuis la création du parc national Banff. Maintenant confronté par le changement climatique, les engagements du Canada sur les aires protégées, la conservation de la biodiversité, le *Plan stratégique pour la biodiversité 2011-2020*, et *l'Accord de Paris* sur les changements climatiques présentent à nouveau une plateforme pour les forces de conservation à se manifester avec l'espoir que nous pouvons surmonter les menaces imminentes de réchauffement de la planète, y compris en premier lieu la conservation des espèces près de l'extinction. Avec cet objectif en mémoire, ce rapport fournit des indications précieuses sur les besoins de conservation, les approches et les actions qui peuvent aider à maintenir les espèces dans les aires protégées et ailleurs qui sont vulnérables aux changements climatiques.

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EXECUTIVE SUMMARY

Anthropogenic climate change has and will continue to alter ecological conditions in the coming decades, and with that, biodiversity. This report presents an exploratory analysis to provide a Canadian perspective on conservation implications of potential range shifts of wildlife species in response to projected changes in climate. It aims to inform conservation advisors, planners and managers of the extent, magnitude and timing of potential changes (relative to current) over the 21st century in the early (2011-2040, or the 2020s), mid (2041-2070, or the 2050s) and late (2071-2100, or the 2080s) time period. The analysis was based on a dataset produced using a bioclimatic modelling approach to simulate shifts in the distributions of 543 species of terrestrial vertebrates (132 mammals, 39 amphibians, 372 birds) that currently occur or are projected to expand into Canada under a mid- to high-range emissions scenario (Intergovernmental Panel on Climate Change [IPCC] Emissions Scenario A2). Two dispersal scenarios were assumed for each 30-year time period: full dispersal and no dispersal. Full dispersal assumes that species can track changing climatic conditions; no dispersal assumes they cannot. For each dispersal scenario, species losses and gains were calculated for each analysis unit and for each time period. Species turnover was calculated by combining losses and gains, relative to present.

Assuming a full-dispersal scenario, local turnover (species loss plus gain relative to present) at a 50-km grid scale in Canada was projected to be 25% or more by the 2020s for all taxa relative to current, increasing to over 100% for the 2080s. In a no-dispersal scenario, however, several cells show no (0) turnover, and very few show greater than 25% by the 2020s; but by the 2050s, few grid cells show no turnover and more show losses above 25%; these patterns expand through the 2080s. The differences between the full- and no-dispersal results are attributable to gains in the full-dispersal scenario. The results reveal a strong geographical gradient, with the greatest changes occurring at more northern latitudes and eastern longitudes centred on the boundary of the Taiga Shield/Hudson Plain and the Arctic Plains/Mountains ecoregions in the North West Territories, Nunavut, Quebec and Newfoundland and Labrador.

The 50-km grid results were combined to generate species gain or loss in all of Canada, in different systems of protected areas (federal, Environment and Climate Change Canada[1], Parks Canada Agency, provincial/territorial, all combined) and for a selection of active conservation planning initiatives: Bird Conservation Regions (BCRs), the Nunavut Settlement Area, and the Acadian/Northern Appalachian ecoregion in eastern Canada and the USA. The system of protected

Northern protected areas will continue to be an important means to protect migratory birds, such as Tundra Swan (*Cygnus columbianus*), even though climate change may impact species in some areas. Location: Kendall Island Migratory Bird Sanctuary, Mackenzie Delta, Northwest Territories (Photo Credit: courtesy Canadian Wildlife Service).

areas in Canada represented 99% of the species modelled and currently in Canada; representation was lowest in the national parks system at 93%. For multi-grid cell analysis units, species loss was consistently higher (median of 2 species more or 1-2% of current) assuming no dispersal than full dispersal for species. For Canada as a whole and for the entire system of protected areas, species turnover relative to current for all assessed taxa was projected to be 3% by the 2020s assuming full dispersal, and 2% assuming no dispersal. Turnover increased to 5% by the 2050s and 8-9% by the 2080s with full dispersal, and remained at 2% by the 2050s and 2080s with no dispersal. Parks Canada's national parks system, which is currently managed for ecological integrity, had the highest projected turnover of any protected area system across all time periods with 6% turnover (mostly gains) involving 27 species of all assessed taxa by the 2020s with full dispersal, and 2% turnover involving 10 species with no dispersal.

While the criterion used to map the existing systems of protected areas to the 50-km grid overestimated coverage, it does suggest that the distribution of the existing system, particularly in the southern parts of Canada, has the potential to provide provisional habitat for those species capable of shifting in response to changing conditions. Real-world losses in southern Canada, however, are likely to be more significant than the results would suggest, given the over-representation of protection; in southern settled regions, protected areas are small yet numerous and dispersed enough to result in widespread coverage when mapped to the 50-km grid. Another challenge appears to be in northern regions where faunal change is projected to be the greatest and a spatial mismatch is evident with the existing system of protected areas.

When changes for 24 Bird Conservation Region planning units in Canada were tallied across all time periods, the magnitude of loss was consistently higher assuming no dispersal (median 17 to 19 species or 9.3 to 10.1%) than full dispersal (median 11 to 12 species or 6.5 to 7.1%) with the highest loss in the Prairie Potholes and the Great Lakes-St. Lawrence Plains in Quebec. The median gain relative to current was between 25 and 28 species (or 15.3% to 15.8%) and was highest in the Arctic Plains/Mountains in Quebec and in Newfoundland.

For the Nunavut Settlement Area, the Acadian/Northern Appalachian Ecoregion and its system of protected areas, species loss overall was higher (median of 1 species) for the no-dispersal than the full-dispersal scenario, due primarily to differences for mammals and birds. By the 2020s under the full-dispersal scenario, the Nunavut Settlement Area had a projected loss of 2 species (both birds) and a gain of 41 species (7 mammals, 1 amphibian, 33 birds), for a turnover of 29% relative to current. In the no-dispersal scenario, projected losses were 3 species (1 mammal, 2 birds), for a turnover of 2% relative to current. By the 2080s, full-dispersal turnover was 60% relative to current with a loss of 3 species (1 mammal, 2 birds) and a gain of 86 species (19 mammals, 1 amphibian, 66 birds); no-dispersal turnover was 6% relative to current with a loss of 9 species (3 mammals, 6 birds). Based on the 50-km grid results, the southern parts of Nunavut and the Nunavut Settlement Area were projected to have some of the highest magnitudes of change in Canada, even within the next 30 years. Establishment of enhanced conservation measures in this region would provide an important hedging strategy against climate change.

By the 2080s, assuming full dispersal, the Acadian/Northern Appalachian (A/NA) ecoregion had a projected turnover of 10% relative to current with a loss of 12 species (2 mammals, 10 birds) and a gain of 17 species (4 mammals, 2 amphibians, 11 birds). With no dispersal, the ecoregion had a projected turnover of 6% with a loss of 17 species (4 mammals, 13 birds).

Although the fine-scale projections remain uncertain, the broad-scale changes revealed by this analysis are likely robust. Estimations of losses are likely to be highly conservative, especially in southern Canada; a finer resolution analysis and additional sets of species are likely to reveal higher losses and lower gains. On the other hand, the incorporation of conservation authority lands, those protected by land trusts and other contributing properties to Canada's biodiversity targets into such analyses would also affect the results and may offset projected losses. However, even with uncertainties, given the urgent need to respond to a changing climate for Canada, it seems prudent to begin adaptation action now based on the information available, put monitoring schemes in place to track changes, and be prepared to modify policies, plans and actions in response to the evidence base. This study highlights a number of key actions necessary to better adapt to climate changes, including further analyses and assessments at finer scales and on a larger number of species, monitoring species in selected areas against modelled and real-world changes, and incorporating climate change in the design of resilient networks of protected areas. Combined with Canada's commitment to the United Nations 2015 *Paris Agreement* on Climate Change, the study provides a good basis upon which to engage informed discussions of spatial planning for protected areas, the *Strategic Plan for Biodiversity 2011-2020*, and biodiversity conservation beyond 2020.

[1]The name of Environment Canada was changed to Environment and Climate Change Canada after the study was completed. Elsewhere in the report, Environment Canada has been retained to reflect the name at the time of the study.

RÉSUMÉ EXÉCUTIF

Le changement climatique anthropique a et continuera à modifier les conditions écologiques dans les prochaines décennies et, avec cela, la biodiversité. Ce rapport présente une analyse exploratoire pour fournir une perspective canadienne sur les implications de conservation des migrations potentielles d'espèces sauvages en réponse aux changements climatiques projetés. Il vise à informer les conseillers en conservation, les planificateurs et les gestionnaires de l'étendue, de l'ampleur et de la période des changements potentiels (par rapport au présent) au cours du 21e siècle, au début (2011-2040, ou les années 2020), à la mi (2041-2070, ou 2050s) et à la fin (2071-2100 ou 2080). L'analyse a été basée sur un ensemble de données produites en utilisant une approche de modélisation bioclimatique pour simuler des changements dans les distributions de 543 espèces de vertébrés terrestres (132 mammifères, 39 amphibiens, 372 oiseaux) qui se produisent actuellement ou qui sont projetés de s'étendre au Canada en vertu de scénario d'émissions moyens à élevés (Groupe d'experts intergouvernemental sur l'évolution du [GIEC] Emissions climatiques scénario A2). Deux scénarios de dispersion ont été avancés pour chaque période de 30 ans: pleine dispersion et aucune dispersion. La dispersion complète suppose que les espèces peuvent suivre l'évolution des conditions climatiques; aucune dispersion suppose qu'ils ne le peuvent pas. Pour chaque scénario de dispersion, les pertes et les gains en espèces ont été calculés pour chaque unité d'analyse et pour chaque période de temps. Le changement des espèces a été calculé en combinant les pertes et les gains, par rapport au présent.

En supposant un scénario complet de dispersion, le changement local (perte d'espèces, plus le gain par rapport à aujourd'hui) à l'échelle du réseau de 50 km au Canada a été projeté pour être 25% ou plus dans les années 2020 pour tous les taxons par rapport au présent, passant à plus de 100% pour les années 2080. Dans un scénario sans dispersion, cependant, plusieurs cellules ne présentent pas (0) de changement et très peu montrent une valeur supérieure à 25% d'ici les années 2020; mais d'ici les années 2050, très peu de cellules de la grille ne présentent pas de pertes de changement et plus encore montrent au-delà de 25%; ces tendances augmentent dans les années 2080. Les différences entre les résultats de pleine dispersion et sans dispersion sont attribuables à des gains dans le scénario de dispersion complète. Les résultats révèlent un gradient géographique marqué, avec les plus grands changements qui se produisent à des latitudes septentrionales et aux longitudes Est centrées sur la limite entre le Bouclier de la Taïga et la plaine d'Hudson et les Plaines Arctiques / écoregions de Montagne dans les Territoires du Nord-Ouest, du Nunavut, du Québec et de Terre-Neuve / Labrador.

Les résultats de la grille de 50 km ont été combinés pour générer un gain de l'espèce ou de la perte dans l'ensemble du Canada, dans les différents systèmes d'aires protégées (fédéral, Environnement et Changement Climatique Canada[1], l'Agence Parcs Canada, provincial / territorial, tout combiné) et pour une sélection d'initiatives actives d'activités de planification de la conservation: régions de conservation des oiseaux (RCO), la région d'établissement du Nunavut, et l'écorégion acadienne/ Appalaches Nord dans l'est du Canada et des États-Unis. Le système des aires protégées au Canada représentait 99% des espèces modélisées et actuellement présentes au Canada; la représentation était la plus faible dans le réseau des parcs nationaux à 93%. Pour les analyses multi- unités d'analyse de cellules, la perte d'espèces était toujours plus élevé (médiane de 2 espèces plus ou 1-2% du présent) en supposant l'absence de dispersion plutôt qu'une pleine dispersion des espèces. Pour l'ensemble du Canada et pour l'ensemble du système des aires protégées, les changements d'espèces par rapport au présent pour tous les taxons évalués ont été projetés à 3% dans les années 2020 en supposant une pleine dispersion, et à 2% en supposant l'absence de dispersion. Le changement a augmenté à 5% dans les années 2050 et à 8-9% d'ici 2080 avec une pleine dispersion, et est resté à 2% dans les années 2050 et 2080 sans dispersion. Le réseau des parcs nationaux de Parcs Canada, qui est actuellement géré pour l'intégrité écologique, avait le changement le plus marqué prévu parmi tous les système d'aires protégées dans toutes les périodes de temps avec un changement de 6% (principalement des gains) impliquant 27 espèces de tous les taxons évalués d'ici les années 2020 avec la pleine dispersion, et le changement de 2% impliquant 10 espèces sans dispersion.

Bien que le critère utilisé pour cartographier les systèmes existants d'aires protégées à une grille de 50 km surestime la couverture, il ne suggère pas que la distribution du système existant, en particulier dans les régions du sud du Canada, a le potentiel de fournir un habitat provisoire aux espèces capable de se déplacer en réponse à des conditions changeantes. Les pertes réelles dans le sud du Canada, cependant, sont susceptibles d'être plus importantes que celles suggérées, compte tenu de la surreprésentation de la protection; dans les régions méridionales habitées, les aires protégées sont petites mais nombreuses, assez pour entraîner une large couverture dispersée lors de la projection à la grille de 50 km. Un autre défi semble résider dans les régions nordiques où le changement faunique devrait être le plus important et une discordance spatiale est évidente avec le système existant d'aires protégées.

Lorsque des modifications pour 24 unités de planification de Régions de conservation des oiseaux au Canada ont été comptées dans toutes les périodes de temps, l'ampleur de la perte était toujours plus élevée en supposant aucune dispersion (médiane 17 à 19 espèces, soit 9,3 à 10,1%) une dispersion complète (médiane 11 à 12 espèces ou 6,5 à 7,1%) avec la plus grande perte dans les "potholes" des Prairies, des Plaines des Grands Lacs et du Saint-Laurent au Québec. Le gain moyen par rapport au présent se situait entre 25 et 28 espèces (ou 15,3% à 15,8%) et était le plus élevé dans le Plaines de l'Arctique / Montagnes au Québec et à Terre-Neuve.

Pour la région d'établissement du Nunavut, de l'écorégion Acadienne/ Appalaches du nord et son système d'aires protégées, la perte d'espèces était globalement plus élevé (médiane de 1 espèce) pour le scenario de non-dispersion que le scénario complet de dispersion, principalement en raison des différences pour les mammifères et les oiseaux. Pour les années 2020, selon le scénario complet de dispersion, la région d'établissement du Nunavut a enregistré une perte projetée de 2 espèces (deux oiseaux) et un gain de 41 espèces (7 mammifères, 1 amphibiens, 33 oiseaux), pour un changement de 29% par rapport au présent. Dans le scénario sans dispersion, les pertes projetées étaient 3 espèces (1 mammifère, 2 oiseaux), pour un changement de 2% par rapport au présent. En 2080, le changement en pleine dispersion était de 60% par rapport au présent avec une perte de 3 espèces (1 mammifère, 2 oiseaux) et un gain de 86 espèces (19 mammifères, 1 amphibiens, 66 oiseaux); sans dispersion, le changement était de 6% par rapport au présent avec une perte de 9 espèces (3 mammifères, 6 oiseaux). Sur la base des résultats de la grille de 50 km, les régions du sud du Nunavut et la région d'établissement du Nunavut ont été projetées pour avoir certaines des plus hautes amplitudes de changement au Canada, même au cours des 30 prochaines années. La mise en place de mesures renforcées de conservation dans cette région constituerait une stratégie de préservation importante contre le changement climatique.

D'ici 2080, en supposant une dispersion entière, l'écorégion Acadienne/ Appalaches du Nord (A / NA) avait un changement prévisionnel de 10% par rapport au présent avec une perte de 12 espèces (2 mammifères, 10 oiseaux) et un gain de 17 espèces (4 mammifères, 2 amphibiens, 11 oiseaux). En l'absence de dispersion, l'écorégion avait un changement prévisionnel de 6% avec une perte de 17 espèces (4 mammifères, 13 oiseaux).

Bien que les projections à une échelle fine restent incertaines, les changements à grande échelle mis en évidence par cette analyse sont certainement solide. Les estimations des pertes sont susceptibles d'être très conservatrices, en particulier dans le sud du Canada; une analyse plus fine de la résolution et des ensembles supplémentaires d'espèces sont susceptibles de révéler des pertes plus élevées et des gains inférieurs. D'autre part, l'incorporation de terres en conservation, celles qui sont protégées par des fiducies foncières et d'autres propriétés qui contribuent aux objectifs de la biodiversité du Canada dans ces analyses pourraient également affecter les résultats et compenser les pertes projetées. Cependant, même avec des incertitudes, compte tenu de la nécessité urgente de répondre à l'évolution du climat pour le Canada, il semble prudent de commencer les mesures d'adaptation maintenant sur la base des informations disponibles, mettre des systèmes de surveillance en place pour suivre les changements et être prêt à modifier les politiques, les plans et les actions à la lumière des données existantes. Cette étude met en évidence un certain nombre d'actions clés nécessaires pour mieux s'adapter aux changements climatiques, y compris d'autres analyses et des évaluations à des échelles plus fines et sur un plus grand nombre d'espèces, la surveillance dans les zones sélectionnées contre les changements modélisés et le monde réel, et l'intégration du changement climatique dans la conception des réseaux résilients d'aires protégées. Combiné à l'engagement du Canada à *l'Accord de Paris* (2015) des Nations Unies sur les changements climatiques, l'étude fournit une bonne base sur laquelle engager des discussions éclairées sur l'aménagement du territoire pour les aires protégées, le *Plan stratégique 2011-2020* pour la biodiversité et la conservation de la biodiversité au-delà de 2020.

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[1]Le nom Environnement Canada a été changé pour Environnement et Changement climatique Canada après que l'étude ait été terminée. Ailleurs dans le rapport, Environnement Canada a été retenu pour refléter le nom de ce ministère au moment de l'étude.

INTRODUCTION

In 2010, the Canadian Council on Ecological Areas (CCEA) published the first major review and synthesis on climate change and adaptation in relation to protected areas in Canada (Lemieux et al. 2010, subsequently 2011a,b). It makes the case that protected areas play a vital role in adapting to the effects of climate change in Canada (and elsewhere), in protecting the livelihoods of Canadians, and in working towards achieving objectives outlined in national and international conservation agreements, policies and plans. As of 2011, Canada's terrestrial protected areas (not including areas under private conservation) numbered 5,771, spanning 102.4 million hectares and representing 9.6% of Canada's total land base (Figure 1, Figure 2). Protected areas are important because they help to mitigate effects of climate change on biodiversity by retaining intact ecosystems and facilitating the movement of species responding to changing conditions. An analysis by Kharouba and Kerr (2010) of historical butterfly distributions suggests that the greatest potential of protected areas is as stepping stones for species shifting in response to changing climates, especially in the north. A projection by Lemieux and Scott (2005) indicates that 15-70% of protected areas in Canada could experience a biome shift from climate change. Using a dataset for 150 bird species in the eastern USA, Olson and Lindsay (2009) have found that reserve networks designed using the current species distributions are likely to lose 21-32% of species in two climate-change scenarios as a result of projected species shifts. In addition, shifts in the geography of conservation priority from the present to climate-change futures suggest a need for additional protected areas in locations identified as of future conservation priority (Olson and Lindsay 2009).

In surveying the state of current efforts on climate-change adaptation employed by protected areas agencies and organizations in Canada, Lemieux et al. (2010) found that no agencies surveyed had a climate-change adaptation strategy or action plan in effect. Since that time, a few provinces have begun to develop climate-change adaptation strategies

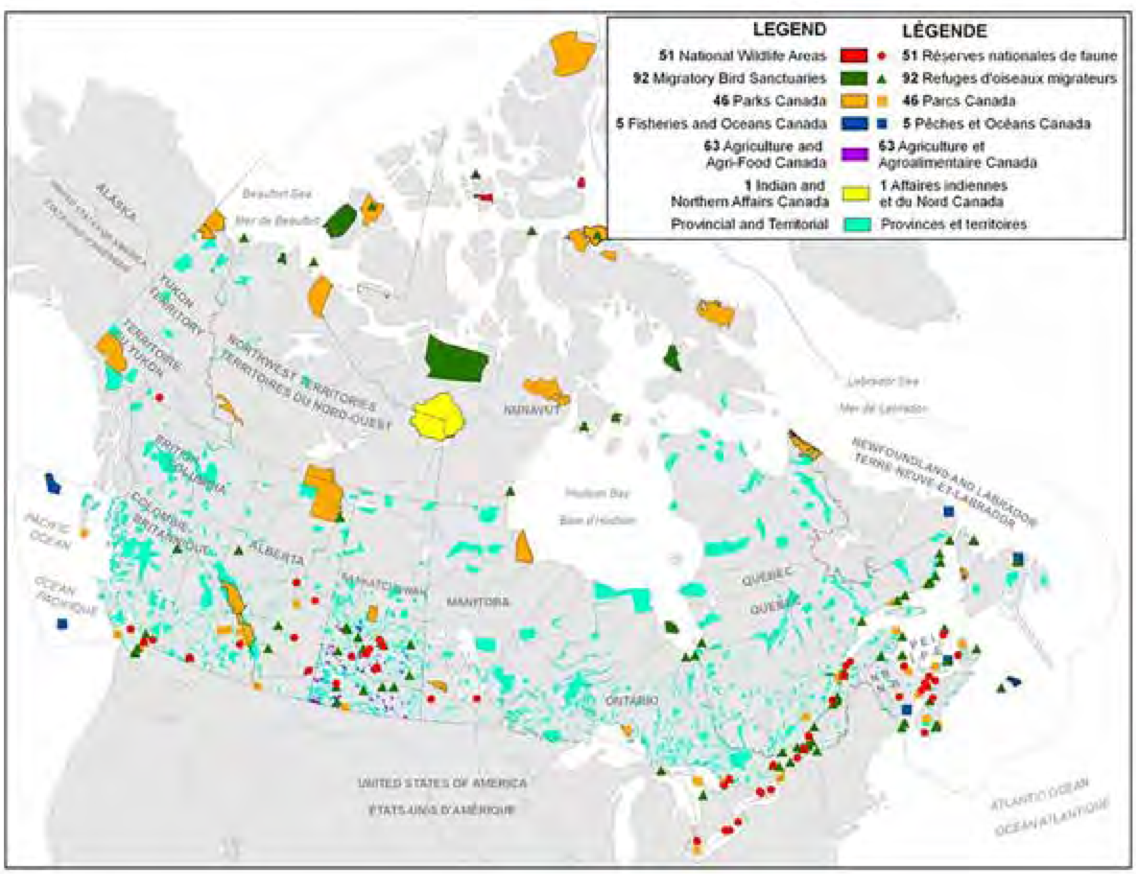


Figure 1: Protected areas in Canada used as a basis for the analysis (CARTS/CCEA 2011). Small sites are not conspicuous for southern Ontario and other southern settled regions due to limitations of scale. Due to limitations in the database, the analysis did not include many areas owned by private conservation organizations involved in securing and managing natural areas.

(Canadian Parks Council 2013). To inform those processes there is a need for more information on the ecological consequences and implications of climate change, including impacts on biodiversity. According to Canada's 4th national report to the *Convention on Biological Diversity* (Government of Canada 2009), the means of maintaining and enhancing resilience of the components of biodiversity to adapt to climate change (Goal 7.1) are poorly understood and the status is getting worse due to recent climate-change-induced impacts on species and ecosystems. A lack of scientific evidence to support decision-making could compromise outcomes and jeopardize investments made in biodiversity conservation.

Lemieux et al. (2010) argue that a key strategy for protected area design in a changing climate is to define, delineate and protect entire ecosystems either directly in protected areas and/or indirectly through cooperative management in the context of a greater parks ecosystem approach to management. This objective is made all the more feasible in Canada due to: (1) the trend over the last two decades towards ecosystem-based management that seeks to meet human requirements to use natural resources, while maintaining the biological richness and ecological processes necessary to sustain the composition, structure and function of the habitats or ecosystems concerned; (2) the increasing integration of system planning for protected areas with more comprehensive land-use planning in Canada; and, (3) the continued efforts of many jurisdicitons to expand their protected area systems, and other conservation initiatives such as private land conservation by land trusts. Examples of international conservation initiatives for Canada include the Yellowstone to Yukon (Y2Y), the Algonquin to Adirondack (A2A), and ecoregional planning in the Acadian/Northern Appalachian ecoregion of eastern Canada and the USA (e.g., Trombulak and Baldwin 2010, www.2c1forest.org). The Canadian Boreal Initiative is currently working with governments, conservation organizations, First Nations, industry and other interested parties to protect at least 50% of the Boreal in a network of large, interconnected protected areas (www.borealcanada.ca).

The present analysis addresses the information needed for the development of adaptation strategies and action plans for protected areas and broader-scale conservation planning and wildlife management in Canada. It is a pilot effort to explore different types of analyses that may prove useful for adapting conservation planning in a climate change context. It uses an analytical tool to project potential species losses, gains and turnover on the basis of range shifts predicted from climate change models relative to current numbers of species. The study focuses on the modelled response of mammal, amphibian and bird species in Canada as a whole. It also examines how those species respond to projected climate change across Canada's federal, provincial and territorial protected areas systems and in a number of areas where regional-scale conservation planning is underway, namely, Bird Conservation Regions[1], the Nunavut Settlement Area[2], and the Acadian/Northern Appalachian Ecoregion[3] in eastern Canada and the USA. Several spatial frameworks are selected for analysis in order to (1) differentiate implications for various responsible agencies and jurisdictions, (2) compare results across various geographical scales and planning units, and (3) highlight potential policy implications. The results are illustrative of a method that assesses two extreme scenarios: no dispersal and full dispersal of species under projected climate change. Consequently, actual outcomes are more likely to lie somewhere between the two extremes.

The analysis utilizes methods developed by Lawler et al. (2009) who used bioclimatic modelling (i.e., using biologically relevant variables based on temperature, sunshine, precipitation and soil texture) to project the ranges of 1818 birds, 723 mammals and 413 amphibians in the Western Hemisphere for a 30-year time period from 2071 to 2100 using future climates from a mid-range (A1B) green house gas emissions

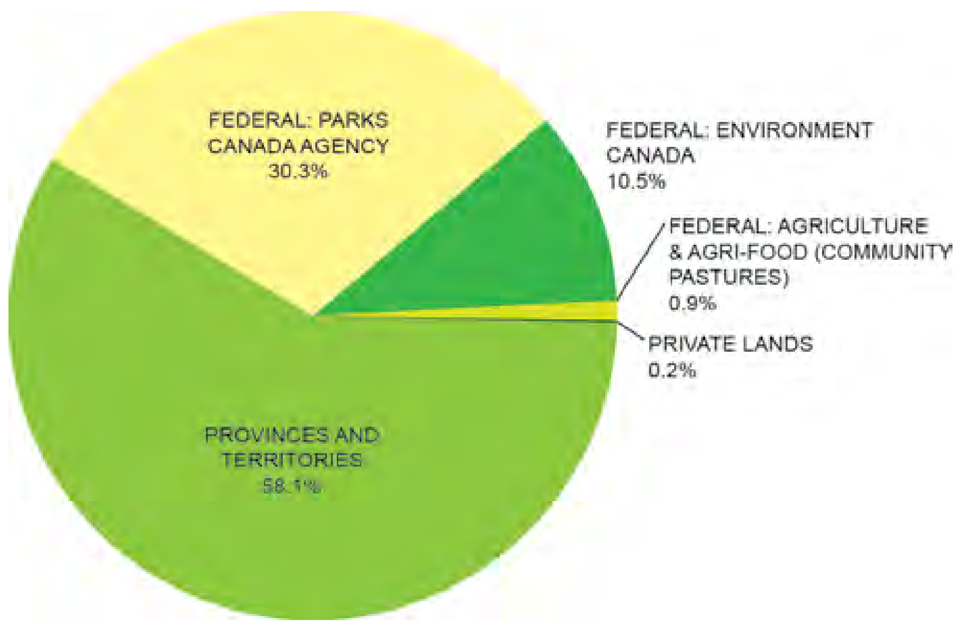
[1] Planning for Bird Conservation Regions (BCRs) is currently being undertaken by Environment Canada to respond to the need for integrated and clearly articulated conservation priorities for birds in Canada to support the implementation of its migratory birds program, both domestically and internationally in collaboration with other planners, land managers and decision-makers (Kennedy and Krebs 2010). The suite of all-bird conservation plans for the 25 planning units in Canada (the 12 BCRs found in Canada divided into jurisdictional planning units; refer to Figure 13) builds on the North American Bird Conservation Initiative for shorebirds, waterbirds, waterfowl and landbirds and integrates actions outlined in recovery documents for birds that are listed as Species at Risk.

[2] Following ratification of the Nunavut Land Claims Agreement (signed in 1993), the Nunavut Planning Commission (NPC) was established with the responsibility to develop, implement and monitor land use plans in the Nunavut Settlement Area (which comprises all but the most southern areas of Nunavut). The NPC currently implements two approved land use plans in the Nunavut Settlement Area (NSA) developed during the 1990s: the *North Baffin Regional Land Use Plan* and the *Keewatin Regional Land Use Plan*. A land use plan for the entire NSA is currently being developed and will replace these plans when it is approved. It will set policies and objectives regarding the conservation, development, management and use of land in the NSA.

[3] A consortium of Canadian and American scientists and non-government organizations, under the auspices of the Two Countries/One Forest (2C1F) (Deux Pay/Une Forêt) conservation initiative, is identifying priorites for landscape conservation and regional linkages in the Northern Appalachian/Acadian ecoregion of Canada and the USA (Trombulak and Baldwin 2010, www.2c1forest.org).

scenario. Lawler et al. (2009) found that 80% of the ten climate projections resulted in local loss of at least 10% of the vertebrate fauna over much of North and South America. The areas projected to have the largest changes included the Canadian tundra with over 90% turnover (species gain plus loss) in local species composition relative to the current number of species. The results for Canada were provided by Lawler to the Canadian Wildlife Service of Environment Canada and used to conduct a preliminary vulnerability assessment of existing protected areas and those proposed for designation under the *Northwest Territories Protected Areas Strategy* (Baril and Lindsay 2009). Those results serve as an impetus for the present analysis, which extends the work of Lawler et al. (2009) and the Canadian Wildlife Service (Baril and Lindsay 2009). The analysis projects species' range shifts over the course of the 21st century using three 30-year time periods (2011-2040, 2041-2070, and 2071-2100) and a mid- to high-range emissions scenario (A2; New et al. 2011), currently used by the Intergovernmental Panel on Climate Change (http://www.ipcc-data.org/sim/gcm_clim/SRES_TAR/ddc_sres_emissions.html), to assess the projected magnitude, extent and timing of change in Canada.

The bioclimatic modelling approach has been validated using historical data for distribution shifts of 116 bird species in Britain (Araújo et al. 2005). The bioclimatic models are based not only on the climatic constraints on species' distributions, but also on any biotic interactions, human land-use effects, historic extirpations, or other constraints on species' fundamental niches that are evident at a coarse spatial resolution. The climatic variables in the models act as proxies, albeit imperfect ones, for many of these other factors. For species with ranges or habitat relationships that are strongly determined by climate, the models will more accurately project range shifts. This is likely to be the case for many species when models are applied at a coarse spatial resolution. In fact, many of the documented shifts in species distributions have been in directions and at rates that correspond directly with climatic changes and currently outweigh other potentially counteractive forces such as habitat loss and fragmentation (Parmesan and Yohe 2003).



JURISDICTION	TOTAL AREA (KM2)	TOTAL AREA (%)
Provinces and territories	605,758 KM^2	58.1%
Federal: Parks Canada Agency	315,912 KM^2	30.3%
Federal: Environment Canada	109,474 KM^2	10.5%
Federal: Agriculture and Agri-Food Canada (community pastures)	9,383 KM^2	0.9%
Private lands	2,085 KM^2	0.2%
TOTAL AREA OF PROTECTED AREAS IN CANADA	1,042,612 KM^2	100%

Figure 2. Overview of the relative contributions of the federal, provincial and territorial, and private sectors in Canada's network of protected areas (CARTS/CCEA 2011).

METHODS

To project climate-induced faunal change in Canada, the methods, data and modelled results previously utilized and generated by Lawler et al. (2009) for the entire Western Hemisphere were used. Species-range mapping, climate modelling, bioclimatic modelling of future ranges, and analyses of faunal changes were conducted for various analytical units in Canada. Current geographic ranges for species were based on digital range maps for birds, mammals, and amphibians. A 50-km grid was used to map continental-scale climate patterns that influence species distributions. Modelling of species' ranges and faunal changes were conducted for 543 species whose current and future ranges are predicted to exist in Canada, including 39 that do not currently exist yet are predicted to occur in future scenarios (see Appendix 1 for a list of species assessed). These methods are summarised in the following sections. For a detailed description of methods, see Lawler et al. (2006, 2009).

SPECIES-RANGE MAPPING

Current geographic ranges for species that occur or are projected to occur in Canada under climate change were based on digital range maps for birds (Ridgely et al. 2003; breeding range only), mammals (Patterson et al. 2003) and amphibians (data available online: www.globalamphibians.org) mapped to a 50 × 50 km grid. This grid size was used to strike a balance between the resolution of digital species range maps and mapping projections of climate variables (see Lawler et al. 2009 for additional explanation). While this resolution is appropriate for these coarse-scale data, it represents a spatial mismatch with finer-scale species distribution and protected areas data. As a consequence, the spatial specificity and reliability of projections are limited by the coarse scale of the analysis.

CLIMATE MODELLING

The 50 × 50 km grid was used to map continental-scale climate patterns that influence species distributions. Current climate was set as a 30-year mean climatology for the years 1961 to 1990, created from cloud cover, temperature, precipitation and sunshine data. To project future ranges of species, ten climate simulations were used from ten coupled atmosphere–ocean general circulation models (AOGCMs) as in Lawler et al. (2009) but based on the mid- to high-range A2 emissions scenario. The use of ensembles of coupled AOGCMs developed at different modelling centres has become the standard approach in climate projection from seasonal to interannual to centennial time scales (IPCC 2007). The ten simulations were used to create bioclimatic variables based on temperature, sunshine and precipitation data (Appendix 2; Lawler et al. 2009) by averaging monthly data for each 30-year time period, namely, 2011-2040 (hereafter referred to as the 2020s), 2041-2070 (hereafter 2050s), and 2071–2100 (hereafter 2080s).

To validate the climate simulations for Canada by Lawler et al. (2009), the ten AOGCMs ensemble they used were compared to projections from the Canadian ensemble of the 24 AOGCMs used in the IPCC Fourth Assessment Report (IPCC 2007) for the A2 emissions scenario. The projections based on the Lawler set and the Canadian ensemble were similar for 14 protected areas in different ecoregions across the country. Small differences were observed but were considered acceptable given the uncertainty in overall global climate modelling. Thus, the use of the simulations used by Lawler et al. (2009) was judged to be an acceptable alternative to the Canadian ensemble approach for projecting future climate conditions for Canada.

BIOCLIMATIC MODELLING OF SPECIES RANGES

A bioclimatic model of the current range of each species was constructed in relation to current climate conditions. Only those models that correctly predicted at least 80% of the presences and at least 90% of the absences in test datasets were used because they were found to produce more accurate predictions of species' current ranges than other commonly used approaches (details in Lawler et al. 2006, 2009). Bioclimatic models were constructed for 543 species in Canada, 39 (7%) of which only occur in future scenarios (see Appendix 1 for species list), comprised of 132 mammals (9 of which occur only in future), 39 amphibians (9 of which occur only in future) and 372 birds (21 of which occur only in future). The future climate projections for each of the ten AOGCMs for each time period were then used to generate potential future ranges for each species.

ANALYSIS OF CHANGE

Each of the ten climate-change projections was used to estimate potential faunal changes by 50 × 50 km grid cell for each 30-year time period as compared against current. The median of model predictions was used as the cut-off for predicting presence in a grid cell in each time period (i.e., the species had to be present in the grid cell in six or more of the ten model predictions in order to be considered present).

Because species will differ in their ability to move into newly suitable habitat as climate changes, potential faunal changes on a grid-cell basis were calculated assuming two scenarios:

1. **Full dispersal,** in which species can disperse into new areas with suitable climatic conditions; and conversely,
2. **No dispersal,** in which species cannot disperse into new suitable areas.

The actual responses of species will likely fall between these two extremes. For each grid cell, the following were used to estimate faunal change.

Species loss: Calculated for each cell as the number of species and the percentage of all species currently modelled to occur in the cell whose projected future range did not include the cell.

Species gain: Calculated for each cell as the number and percentage of species occurring in a cell as a result of a projected range expansion relative to the current species in the cell. Gains can only occur in the full-dispersal scenario because by definition species cannot move into new cells in the no-dispersal scenario.

Species turnover: Calculated as a composite measure of species losses plus gains in a cell, expressed both as the number of species and as a percentage relative to the species currently occurring in the cell. In the no-dispersal scenario, because gains are not possible by definition, turnover is identical to loss.

Species loss, gain and turnover were generated and mapped for Canada at the 50 × 50 km cell resolution and used to generate results for 11 analysis areas: (1) Canada as a whole; (2) five protected area systems, including (i) all protected areas collectively in Canada, (ii) all federal protected areas (i.e., under the jurisdiction of Parks Canada Agency and Environment Canada), (iii) Parks Canada Agency protected areas (National Parks), (iv) Environment Canada protected areas (National Wildlife Areas and Migratory Bird Sanctuaries), and (v) protected areas under the jurisdiction of provincial and territorial governments; (3) (i) Bird Conservation Regions (BCRs), and (ii) the system of protected areas within a sample of those BCRs; (4) the Nunavut Settlement Area; and, (5) the binational (i) Acadian/Northern Appalachian (A/NA) ecoregion, and (ii) its system of protected areas. Within each multi-celled analysis area, a species only needs to remain in one grid cell to qualify as "present". In the full-dispersal scenario, species loss in any grid cell can be mitigated by species gain in another grid cell within the analysis area.

Canada's protected areas network (Figure 1) was mapped to the 50 × 50 km grid (Figure 3). All protected areas in Nunavut Settlement Area and the Acadian/Northern Appalachian Ecoregion were also mapped to the 50 × 50 km grid (Figure 4). A binary system was used such that a cell was considered "protected" if it overlapped a protected area of any size. It was considered "unprotected" only if no portion of a protected area overlapped the cell. This resulted in approximately twice the coverage of protected areas as exists (23% vs 10% of total land area in Canada), largely from overestimation of the provincial/territorial system (18.8% vs 5.0% of total land area in Canada). Most (95%) of this overestimation occurs in southern Canada where protected areas are small, yet numerous and dispersed enough to result in widespread coverage when mapped to the 50 × 50 km grid. The overestimation of protection, particularly in southern Canada, coupled with the criterion that a species only had to occur in a single grid cell within an analysis area to be considered present, made it more difficult to obtain a loss and easier to obtain a gain. Thus, losses are underestimated and gains are overestimated in general. These over and under estimations may, however, represent compensating effects in the full-dispersal scenario when overestimated gains and underestimated losses are combined to calculate species turnover. Nonetheless, real-world losses are likely to be more significant than results from both the full- and no-dispersal scenarios would suggest given the over-representation of protection across 50 × 50 km grid cells, particularly in southern Canada. For the same reason, real-world gains are likely to be less significant than results in the full-dispersal scenario would suggest. Given these limitations, estimations of losses are likely to be highly conservative in both scenarios, and gains are likely to be exaggerated in the full-dispersal scenario.

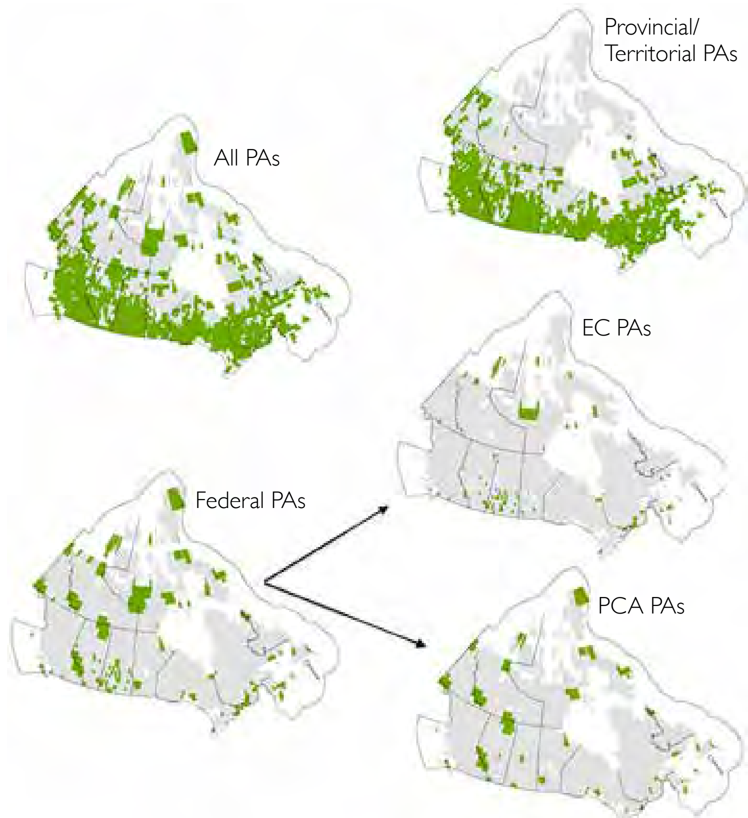


Figure 3: Coverage of 50 × 50 km grid cells used in the analyses for protected area systems in Canada. Green areas represent the spatial coverage of the grid for the respective protected area systems, combined (all PAs; provincial/territorial PAs; federal PAs) and separately (Environment Canada protected areas [EC PAs]; Parks Canada Agency protected areas [PCA PAs]). A single presence of a protected area in a grid cell results in coverage of the entire 50 × 50 km grid cell.

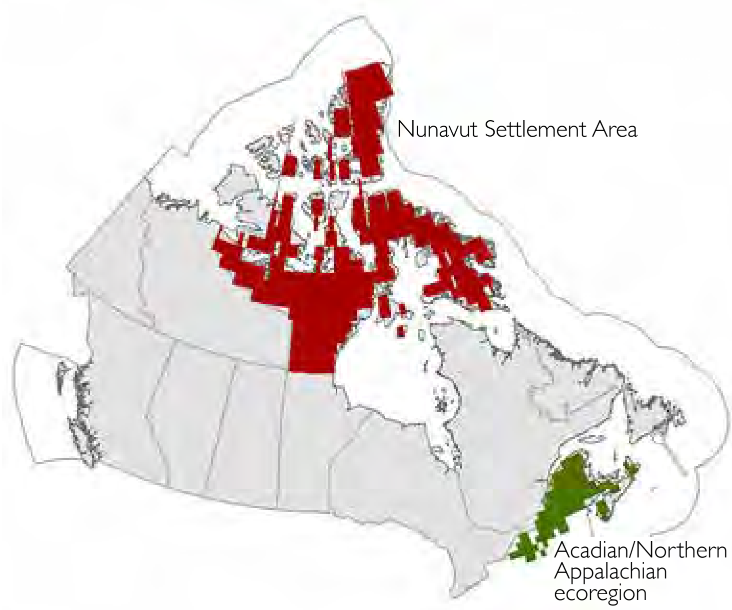


Figure 4: 50 × 50 km grid map used in the analyses for the Nunavut Settlement Area (red cells) and the Acadian/Northern Appalachian ecoregion (green cells).

Modelling projections identifying possible losses of Muskox (*Ovibus moschatus*) and other charismatic wildlife from Canada's network of protected areas in the 21st century are cause for concern about the long-term persistence of these species. Location: Auyuittuq National Park, Ellesmere Island, Nunuvut (Photo Credit: Joyce Gould).

RESULTS

Grid maps of current (c. 2010) species richness for mammals, amphibians and birds (Figure 5) provided the baseline for analysis of species loss, gain, and turnover. Numbers and percentages of loss, gain and turnover in the no-dispersal and full-dispersal scenarios for each 30-year time period to 2100 by taxa and the various analytical units are summarized for comparison in Tables 1-6. Grid maps of percent loss and gain are provided for 30-year time periods from 2011 to 2100 (2020s, 2050s, 2080s) for mammals, amphibians and birds (combined and separately), and for migratory birds (Appendix 3). Turnover results for the no-dispersal scenario are equivalent to the modelled losses because, by definition, no gains are possible in the no-dispersal scenario (Figures 6a-10a). Thus, for the no-dispersal scenario, tabular results and grid maps of losses also reflect turnover (losses plus zero/no gains). In contrast, for the full-dispersal scenario separate turnover results are presented summarizing the combination of losses and gains (Figures 6b-10b). A list of the species projected as gains and losses is provided in Appendix 4; however, results are less reliable at the level of individual species and thus should be interpreted with caution. In the following sections, results are presented by analytical unit for Canada as a whole, protected area systems, Bird Conservation Regions, and Nunavut Settlement Area and Acadian/Northern Appalachian Ecoregion.

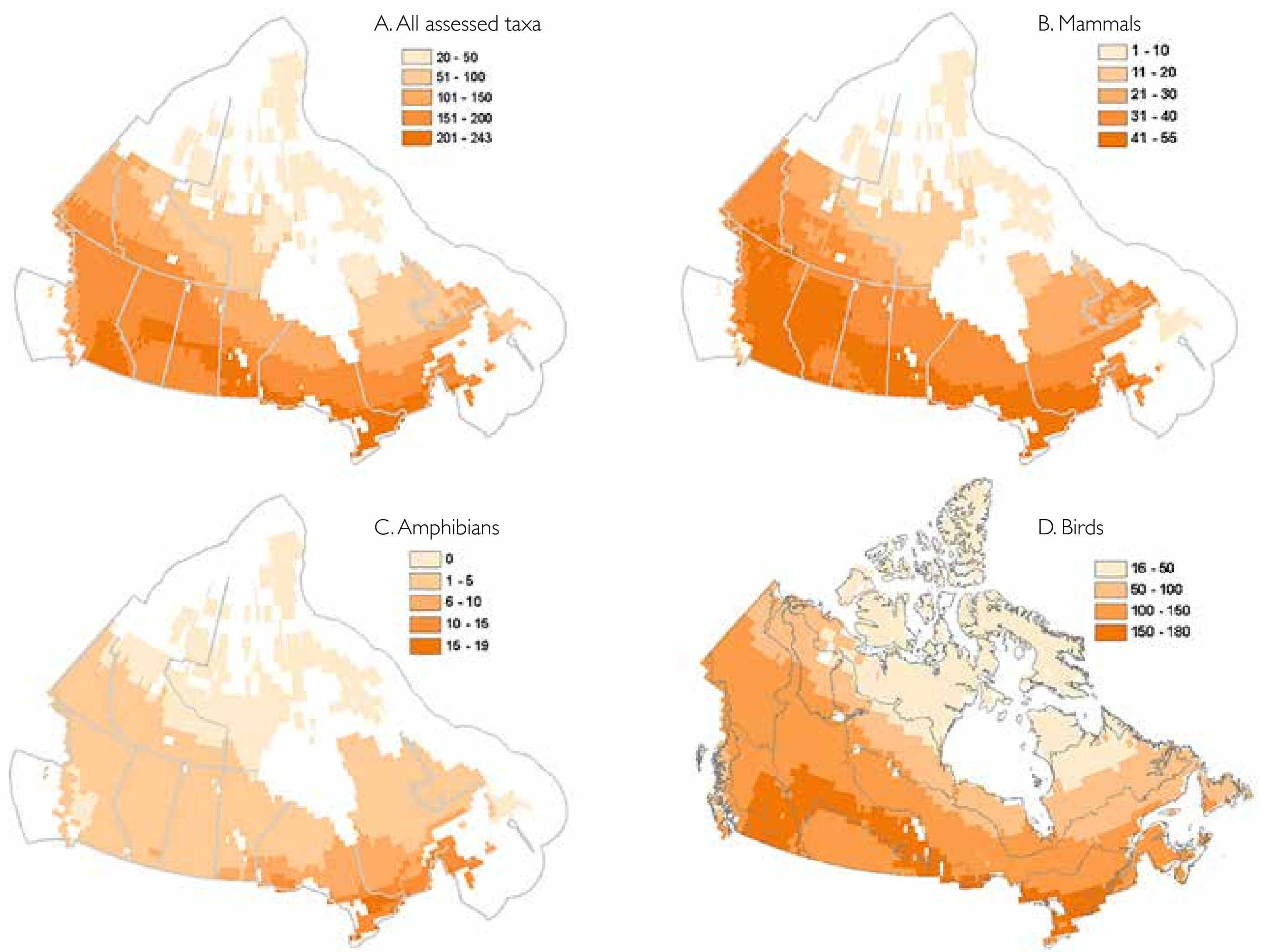


Figure 5: Grid maps of richness distribution for species modelled that are currently in Canada for A. all assessed taxa, B. mammals, C. amphibians, and D. birds (89% which are migratory). Richness represents the number of species analyzed in each 50-km grid cell.

Table 1: Projected changes in species modelled for Canada for 30-year time periods to 2100 in terms of number of species and a percentage relative to current.

Full-dispersal scenario (Loss from No-dispersal scenario in parenthesis when differs)										
Canada	Current No. Spp. Modelled	Current to 2011-2040			Current to 2041-2070			Current to 2071-2100		
		Loss	Gain	Turnover	Loss	Gain	Turnover	Loss	Gain	Turnover
All assessed species										
Number	505	5 (9)	11	16	6 (12)	17	23	2 (10)	38	40
Percentage		1 (2)	2	3	1 (2)	3	5	0 (2)	8	8
Mammals										
Number	123	0 (1)	3	3	0	4	4	0 (2)	9	9
Percentage		0 (1)	2	2	0	3	3	0 (2)	7	7
Amphibians										
Number	31	2 (3)	2	4	2 (4)	5	7	0 (2)	8	8
Percentage		6 (10)	6	13	6 (13)	16	23	0 (6)	26	26
Birds										
Number	351	3 (5)	6	9	4 (8)	8	12	2 (6)	21	23
Percentage		1	2	3	1 (2)	2	3	1 (2)	6	7

Table 2: Projected changes as a percentage relative to current by protected area system for 30-year time periods to 2100.

Full-dispersal scenario (Loss for No-dispersal scenario in parenthesis when differs)										
Protected Area System	Current Representivity # species / % of Canada	Current to 2011-2040			Current to 2041-2070			Current to 2071-2100		
		% Loss	% Gain	% Turnover	% Loss	% Gain	% Turnover	% Loss	% Gain	% Turnover
All assessed species										
All protected areas	502 / 99	1 (2)	3	3	1 (2)	4	5	1 (2)	7	9
Federal protected areas	495 / 98	2	3	5	2	4	6	2 (3)	6	8
Parks Canada Agency protected areas	469 / 93	1 (2)	4	6	1	6	7	2 (3)	8	10
Environment Canada protected areas	486 / 96	2	3	5	2 (3)	5	8	2 (3)	7	9
Provincial/Territorial protected areas	499 / 99	1 (2)	3	4	1 (3)	4	5	2 (3)	8	9
Mammals										
All protected areas	122 / 99	0 (1)	3	3	0	4	4	2	7	9
Federal protected areas	119 / 97	2 (3)	4	6	1	6	7	3	7	9
Parks Canada Agency protected areas	108 / 88	3	9	12	1	11	12	3	15	18
Environment Canada protected areas	116 / 94	3	3	6	1 (2)	7	8	3	9	11
Provincial/Territorial protected areas	122 / 99	0 (1)	3	3	1	4	5	2	7	9
Amphibians										
All protected areas	29 / 94	3 (7)	10	14	3 (10)	17	21	0 (7)	34	34
Federal protected areas	27 / 87	7	19	26	7 (11)	22	30	0 (7)	30	30
Parks Canada Agency protected areas	24 / 77	0	8	8	0	17	17	0 (4)	25	25
Environment Canada protected areas	25 / 81	4	24	28	4 (8)	24	28	4	40	44
Provincial/Territorial protected areas	28 / 90	0 (4)	11	11	0 (7)	18	18	0 (4)	39	39
Birds										
All protected areas	351 / 100	1	2	3	1 (2)	2	3	1(2)	5	6
Federal protected areas	349 / 99	1	1	3	1 (2)	2	4	2 (2)	4	6
Parks Canada Agency protected areas	337 / 96	1 (2)	2	4	1 (2)	4	5	2 (3)	4	6
Environment Canada protected areas	345 / 98	1 (2)	1	3	2 (3)	2	4	2 (3)	4	6
Provincial/Territorial protected areas	349 / 99	1 (2)	2	3	2 (3)	2	4	2 (3)	5	7

Table 3: Projected changes in number of species relative to current by protected area system for 30-year time periods to 2100.

Full-dispersal scenario (Loss for No-dispersal scenario in parenthesis when differs)										
Protected Area System	Current No. Species	Current to 2011-2040			Current to 2041-2070			Current to 2071-2100		
		# Loss	# Gain	# Turnover	# Loss	# Gain	# Turnover	# Loss	# Gain	# Turnover
All assessed species										
All protected areas	502	4(8)	13	17	5(11)	18	23	6(12)	37	43
Federal protected areas	495	9(10)	15	24	8(10)	21	29	9(14)	30	39
Parks Canada Agency protected areas	489	7(10)	20	27	5(7)	29	34	9(13)	36	45
Environment Canada protected areas	486	9(10)	14	23	9(13)	22	31	10(15)	35	45
Provincial/Territorial protected areas	499	5(8)	13	18	7(15)	18	25	8(16)	38	46
Mammals										
All protected areas	122	0(1)	4	4	0	5	5	2(3)	9	11
Federal protected areas	119	2(3)	5	7	1	7	8	3(4)	8	11
Parks Canada Agency protected areas	108	3	10	13	1	12	13	3	16	19
Environment Canada protected areas	116	3	4	7	1(2)	8	9	3(4)	10	13
Provincial/Territorial protected areas	122	0(1)	4	4	1	5	6	2(3)	9	11
Amphibians										
All protected areas	29	1(2)	3	4	1(3)	5	6	0(2)	10	10
Federal protected areas	27	2	5	7	2(3)	6	8	0(2)	8	8
Parks Canada Agency protected areas	24	0	2	2	0	4	4	0(1)	6	6
Environment Canada protected areas	25	1	6	7	1(2)	6	7	1	10	11
Provincial/Territorial protected areas	28	0(1)	3	3	0(2)	5	5	0(1)	11	11
Birds										
All protected areas	351	3(5)	6	9	4(8)	8	12	4(7)	18	22
Federal protected areas	349	5	5	10	5(6)	8	13	6(8)	14	20
Parks Canada Agency protected areas	337	4(7)	8	12	4(6)	13	17	6(9)	14	20
Environment Canada protected areas	345	5(6)	4	9	7(9)	8	15	6(10)	15	21
Provincial/Territorial protected areas	349	5(6)	6	11	6(12)	8	14	6(12)	18	24

Table 4: Projected changes by Bird Conservation Region planning units in Canada (see Figures 9, 10 and 13 for mapped boundaries of BCRs) summarized across time periods to 2100 assuming full-dispersal scenario (with loss for no-dispersal scenario in parenthesis when differs). Additional details including results by individual species in Gobeil et al. (2010).

BCR	BCR unit	BCR/Ecoregion	No. Species			Percentage (relative to current)		
			Current	Loss	Gain	Loss	Gain	Turnover
3	3NL	Arctic Plains & Mountains	43	4	69	9.3	160.5	169.8
3	3QC		56	3 (5)	88	5.4 (8.9)	157.1	162.5
3	3PNR		135	6 (10)	33	4.4 (7.3)	24.4	28.9
4	4PYR	Northwestern Interior Forest	192	8 (17)	22	4.2 (8.9)	11.5	15.6
5	5PYR	Northern Pacific Rainforest	211	8 (11)	16	3.8 (5.2)	7.6	11.4
6	6PNR	Boreal Taiga Plains	277	18 (28)	21	6.5 (10.1)	7.6	14.1
7	7NL	Taiga Shield/Hudson Plains	100	6 (8)	63	6.0 (8.0)	63.0	69.0
7	7QC		147	6 (11)	72	4.1 (7.5)	49.0	53.1
7	7ON		160	23 (28)	49	14.4 (17.5)	30.6	45.0
7	7PNR		167	8 (14)	44	4.8 (8.4)	26.3	31.1
8	8NL	Boreal Softwood Shield	128	16 (19)	48	12.5 (14.8)	37.5	50.0
8	8QC		169	12 (19)	40	7.1 (11.2)	23.7	30.8
8	8ON		185	9 (10)	23	4.9 (5.4)	12.4	17.3
8	8PNR		205	16 (21)	24	7.8 (10.2)	11.7	19.5
9	9PYR	Great Basin	194	11 (13)	14	5.7 (6.7)	7.2	12.9
10	10PYR	Northern Rockies	229	17 (24)	50	7.4 (10.5)	21.8	29.3
11	11PNR	Prairie Potholes	250	31 (47)	10	12.4 (18.8)	4.0	16.4
12	12QC	Boreal Hardwood Transition	177	8 (10)	28	4.5 (5.6)	15.8	20.3
12	12ON		207	23 (24)	18	11.1 (11.6)	8.7	19.8
13	13QC	Gt Lakes/St.Lawrence Plain	174	34	19	19.5	10.9	30.5
13	13ON		195	33 (35)	9	16.9 (17.9)	4.6	21.5
14	14NS	Atlantic Northern Forest	155	28 (30)	30	18.1 (19.4)	19.4	37.4
14	14NB		163	15 (19)	25	9.2 (11.7)	15.3	24.5
14	14QC		171	8 (15)	19	4.7 (8.8)	11.1	15.8
14	14PE		Insufficient data					

Table 5: Projected changes as a percentage relative to current in the Nunavut Settlement Area and Acadian/Northern Appalachian (A/NA) ecoregion and its protected areas system for 30-year time periods to 2100.

Full-dispersal scenario (Loss for No-dispersal scenario in parenthesis when differs)										
Conservation Area	Current No. Species	Current to 2011-2040			Current to 2041-2070			Current to 2071-2100		
		% Loss	% Gain	% Turnover	% Loss	% Gain	% Turnover	% Loss	% Gain	% Turnover
All assessed species										
Nunavut Settlement Area	148	1 (2)	28	29	3 (4)	42	45	2 (6)	58	60
Acadian/Northern Appalachian (A/NA) Ecoregion	284	2	3	5	3 (4)	4	7	4 (6)	6	10
Protected areas in A/NA Ecoregion	259	4 (5)	4	8	5 (6)	5	10	10 (12)	9	19
Mammals										
Nunavut Settlement Area	34	0 (3)	21	21	0 (3)	44	44	3 (9)	56	59
Acadian/Northern Appalachian (A/NA) Ecoregion	60	3 (5)	3	6	3 (5)	3	6	3 (6)	6	10
Protected areas in A/NA Ecoregion	53	2	6	7	2	7	9	6	11	17
Amphibians										
Nunavut Settlement Area	1	0	100	100	0	100	100	0	100	100
Acadian/Northern Appalachian (A/NA) Ecoregion	22	0	4	4	0	4	4	0	8	8
Protected areas in A/NA Ecoregion	19	0	0	0	0	5	5	0	21	21
Birds										
Nunavut Settlement Area	113	2	29	31	4	41	44	2 (5)	58	60
Acadian/Northern Appalachian (A/NA) Ecoregion	202	2	3	5	3 (5)	4	7	5 (6)	5	10
Protected areas in A/NA Ecoregion	187	5 (6)	4	9	6 (8)	5	11	12 (15)	7	20

Table 6: Projected changes in number of species relative to current in the Nunavut Settlement Area and Acadian/Northern Appalachian (A/NA) ecoregion and its protected areas system for 30-year time periods to 2100.

Full-dispersal scenario (Loss for No-dispersal scenario in parenthesis when differs)										
Conservation Area	Current	Current to 2011-2040			Current to 2041-2070			Current to 2071-2100		
	#	# Loss	# Gain	# Turnover	# Loss	# Gain	# Turnover	# Loss	# Gain	# Turnover
All assessed species										
Nunavut Settlement Area	148	2(3)	41	43	4(6)	62	66	3(9)	86	89
Acadian/Northern Appalachian (A/NA) Ecoregion	284	6(7)	9	15	8(13)	11	19	12(17)	17	29
Protected areas in A/NA Ecoregion	259	10(14)	10	20	13(16)	14	27	26(31)	24	50
Mammals										
Nunavut Settlement Area	34	0(1)	7	7	0(1)	15	15	1(3)	19	20
Acadian/Northern Appalachian (A/NA) Ecoregion	60	2(3)	2	4	2(3)	2	4	2(4)	4	6
Protected areas in A/NA Ecoregion	53	1	3	4	1	4	5	3	6	9
Amphibians										
Nunavut Settlement Area	1	0	1	1	0	1	1	0	1	1
Acadian/Northern Appalachian (A/NA) Ecoregion	22	0	1	1	0	1	1	0	2	2
Protected areas in A/NA Ecoregion	19	0(1)	0	0	0	1	1	0	4	4
Birds										
Nunavut Settlement Area	113	2	33	35	4(5)	46	50	2(6)	66	68
Acadian/Northern Appalachian (A/NA) Ecoregion	202	4	6	10	6(10)	8	14	10(13)	11	21
Protected areas in A/NA Ecoregion	187	9(12)	7	16	12(15)	9	21	23(28)	14	37

CANADA AS A WHOLE

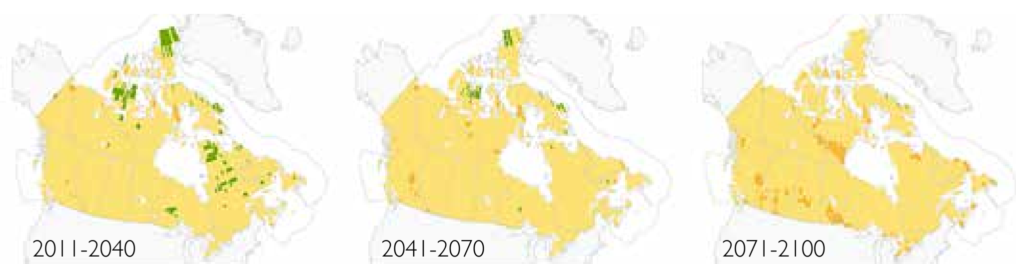
Across Canada, the distribution of losses, gains and turnover varied spatially and by taxonomic group (Figures 6-10; Appendix 3). In both the no- and full-disersal scenarios, by the 2020s, most 50-km grid cells (except for amphibians) were projected to have 1% to 25% turnover (relative to current). In the no-dispersal scenario, however, several cells showed no (0) turnover, and very few showed greater than 25%. In contrast, in the full-dispersal scenario, some grid cells showed greater than 75% turnover. The differences between the full- and no-dispersal results are attributable to gains in the full-dispersal scenario, most notably along the boundary between the Taiga Shield/Hudsons Plain and the Arctic Plains/Mountains ecoregions in the Northwest Territories and Nunavut.

By the 2050s, few grid cells in the no-dispersal scenario showed no turnover (with the exception of amphibians), and more cells showed losses above 25%. In the full-dispersal scenario, turnover along the boundary between the Taiga Shield/Hudsons Plain and the Arctic Plains/Mountains ecoregions in the Northwest Territories and Nunavut increased to over 100%. These patterns expanded through the 2080s.

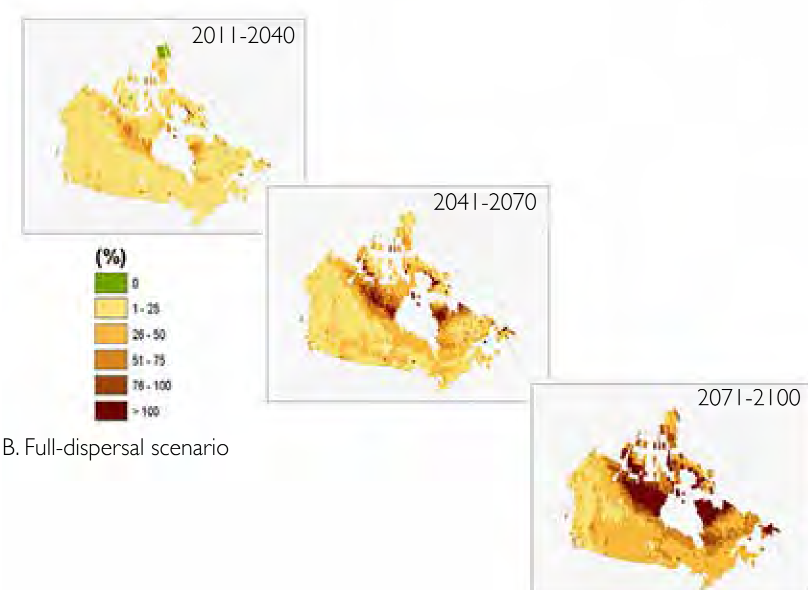
Amphibians currently have a more southerly distribution and lower number of species relative to the other taxa (Figure 5). By the 2020s in the no-dispersal scenario, most grid cells showed no turnover, however several cells showed turnover ranging from 1-25% up to 100% (Figure 8a). This pattern intensified through the 2080s. In the full-dispersal scenario, by the 2020s many grid cells showed turnover projected to be over 50% (largely attributable to gains), especially along the northern edge of their current distribution (Figure 8b). That pattern of change similarly intensified through the 2080s, when many grid cells showed turnover projected at over 100%.

Not surprisingly, when results were amalgamated for Canada as a whole, the magnitude of change was much lower (Table 1). The "worst-case" represented by the no-dispersal scenario was evident in that losses were higher (median difference of 2 species more; range 0-8 species) than under the full-dispersal scenario. In the no-dispersal scenario, national losses by the 2020s were 9 species overall (3 amphibians, 1 mammal, and 5 birds) or 2% of the current number of species for all taxa (10% of amphibians, 1% of mammals, 1% of birds). By comparison, under the full-dispersal scenario, national losses were 5 species overall (2 amphibians and 3 birds) or 1% of the current number of species for all taxa (6% of amphibians,

Figure 6: Grid maps of turnover for species of all taxa modelled for Canada (as a percentage relative to current) for 30-year time periods to 2100, assuming A. no-dispersal scenario, and B. full-dispersal scenario.



A. No-dispersal scenario



B. Full-dispersal scenario

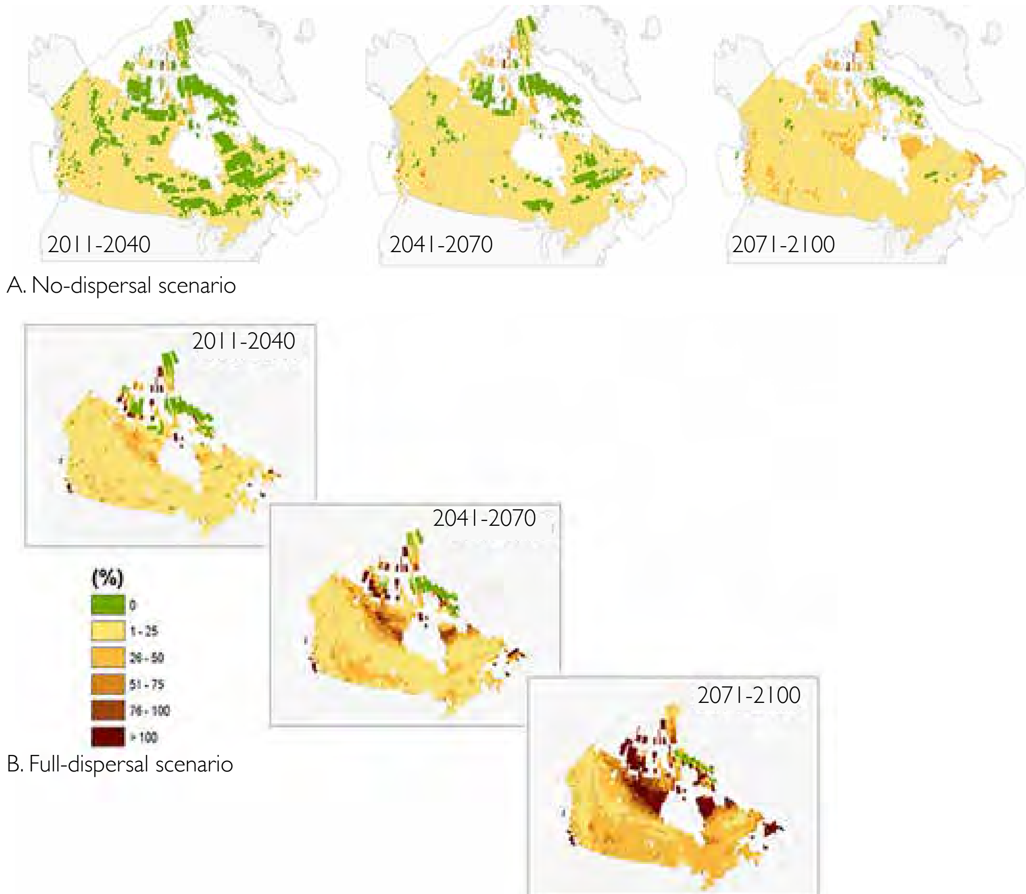


Figure 7: Grid maps of turnover for mammal species modelled for Canada (as a percentage relative to current) for 30-year time periods to 2100, assuming A. no-dispersal scenario, and B. full-dispersal scenario.

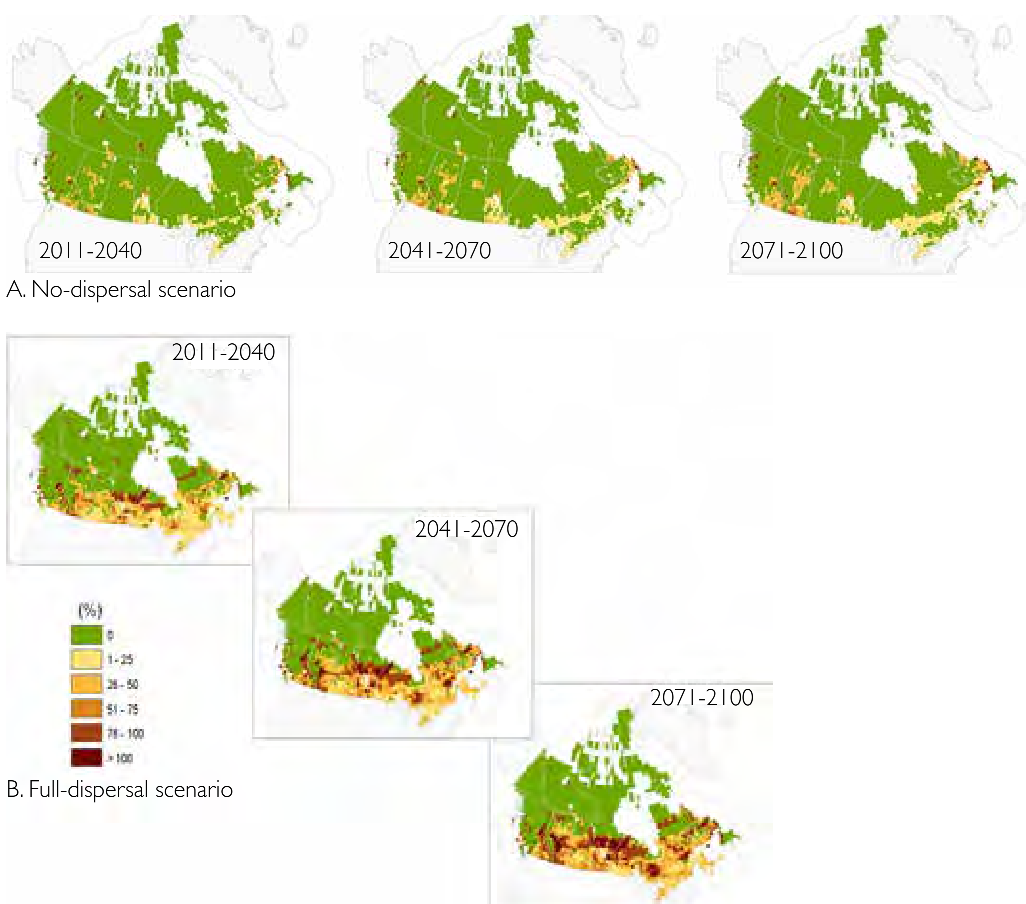
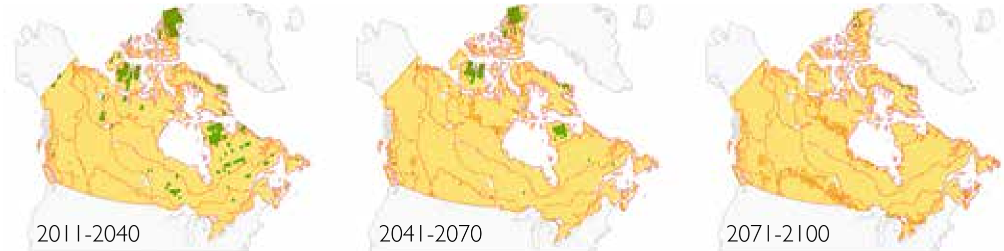
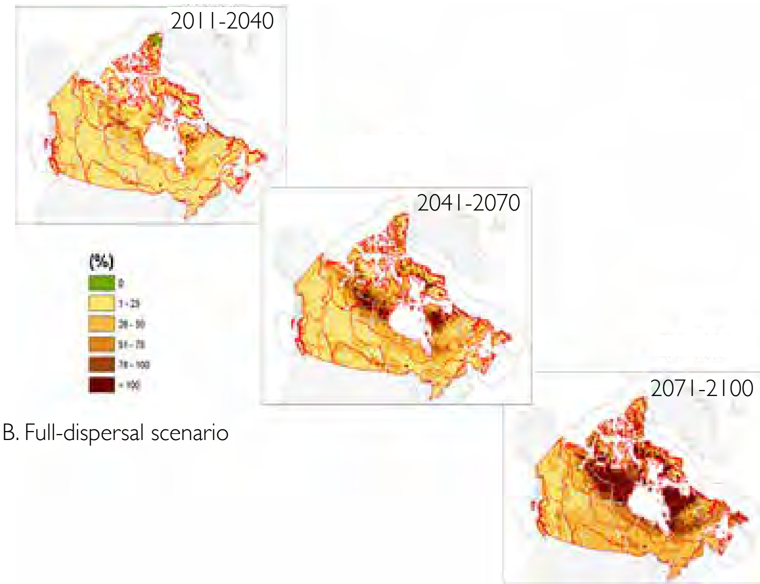


Figure 8: Grid maps of turnover for amphibian species modelled for Canada (as a percentage relative to current) for 30-year time periods to 2100, assuming A. no-dispersal scenario, and B. full-dispersal scenario.

Figure 9: Grid maps of turnover for all bird species modelled for Canada (as a percentage relative to current) for 30-year time periods to 2100, assuming A. no-dispersal scenario, and B. full-dispersal scenario. BCR planning unit boundaries are shown in red.

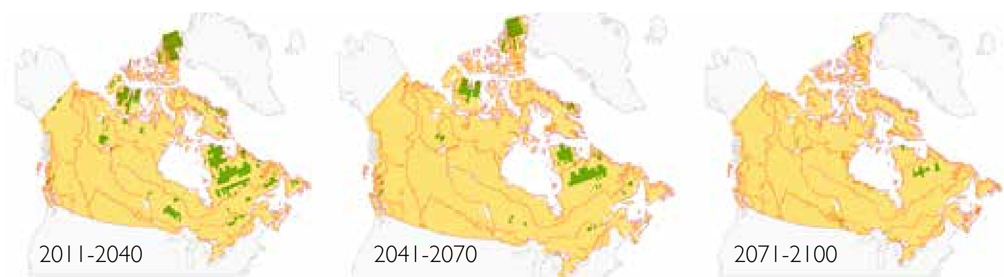


A. No-dispersal scenario

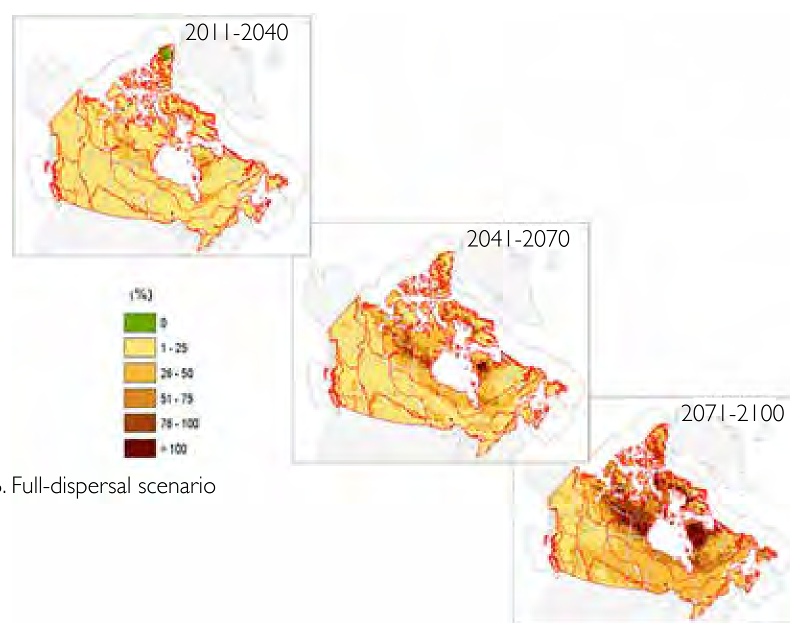


B. Full-dispersal scenario

Figure 10: Grid maps of turnover for migratory bird species modelled for Canada (as a percentage relative to current) for 30-year time periods to 2100, assuming A. no-dispersal scenario, and B. full-dispersal scenario. BCR planning unit boundaries are shown in red.



A. No-dispersal scenario



B. Full-dispersal scenario

1% of birds). In this scenario, species gained by the 2020s were 11 overall (3 mammals, 2 amphibians, 6 birds) or 2% relative to current (2% for mammals, 6% for amphibians, 2% for birds). Thus, in the full-dispersal scenario, by the 2020s, the national turnover was 3% overall (5 losses, 11 gains), 2% for mammals (3 gains), 13% for amphibians (2 losses, 2 gains) and 3% for birds (3 losses, 6 gains).

By the 2050s (Table 1), in the no-dispersal scenario, the national turnover/losses relative to current was 2% overall (12 losses, 0 gains), with 13% for amphibians (4 losses, 0 gains) and 2% for birds (8 losses, 0 gains). In the full-dispersal scenario, the national turnover relative to current was 5% overall (6 losses, 17 gains), 3% for mammals (4 gains), 23% for amphibians (2 losses, 5 gains) and 3% for birds (4 losses, 8 gains). By the 2080s, in the no-dispersal scenario, the national turnover/losses relative to current remained at 2% overall, with 2% for mammals (2 losses, 0 gains), 6% for amphibians (2 losses, 0 gains) and 2% for birds (6 losses, 0 gains). In the full-dispersal scenario, the national turnover relative to current was 8% for all species (2 losses, 38 gains), 7% for mammals (9 gains), 26% for amphibians (8 gains) and 7% for birds (2 losses, 21 gains). The decrease in projected losses relative to previous periods assumes that species can be recovered in a later period as their bioclimatic ranges shift back into Canada. A list of the species projected as a gain or loss in Canada in both scenarios for each time period by taxa is provided in Appendix 4.

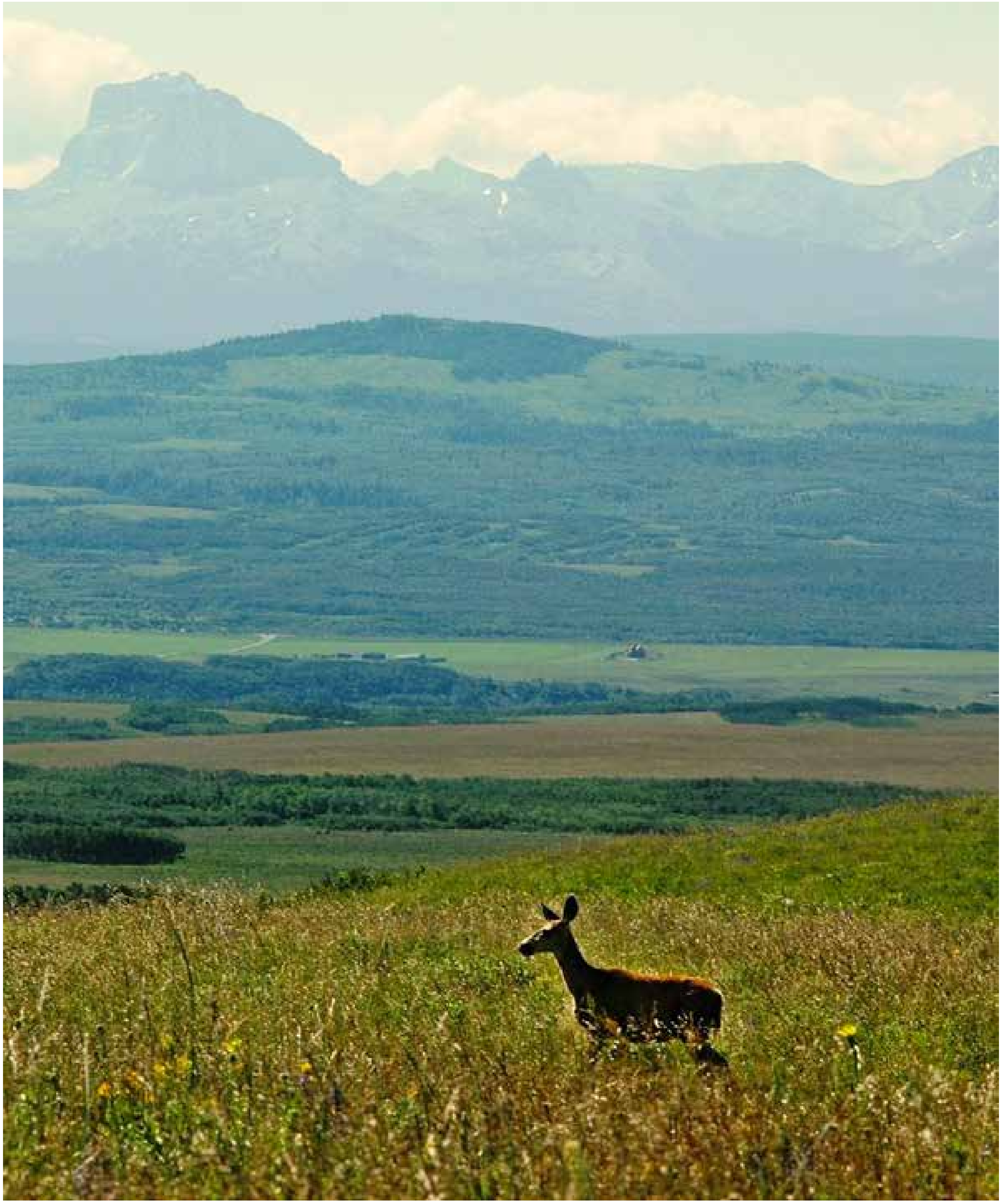
PROTECTED AREA SYSTEMS

When Canada's protected area system was mapped to the 50 x 50 km grid, collectively (i.e., "all" protected areas) the grid cells captured at least some portion of the species ranges of 99% of species modelled and currently known to occur in Canada (Figure 3; Table 2). Grid cells containing at least some portion of each of Canada's protected area systems when considered individually also captured samples of most of the species' ranges modelled and currently found in Canada. Of the protected area systems examined (Figure 1), the Parks Canada Agency system captured the lowest percentage of species ranges (93%) because of the relatively lower density of its sites and broad geographic distribution in Canada. Provincial and territorial protected areas captured the highest percentage (99%). As was noted earlier, however, these results should be interpreted with caution because, due to their coarse scale, the grid cells represent much larger areas than the actual boundaries of the protected areas, especially in southern Canada where protected areas are small and widely dispersed. Nonetheless, interesting patterns emerge and are presented for each of the time periods (relative to current) for five analytical units (all protected areas; federal protected areas; Parks Canada Agency; Environment Canada; and provincial and territorial protected areas). Species loss, gain and turnover results are presented as percentages (Table 2) and numbers (Table 3, Figures 11 and 12) by time period, analytical unit and taxa.

As was seen for Canada (Table 1), species loss was higher under the no-dispersal scenario than under the full-dispersal scenario for every protected areas system (median difference of 1 species; range 0-8 species) (Table 3, Figure 11). By the 2020s, under the no-dispersal scenario, Canada's protected area system collectively was projected to experience a loss of 8 species (Table 3, Figure 11), comprised of 1 mammal, 2 amphibians and 5 birds (Table 3, Figure 12). Under the full-dispersal scenario, losses were projected as 4 species, comprised of 1 amphibian and 3 birds; and gains as 13 species comprised of 4 mammals, 3 amphibians, and 6 birds (Table 3, Figures 11 and 12). Together, these comprise a turnover of 17 species, a pattern close in magnitude and composition to that for Canada as a whole under the full-dispersal scenario.

Compared to Canada's protected area system, changes under both no- and full-disperal scenarios were typically, though not always, higher for individual protected area systems by the 2020s (Table 3, Figure 11). The federal protected areas system and Environment Canada's system had the highest losses, both with 10 losses in the no-dispersal scenario and 9 in the full-dispersal scenario. For Environment Canada, these were comprised of 3 mammals, 1 amphibian and 6 birds in the no-dispersal scenario, and 3 mammals, 1 amphibian and 5 birds in the full-dispersal scenario (Table 3, Figure 12). The Parks Canada Agency system fared the same in the no-dispersal scenario (10 losses), however it showed only 7 losses in the full-dispersal scenario. In the full-dispersal scenario, the Parks Canada Agency system had the highest gains (20 species), comprised of 10 mammals, 2 amphibians, and 8 birds. Coupled with the losses in this scenario, the Parks Canada Agency system had the highest turnover at 27 species, as compared to the next highest (federal protected areas at 24 species, and Environment Canada's system at 23 species). The provincial/territorial system had the smallest turnover (18 species).

As a percentage relative to the current number of species represented, Canada's protected area system collectively was projected to have a 2% loss in the no-dispersal scenario, and 1% loss, 3% gain and 3% turnover (with rounding) in the full-dispersal scenario for all species by the 2020s (Table 2), a pattern close to that for Canada as a whole (Table 1). Changes for individual systems were generally similar (within 1%) for losses (range 1-2%) in both scenarios and gains (range 3-4%) in the full-dispersal scenario. However, in the full-dispersal scenario, the aggregate (and with rounding) of losses and gains resulted in higher turnovers (range 4-6%) compared to Canada's system collectively (3%) (Table 2). Within groups of taxa, amphibians had the highest turnover



The interface of dramatic landscapes such as prairies and mountains in western Canada generate complex ecosystem mosaics with high habitat diversity that can possibly help to dampen the effects of regional climate change for wildlife. Location: Pine Ridge, Southern Alberta (Photo Credit: Bob Lee, courtesy Nature Conservancy of Canada).

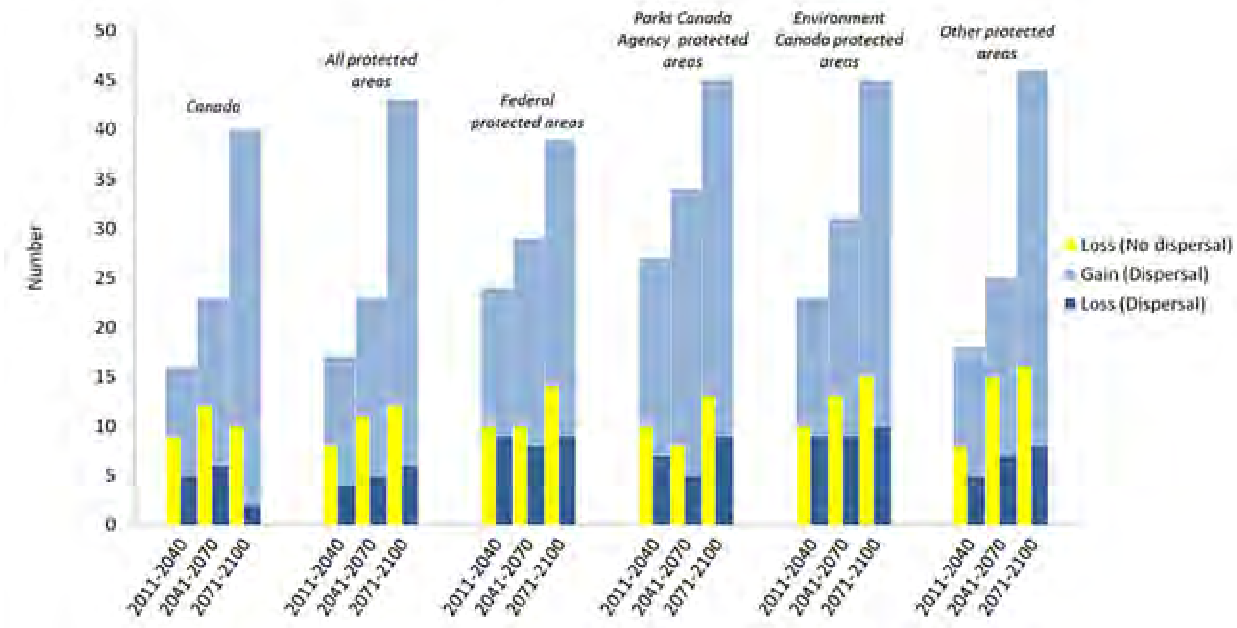


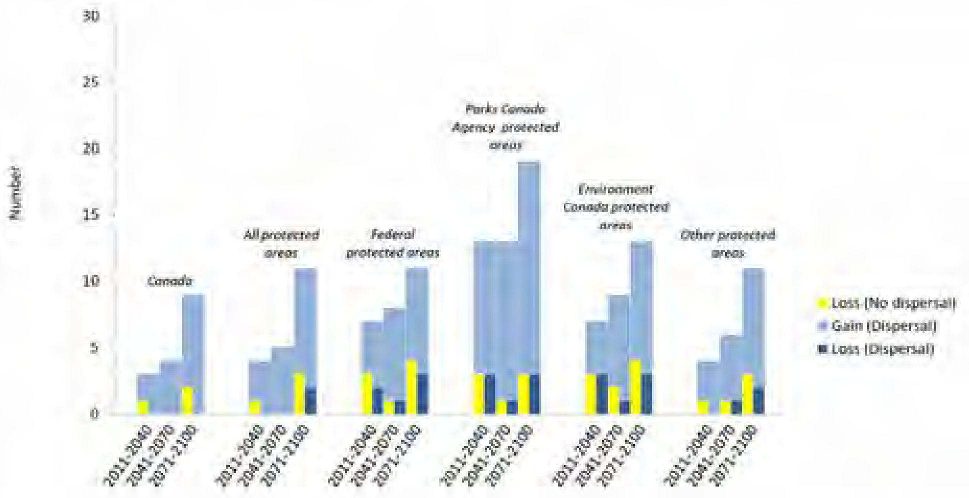
Figure11: Projected changes (in number of species relative to current) for species of all taxa modelled for Canada and by protected area system for 30-year time periods to 2100. (Species loss, gain and turnover in percentages and numbers are summarized in Tables 1-3 and species names are listed in Appendices 1 and 4).

rate in percentage in the Environment Canada system at 28% (4% loss, 24% gain); mammals had the highest turnover in the Parks Canada Agency system at 12% (3% loss, 9% gain); and birds in the Parks Canada Agency system at 4% (with rounding; 1% loss, 2% gain).

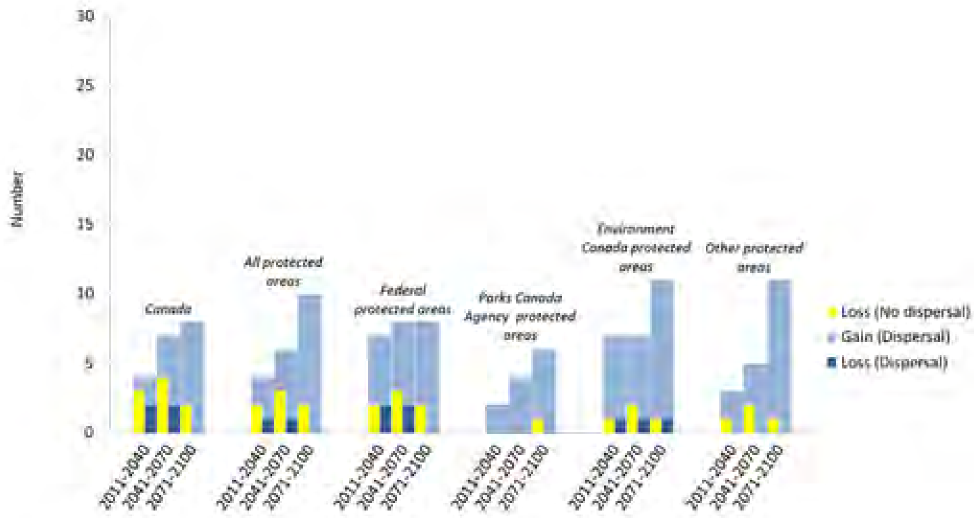
By the 2050s, losses/turnover had increased in all protected areas (11 species), Environment Canada's system (13 species) and provincial and territorial protected areas (15 species) in the no-dispersal scenario. Losses had also increased or remained the same in these systems in the full-dispersal scenario, but not by as much (5, 9 and 7 species respectively). Turnover in the full-dispersal scenario in Canada's system collectively had increased to 23 species (from 19) (Table 3, Figure 11), comprised of a loss of 1 amphibian and 4 birds, and a gain of 5 mammals, 5 amphibians and 8 birds (Table 3, Figure 12) or 5% of current species represented (Table 3); again, a result similar to Canada as a whole in magnitude and composition. Changes in the provincial and territorial system were the most similar to Canada's system collectively, with the remaining systems having higher turnover in both species number (Table 3) and as a percentage relative to current (Table 2). Within groups of taxa (Table 2), amphibians had the highest percent turnover rate in the federal protected areas system at 30% (with rounding, 7% loss, 22% gain); mammals had the highest turnover in the Parks Canada Agency system at 12% (1% loss, 11% gain); and birds in the Parks Canada Agency system at 5% (1% loss, 4% gain). In terms of numbers, losses were highest for birds, with losses of 12 species from provincial and territorial, 9 from Environment Canada, and 6 from Parks Canada Agency systems in the no-dispersal scenario, and 6, 7 and 4 species respectively in the full-dispersal scenario.

By the 2080s, losses/turnover in Canada's system collectively in the no-dispersal scenario had increased to 12 species (Table 3, Figure 11), comprised of a loss of 3 mammals, 2 amphibians, and 7 birds, or 2% of current species (Table 2). Losses in the full-dispersal scenario consisted of 6 species (2 mammals and 4 birds). In comparison with previous time periods, losses for all taxa had increased by the 2080s in both no-and full-dispersal scenarios, and in all systems of protected areas, due to increases in losses of mammals and birds. Turnover in Canada's system collectively in the full-dispersal scenario had increased to 43 species (Table 3, Figure 11) comprised of these losses, and a gain of 37 species (9 mammals, 10 amphibians and 18 birds) (Figure 12), or 9% of current species (Table 2). This pattern of change is somewhat greater in Canada's protected areas system than for Canada as a whole, again due to a higher loss of mammals and birds. In contrast to previous time periods, the provincial and territorial system had the highest turnover in the full-dispersal scenario at 46 species (Table 3, Figure11), comprised of losses of 8 species (2 mammals and 6 birds), and gains of 9 mammals, 11 amphibians and 18 birds (Figure 12). Loss/turnover is also highest in this system in the no-dispersal scenario, totaling 16 species (3 mammals, 1 amphibian, and 12 birds). The Parks Canada Agency system had the highest

A. Mammals



B. Amphibians



C. Birds

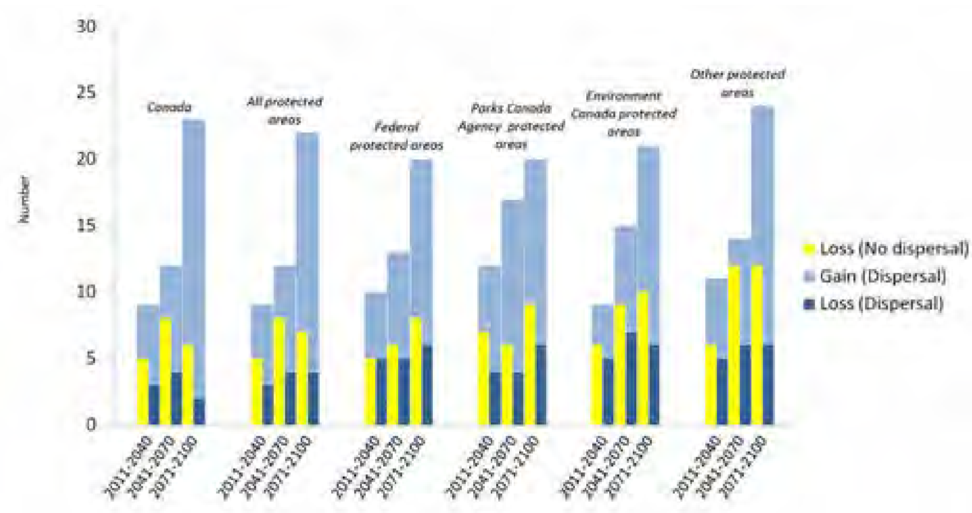


Figure12: Projected changes (in number of species relative to current) for Canada and by protected area system for 30-year time periods to 2100 for A. mammals, B. amphibians, and C. birds. (Species loss, gain and turnover in percentages and numbers are summarized in Tables 1-3 and species names are listed in Appendices 1 and 4).

turnover as a percentage of current at 10% (2% loss, 8% gain; Table 3). For taxa, mammals had the highest turnover in the Parks Canada Agency system at 18% (3% loss, 15% gain), amphibians in the Environment Canada system at 44% (4% loss, 40% gain) and birds in the system of provincial and territorial protected areas at 7% (2% loss, 5% gain) (Table 2). These differences, however, are primarily driven by gains in the full-dispersal scenario. In the no-dispersal scenario, percent loss/turnover is highest for amphibians in the federal protected area system. A list of the species projected as a gain or loss for each protected area system in each scenario and time period by taxa is provided in Appendix 4.

BIRD CONSERVATION REGIONS

When changes relative to current were tallied for BCRs across time periods, losses were consistently higher in the no-dispersal than the full-dispersal scenario (Table 4). For no-dispersal, the median loss was between 17 and 19 species (range 4-47 species) compared to between 11 and 12 (range 3-34 species) for the full-dispersal scenario. The highest loss for the no-dispersal scenario was in the Praire Potholes (47 species), and for the full-dispersal scenario was in the Great Lakes-St. Lawrence Plains in Quebec (34 species) (11PNR and 13QC, respectively) (Table 4; Figures 13 and 14). As a percentage relative to current, the median of loss for the no-dispersal scenario was between 9% and 10% (range 5-20%) and for full-dispersal between 6% and 7% (range 4-20%). The highest loss (20%) was in the Great Lakes–St. Lawrence Plain in Quebec (13QC) in both scenarios. In the full-dispersal scenario, the median gain relative to current was between 25 and 28 species (range 9-88 species) or 15%-16% (range 4-161%). The highest gain occurred in the Arctic Plains/Mountains in Quebec (3QC) for species number (88 species) and in Newfoundland & Labrador (3NL) as a percentage (161%) (Figure 13). Additional details on the analysis, including a list of species by gain or loss by BCR, by time period, and under no- and full-dispersal scenarios, are available in Gobeil et al. (2010) and in individual BCR strategies (http://www.nabci.net/Canada/English/bird_conservation_regions.html).

NUNAVUT SETTLEMENT AREA AND ACADIAN/NORTHERN APPALACHIAN ECOREGION

For the Nunavut Settlement Area, the Acadian/Northern Appalachian Ecoregion and its system of protected areas,

Figure 13: Projected changes by Bird Conservation Region planning units in Canada summarized across time periods to 2100 (assuming full-dispersal scenario). C: number of modelled species currently in BCR planning unit / number of species gained in any time period / number of species lost in any time period. T: turnover (species gain plus loss as a percentage of current number of species). (Species loss, gain and turnover in percentages and numbers are summarized in Table 4. Additional details including results by individual species in Gobeil et al. 2010).

species loss overall was higher (median of 1 species, range 0-5 species and 0-6% difference) for the no-dispersal than the full-dispersal scenario due primarily to differences for mammals and birds (Tables 5-6, Figure 15).

By the 2020s, losses under the no-dispersal scenario in the Nunavut Settlement Area were projected as 3 species (1 mammal and 2 birds) (Table 6, Figure 15), representing a loss of 2% of all species relative to current (Table 5). In the full-dispersal scenario, losses were projected as 2 species (both birds), and gains as 41 species, comprised of 7 mammals, 1 amphibian and 33 birds, for a turnover of 29% relative to current (Tables 5 and 6). By the 2050s, losses of species in the no-dispersal and full-dispersal scenarios represented 4% (6 species) and 3% (4 species), respectively, relative to current. Gain in the full-dispersal scenario was 42% (62 species: 15 mammals, 1 amphibian, 46 birds), which when combined with losses represented a turnover of 45% relative to current. By the 2080s, losses of species in the no-dispersal and full-dispersal scenarios represented 6% (9 species) and 2% (3 species), respectively, relative to current. When a gain of 86 species (19 mammals, 1 amphibian, 66 birds) was considered in the full-dispersal scenario, turnover was 60% relative to current.

By the 2020s, the Acadian/Northern Appalachian (A/NA) ecoregion was projected to have a loss of 7 species in the no-dispersal and 6 species in the full-dispersal scenario (Table 6, Figure 15). With the addition of a gain of 9 species (2 mammals, 1 amphibian and 6 birds) under the full-dispersal scenario, turnover consisted of 15 species, or 5% relative to current (Tables 5 and 6). By the 2050s, the losses were 8 and 13 species, respectively, for full- and no-dispersal scenarios. With gains of 11 species (2 mammals, 1 amphibian, 8 birds) in the full-dispersal scenario, turnover was 19 species, or 7% relative to current. By the 2080s, the turnover was 10% relative to current, comprised of a loss of 12 species (2 mammals, 10 birds) and a gain of 17 species (4 mammals, 2 amphibians, 11 birds) in the full-dispersal scenario. Under the no-dispersal scenario, l7 species were lost (4 mammals and13 birds). The system of protected areas in the A/NA ecoregion represented 91% of the current species modelled in the ecoregion.The pattern of change for the A/NA system of protected areas was consistently higher than for the ecoregion as a whole in terms of numbers and percentages of species losses, gains and turnover, relative to the current.

A list of the species projected as a gain or loss for the Nunavut Settlement Area and the Acadian/Northern Appalachian ecoregion and its system of protected areas in the full-dispersal and no-dispersal scenarios for each 30-year time period to 2100 by taxa is provided in Appendix 4. It should be interpreted with caution, as the analysis results are less reliable at the level of individual species.

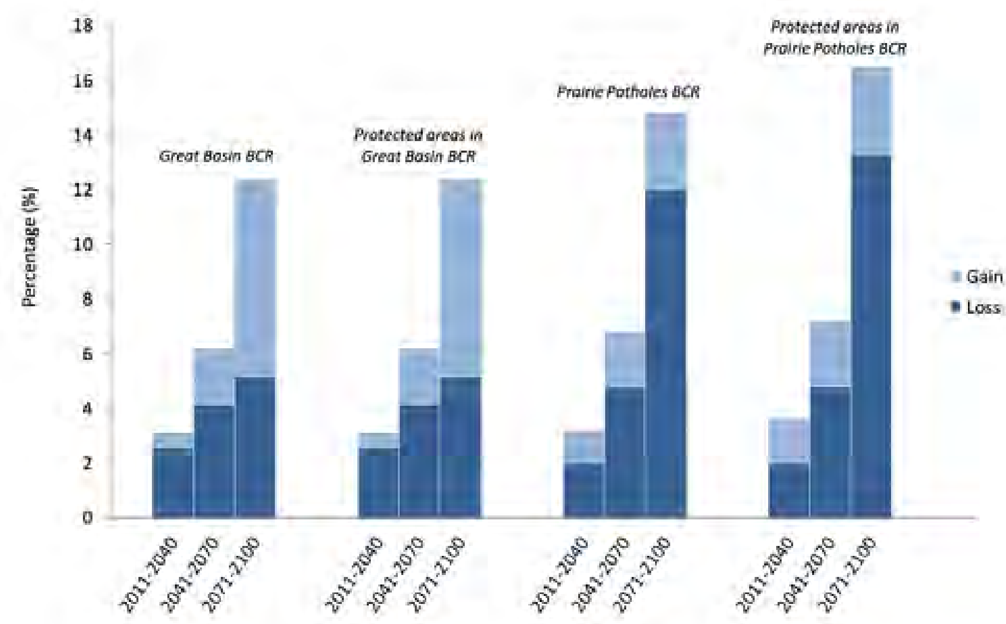


Figure 14: Projected changes in bird species (as percentage relative to current) in the Great Basin BCR (9PYR) and Prairie Potholes BCR (11PNR) and their system of protected area for 30-year time periods to 2100 (assuming full-dispersal scenario).

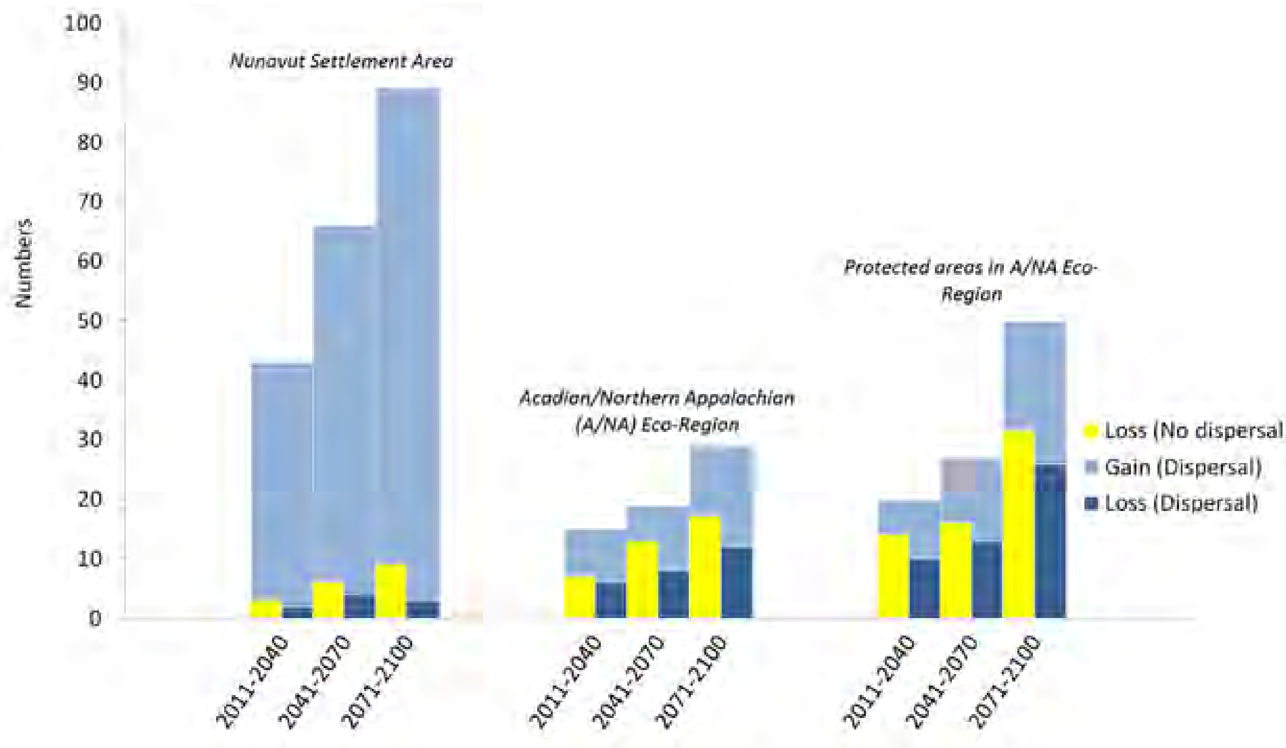


Figure 15: Projected changes (in number of species) relative to current for species of all assessed taxa in the Nunavut Settlement Area and Acadian/Northern Appalachian (A/NA) ecoregion (and its protected areas system) for 30-year time periods to 2100. (Species loss, gain and turnover in percentages and numbers are summarized in Tables 5 and 6, and species names are listed in Appendices 1 and 4).

DISCUSSION

The analyses presented in this report were conducted to provide a Canadian perspective on potential changes in the ranges and distribution of wildlife species - birds, mammals and amphibians - in response to an accepted scenario for climate change, and to project the implications for species representation in protected areas and wider conservation efforts. The results serve to inform conservation advisors, planners and managers of the extent, magnitude and timing of potential change in the early (2011-2040), mid (2041-2070) and late (2071-2100) 21st century. Nationally, losses were projected in no- and full-dispersal scenarios, respectively, to be 1-2% of all species from the combined system of federal and provincial protected areas by the 2020s and remaining so to the 2080s. When protected area systems were considered separately, losses increased to 2-3% by the 2080s, representing 8-16 species, depending upon the protected area system and whether a full- or no-dispersal scenario was assumed. When gains were also factored into the equation in the full-dispersal scenario, turnover rates were 9-10% (45-46 species) by the 2080s, varying with the protected area system. Species gains and losses occurred across all of the modelled taxonomic groups.

Local results were more dramatic. In the Nunavut Settlement Area, for example, projected losses increased from 1-2% by 2040s, to 2-6% by the 2080s for full- and no-dispersal scenarios, respectively. When gains were factored in, through the full-dispersal scenario, turnover by 2080 was 60%, largely attributed to a 58% gain in species. However, even by the 2020s, local turnover in some areas of Canada was projected to be 25% or more relative to current, assuming the full-dispersal scenario. In some cases, this number increased to over 100% by the 2080s. Such high percentages reflect relatively large numeric gains in species where relatively fewer species currently exist, such as in more northerly areas and for amphibians. For example, a turnover rate of >100% was projected for Nunavut Settlement Area due to a gain of 1 amphibian species where none currently exist. Caution is advised in interpreting percentage-based results in such cases.

Nonetheless, turnover in full-dispersal scenarios showed a strong latitudinal effect, with the greatest change occurring at higher latitudes centred on the boundary of the Taiga Shield/Hudsons Plain and the Arctic Plains/Mountains ecoregions in the North West Territories, Nunavut, Quebec and Newfoundland and Labrador. Along this boundary, existing protected areas (such as the Thelon Game Sancturary and protected areas in northern Quebec) and bioregional conservation planning initiatives (such as the Nunavut Land Use Plan, the Plan Nord initiative in Quebec and the Far North initiative in Ontario) would appear to have a particularly key role to play on the landscape in providing for wildlife adaptation to changing conditions in Canada.

Although turnover in some scenarios was relatively high (even where multiple, not single, species are involved), gains generally outweighed losses, and absolute losses for the most part were relatively low (again recognizing that finer resolution analysis and additional sets of species are likely to reveal higher losses especially in southern settled regions). In one sense, solace may be taken in the relatively low level of projected species losses and turnover in most protected area scenarios and beyond the Taiga Shield/Hudson Plain and Arctic Plains/Mountains ecoregions interface, although there may be a lag effect not evident in the results that may emerge in subsequent finer grain and/or longer term projections. By comparison, the rate of species turnover since European settlement may be similar or even greater. This may be the case, especially, in settled southern regions of Canada, where massive habitat conversion has generated extensive eradication and turnover, including the extirpation of many apex predators.

There are many uncertainties to consider in using these results, starting with climate projections. The model ensemble approach used here is considered best practice (IPCC 2007) and the ten climate models used by Lawler et al. (2009) were validated for a selection of locations across Canada against the larger Canadian ensemble of 24 models. While analyses were originally done using both a mid-range (B1) and mid-to-high-range (A2) emissions scenario, only the A2 results are reported here because it is considered to be the most realistic scenario (and possibly even conservative) given recent trends in emissions (New et al. 2011).

Ecological uncertainty is also a major factor influencing the interpretation of the present analyses. Bioclimatic modelling is a simplification of complex ecological processes influencing species distributions. Validations of selected bioclimate envelope models suggest that predictions can agree reasonably well with observations (e.g., Araujo et al. 2005). In addition, the modelling approach developed by Lawler et al. (2006, 2009) and used here was based on robust statistical methods including subsetting of the current range to assess model fit and culling of species models that did not meet high thresholds for prediction accuracy.

Projected losses were also assessed assuming both no-dispersal as a "worst-case" and full-dispersal as a "best-case" scenario in relation to the ability of species to adjust to changing conditions. The latter assumes that species projected as losses from a grid cell or an analysis area in an interim period can be recovered at a later period as their ranges shift back into a grid cell or analysis area. Such recovery over 30-year time frames may not be possible for many species in real landscapes, especially where habitat fragmentation is high. In addition, with climate change exacerbating the adverse cumulative effects of habitat loss, fragmentation and degradation, full dispersal (and establishment) is unlikely, and realized effects on species are more likely to align somewhere between a full-dispersal and no-dispersal scenario. Indeed, in more southerly and coastal regions of Canada, where significant habitat loss and fragmentation has already occurred and is continuing as a consequence of more concentrated human developments, and where protected areas are small and isolated by distance and largely inhospitable intervening landscapes, a no-dispersal scenario may well be more realistic. The analysis is also conservative by underestimating losses and liberal by overestimating gains because a species had only to occur in a single grid cell in an analysis area to be assessed as present, and thus labelled as 'no change' if currently present, or as 'gain' if not currently present.

To address ecological uncertainty related to species selection, three major taxa were modelled to assess projected changes both as a suite and by taxon to explore at least some aspects of variability in response among taxa. Although two-thirds of the species modelled were birds (372 species of 543 modelled), the results for all taxa combined were similar to those for both birds and mammals separately for Canada as a whole and for protected area systems collectively. Amphibians had the greatest magnitudes of change as a percentage of current but had a relatively small influence overall because of their low species number and more southerly distribution. Nonetheless, further analyses are warranted to include reptiles and other taxa, to determine whether projected lost species are currently considered conservation priority species, and to improve the assessment of the nature of the potential risk and the need to adapt conservation actions.

Spatial uncertainty was addressed by conducting analyses at multiple extents including the 50 × 50 km grid, Canada as a whole, and national and regional systems of protected areas mapped to the 50 × 50 km grid, and bioregional conservation planning areas (i.e., Bird Conservation Regions, Nunavut Settlement Area, and the Acadian/Northern Appalachian ecoregion). Mapping of protected areas systems to the 50 × 50 km grid could be improved, reducing coverage by eliminating the smallest sites until the existing percent coverage is matched. Incorporation of lands protected by conservation authorities and land trusts and other properties contributing to Canada's biodiversity targets, however, would

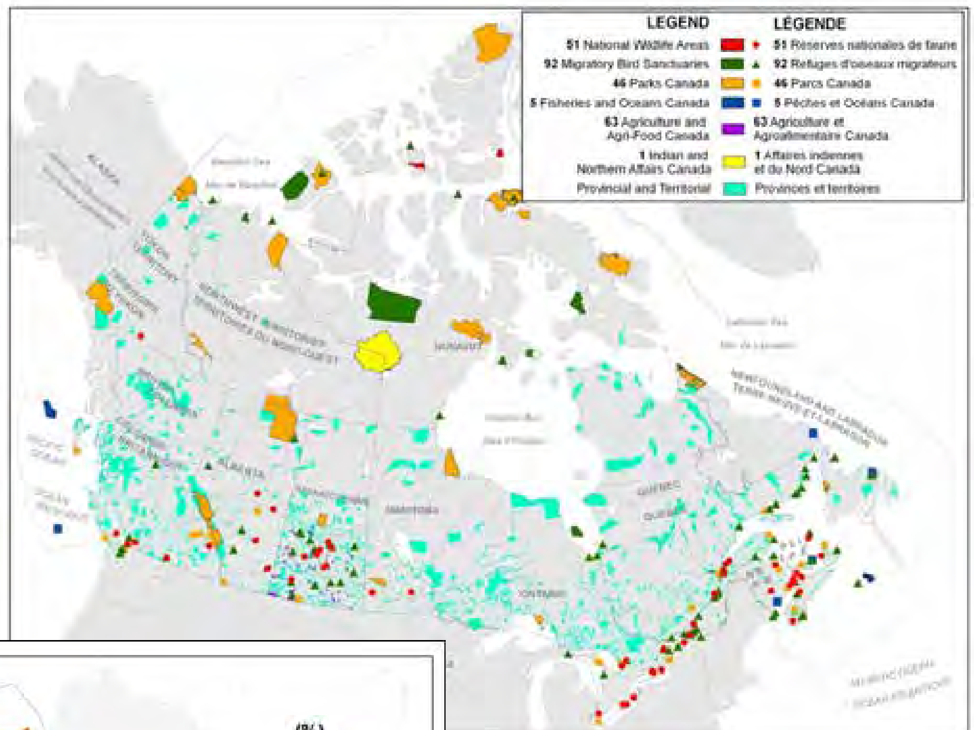
Southern species will not escape impacts of climate change with modelling revealing potential losses of some amphibians in protected areas while others like Spring Peeper (*Pseudacris crucifer*) seem to display resilience. Location: Sauble Dunes Nature Reserve, Southern Ontario (Photo Credit: Noah Cole: courtesy Ontario Nature).

provide a wider and more accurate coverage and also affect the results.

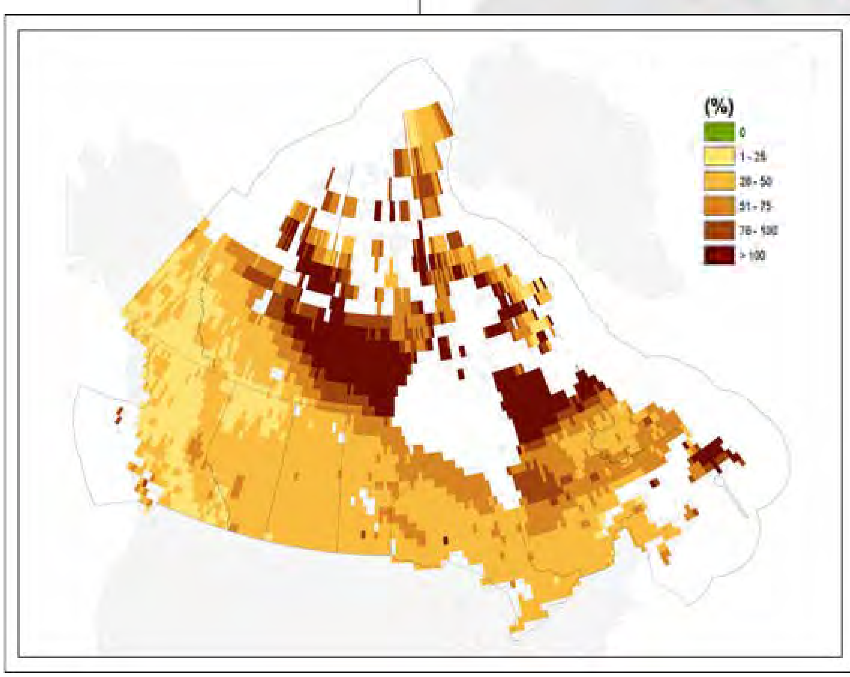
As modelled, the results suggest that the distribution of the existing protected area system, particularly in southern parts of the Canada, will continue to represent or fall within projected future ranges of most species that currently exist in Canada. However, representation by a protected area within a species range does not guarantee that the actual size and configuration of individual protected areas or systems are sufficient to support population viability or to accommodate dispersal in response to shifting ranges. The predicted future persistence of species in the southern parts of Canada may be overly optimistic in areas that have been more significantly altered by human activities and where some species might have greater difficulty moving across the landscape (e.g., Gobeil and Villard 2002). A significant challenge also exists in northern regions where faunal change is projected to be the greatest in areas outside of the existing system of

Figure 16: Spatial mismatch between the geographic distribution of A. the current (2011) system of protected areas in Canada and B. the greatest projected turnover (shown for all assessed taxa assuming the full-dispersal scenario).

A. System of protected areas in Canada (2011).



B. Projected turnover in all assessed taxa (as a percentage relative to current) by the 2071-2100 period, assuming full-dispersal scenario.



protected areas (Figure 16). Thus, greater densification of protected areas (i.e., additional protected areas with greater connectivity among them) in both southern and northern parts of Canada is required to improve the ability of species to move in response to climate changes. Otherwise, only the best dispersers will be able to colonize, resulting in simplified ecosystems dominated by pioneering, aggressive and/or generalist (r-selected) species and possibly more vulnerable to invasive alien species.

Given the important role of protected areas in biodiversity conservation in a climate-change context, it would be prudent to address the gaps that are projected to emerge by conducting systematic spatial planning. Complementary analyses should be conducted to identify climate-change refugia, resilient sites or land facets, emerging or possible future hotspots of concentrated diversity, and local and regional flow patterns across landscapes (e.g., Olson and Lindsay 2009, Beier and Brost 2010, Trombulak and Baldwin 2010, Game et al. 2011, Anderson et al. 2012). This would include the identification of networks of conservation areas that should be managed to support ecosystem functions and ensure landscape-level connectivity to accommodate the impacts of climate change, as also called for in Canada by Lemieux et al. (2010) and MacKinnon et al. (2015). If implemented, protection of such key areas would serve to safeguard or enhance biodiversity conservation in Canada and, in at least some situations, to accommodate species shifts in an era of climate change.

Useful broad-scale datasets are emerging, such as the one developed by Lawler et al. (2009) for vertebrates in the Western Hemisphere, but also those by McKenney et al. (2007a, b) for North American tree species, and the National Audubon Society (2014) for bird species. Similar analyses can be extended to other taxa and to tri-national, continental and hemispheric scales for species of concern (e.g., species at risk) or of common conservation interest (e.g., migratory birds and butterflies). Making datasets such as these more readily accessible would go a long way to facilitating information sharing and encouraging additional analyses with more taxa and over multiple spatial scales.

Temporal uncertainty was addressed in the present study by partitioning range projections into 30-year time periods from 2011 to 2100 so that the magnitude, extent and timing of change could be examined. The certainty of climate change and its impact on species, ecosystems and conservation areas may be subdued by its incremental nature and its localized expression. Even acknowledging uncertainties, given the urgent need to respond to climate change, it seems prudent to begin adaptation action now based on the information available. Monitoring schemes should also be put in place to track changes in measures such as species composition, trophic diversity, ice/shore phenology and those related to indicator species that are more sensitive to climate-related change (e.g., species senstive to changes in water levels and temperature and those at the southern and northern limits of their ranges). As needed, policies, plans and actions should be modified in response to the evidence base. Indeed, in a survey conducted by Lemieux et al. (2010: p. 77), two-thirds of protected area agencies surveyed in Canada disagreed with the statement that "there are too many uncertainties regarding climate change to develop adaptation strategies for protected areas."

Lemieux et al. (2010: p. 80) also concluded that, "the impacts of climate change may effectively alter traditional 'rules' of biodiversity conservation in Canada and may have far-reaching consequences for those agencies and organizations that manage them." Contemporary approaches based on establishing representative nodes of ecoregional or biogeoclimatic distributions and managing for ecological integrity as currently understood will become increasingly problematic as species are shifting and ecological processes (such as natural disturbance related to fire and pest outbreaks) are changing as a consequence of climate change. The Parks Canada Agency system, which is currently managed for ecological integrity, had projected species losses/turnover of 2-6% involving 10-27 species (in no-/full-dispersal scenarios, respectively) by the 2020s, and increasing to 3-10% (13-45 species) by the 2080s. Such projected changes highlight the need to refine and enhance the long-term vision for ecological integrity to make it more appropriate for a rapidly changing climate (cf. Lemieux et al. 2010). This may include rethinking our understanding of what constitutes an invasive/alien species and our associated values, while at the same time addressing aggressive invasive species that threaten or simplify ecosystems. A significant conservation challenge that appears to be emerging is the potential threat posed by expansion of species ranges into those of current species (particularly those that are of conservation priority) in response to a changing climate.

Regardless, emerging projections of high magnitudes and rates of change support the need to manage for long-term processes of change, to accommodate conservation of a broad range of biodiversity by ensuring connectivity to allow for dispersal of species, including those with limited or slow dispersal abilities and with dependence upon late-successional habitat, such as forest canopy. An important role of protected areas, in contrast to the greater landscape, is to provide refugia for late-successional ecosystems and spatial and temporal cycling of ecosystems to allow them to develop to late stages and associated habitat for species that depend upon these conditions. At the same time, integrated management in the greater landscape, in conjunction with more environmentally sympathetic stewardship activites, are needed to protect species-at-risk, endemic species, critical wildlife habitat and other highly valued components of biodiversity outside of protected areas.

Bird Conservation Region (BCR) planners need to be cognisant of the magnitude and composition of change projected for bird species in their planning units to enable them to consider the extent to which creating conservation plans based on current bird species composition is problematic given a changing climate. Half of the BCR planning units had a projected loss of at least 17 species or 9.3% of current under the no-dispersal scenario and 11 species or 6.5% of current under the full-dispersal scenario by the 2080s for all bird species modelled.

The southern parts of Nunavut and the Nunavut Settlement Area are projected to have some of the highest magnitudes of change in Canada even within the next 30 years. The establishment of additional protected areas together with enhanced conservation measures in this region, including linkages and corridors to connect protected areas for wildlife migration, would represent an important strategy in response to climate change. Areas for application of such conservation measures should be large, straddle several ecological regions and contain a wide range of habitat and geophysical types. Widespread application of carefully selected and sited measures should include identification and protection of resilient ecosystems that better buffer the impacts, provide habitat for native species for longer periods of time and provide healthy, evolving systems with habitat for new combinations of species capable of adapting to the new climate envelope, as recommended by Lemieux et al. (2010) and Anderson et al. (2012). This is important in the North to accommodate wide-ranging species and in this region of Nunavut in particular that provides historic calving areas for caribou (*Rangifer tarandus*) (Nunavut Planning Commission, Draft NLUP 2010: Map 1-7). Special management areas such as the Thelon Game Sanctuary take on even more importance as conservation measures in regions such as this. Such measures are also important in southern Canada, however, where opportunities for dispersal are already limited by habitat loss and fragmentation. Remaining resilient sites and regional flows should be identified, secured and restored as soon as possible.

Past experience may not serve as a guide for decision-making in novel future conditions. New information about climate and ecosystem function is needed on an on-going basis to help practitioners and stakeholders make rational decisions related to climate change and conservation. An important aspect of that process is to document and report case studies on various adaptive approaches and techniques initiated to deal with climate change so that knowledge and experiences are shared among practitioners.

Given the broad scope of issues related to climate change, adaptation in the conservation sector can really only progress by means of a more integrated approach within government and institutions, among sectors, and between a complex overlay of ecological and jurisdictional scales, from the local to international which, for Canada, particularly entails coordination with the United States and Mexico. Domestically, Lemieux et al. (2010) contend that agencies and organizations responsible for biodiversity conservation will have to work collaboratively in order to maintain comprehensive networks of federal, provincial, territorial and privately owned conservation areas that are resilient to climate change. National and hemispheric efforts would also benefit from regional efforts to track and forecast climate change implications and mitigation measures for more local and ecoregional situations such as in the Acadian/Northern Appalachian ecoregion (e.g., Trombulak and Baldwin 2010, www.fws.gov/science/shc/index.html). The analyses presented here for the Acadian/Northern Appalachian ecoregion could be extended to other transboundary (Canada-USA) regions to inform the development of binational climate-change adaptation strategies and actions.

The implications of climate change for both marine and freshwater ecosystems have been explored in only a rudimentary way to date (Jessen and Patton 2008, Lemieux et al. 2010, Stortini et al. 2015). Cheung et al. (2009) published a global analysis of projected marine species shifts for 1066 exploited fish and invertebrate species between 2003 and 2050. Their projections show that climate change may lead to numerous local extinctions (i.e., loss) in the sub-polar regions and semi-enclosed seas, and high species invasions (i.e., gain) in the Arctic Ocean. When combined, invasions and extinctions result in species turnovers of over 60% of the extant biodiversity. Recent analyses for Canada reported in Cheung et al. (2011) can be used to inform marine spatial planning in Canada including bioregional planning for a national system of marine protected areas and an Atlantic to Caribbean system in the North American Marine Protected Areas Network under the auspices of the tri-lateral Commission for Environmental Cooperation. Such science-based information and principles for use in protected area site and system planning were not available when Canada's system of terrestrial protected areas was being doubled in extent over the last 20 years.

Protected areas and other stewardship lands can serve to maintain or strengthen ecological resilience (including the provision of wildlife habitat and movement corridors), play an important role in maintaining and renewing essential ecosystem services (such as clean air and clean water), and in some cases, provide protection against the physical effects of extreme weather events and other climate-related impacts.

Development of climate-change adaptation strategies and actions within the context of integrated landscape planning and management is being advanced in Canada by various agencies and organizations (Canadian Parks Council 2013). Continuing to generate the evidence base to put adequate mitigation and adaptation measures in place is key to addressing the mostly adverse consequences of climate changes on biodiversity. By concentrating on stable physiographic features, protected areas and stewardship actions can capture and support a network of the environmental mosaics and habitats in any given ecoregion that not only expresses the full range of climate regimes at macro-, meso- and micro-scales but also seems to capture representative complements of species. Rather than abandon this construct, adaptation now calls for innovative design to strengthen connectivity, resiliency and ecological integrity among the already existing core protected areas, together with ongoing efforts to establish new protected areas.

Concentrated populations of wildlife, such as Murres (*Uria*) and other colonial seabirds, can present added complications for designing and managing protected areas aimed at conserving species that may be challenged by climate change. Location: Prince Leopold Island Migratory Bird Sanctuary, Nunavut (Photo Credit: courtesy Canadian Wildlife Service).

CONCLUSION

This report builds upon CCEA's initial work on a national framework for protected areas (Gauthier 1992, Gauthier et al. 1995), which was adopted by many jurisdictions through the 1990s and served as a basis for the unprecedented growth of protected area networks over the past two decades. It adds substance to CCEA's work on Northern Protected Areas, which made the case for large protected areas in the North to enhance ecological integrity and connectivity (Wiersma 2007, Wiersma et al. 2005). It also recognizes the United Nations *Convention on Biological Diversity (United Nations 1992a)* and Canada's commitment to it with the *Strategic Plan for Biodiversity 2011-2020*, specifically Aichi Target 11 (United Nations 2010), which calls for the expansion of protected area systems to include at least 17% terrestrial and inland waters and 10% coastal and marine areas by 2020. This backdrop, now reinforced by the United Nations 2015 *Paris Agreement* on Climate Change to curb global warming, adds force for CCEA and its partner jurisdictions to respond to the imperative for adaptation posed by climate change. The methods, results and discussion relate explicit and implicit conclusions, applications and actions in response to this research. The following summary outlines recommended key actions.

1. Conduct follow-up modelling at regional, national and continental scales with finer grain analysis to confirm projected trends and build upon these initial results.
2. Analyse other mapping classifications, elements and data sets, notably ecozones, ecoregions and ecodistricts, and native trees, vascular plants, reptiles and other groups of species.
3. Ground-truth modelled species ranges against documented species occurrences in a suite of protected areas (e.g., Kejimkujik National Park, Algonquin Provincial Park, Point Pelee National Park, Mont Saint-Hilaire, Banff National Park and many other areas) where comprehensive inventories of flora and fauna have been compiled.
4. Develop finer-scaled localized models at higher resolution, especially in settled southern regions where biodiversity is the greatest and most at risk; study refinements could include finer grain analyses which may expose different rates of turnover in southern settings, since the 50 × 50 km sq. grid is 100 to 1000 times larger than most protected areas in settled regions.
5. Analyze species losses in various scenarios to discern any patterns in the dropout of species associated with similarities in life history, habitat preference, or other environmental factors that could provide guidelines for refinements in the design of protected area networks and management to better retain species in protected area systems.
6. Communicate results of such studies more widely to the public through interpretative programmes within and beyond protected areas through various media outlets.
7. Identify biodiversity hot-spots, key buffers and critical linkages that need to be protected or otherwise managed to enhance representation, integrity, resilience and connectivity.
8. Promote complementary land-use around protected areas to buffer protected areas from surrounding extraction and consumptive uses and ensure sympathetic management in the wider landscape.
9. Perpetuate habitats and species at risk by utilizing restoration projects and species re-introductions in suitable protected areas.
10. Increase collaboration among researchers, practitioners and management agencies to develop a more coordinated approach to strategic planning for the location design and management of protected areas and greater area ecosystems.
11. Secure more resources to continue with studies and the development and implementation of mitigating measures and adaptive responses for planning and managing protected areas.
12. Enhance standardized monitoring programmes for protected areas to gauge and adapt management regimes to minimize the impact of climate change on species and habitats.

The analysis of the three species data sets—birds, mammals, and amphibians—against the protected areas, Bird Conservation Regions and case-study ecoregions casts an insightful range of scenarios that demonstrate the potential impact of projected climate-change for three diverse species groups. The inclusion of ecozones, ecoregions and ecodistricts as analytical units, and data sets on the distribution of native tress and other selected plants would strengthen the backdrop for the protected areas analysis. In particular, plants and vegetation more directly determine habitat structure and function, and may be somewhat more characteristic as benchmarks for climate change than the more mobile faunal groups. While some such analyses have been the focus of previous studies, further analyses in Canadian protected areas planning contexts are warranted and could form the basis of future research. Despite some design limitations noted in the methodology, the no- and full-dispersal scenarios serve to generate thought and discussion, and ultimately are the only way that such an analysis can be framed to set endpoints for projected change. Real-world responses will likely fall somewhere in between. These, too, will not be constant among species, due to limitations of such analyses, variability among species, and other factors.

Notwithstanding these observations, the analysis and the results presented herein remain highly informative, providing generalized but still illuminating results and conclusions. Results should be cautiously interpreted in light of the limitations of the coarse grain, selected species sets, ameliorating and attenuating factors, and time intervals covering the temporal projections. Despite the often indirect influence of macro-climate on species distributions, and the likely high variability in range changes among such a large and diverse suite of species, the study still represents a very worthwhile and revealing exercise. For the most part, the results trend with intuitive expectations on species range shifts in response to climate change. The inherent value in the study accrues from five perspectives:

1. it presents a model, open to refinement, that illustrates the kind of analysis that can be done to assess species loss/gain/turnover range-wide and in protected area networks in response to climate change;
2. it provides an initial assessment of wildlife species turnover in Canada that confirms other such projections and ecological intuition with results that add some specificity to the impact of climate change on wildlife in Canada;
3. it generates a good basis to discuss the implications of climate change and to contemplate remedial measures and adaptation for protected areas and biodiversity conservation from both system design and area management perspectives;
4. it can help to inform subsequent planning for the location and design of new protected areas that best contribute to the achievement of Canada's commitments on biodiversity conservation, notably the fulfillment of Aichi Target 11; and,
5. it extends CCEA's core contribution over the past two decades in providing science-based insight and guidance on the selection, design, protection and management of protected areas.

On an optimistic note, Canada's latitudinal expanse, especially in the high North, may provide room for current biologically-diverse climatic belts to migrate north with the hope that constituent habitats and species will do so as well to help to prevent catastrophic losses of northern biodiversity. At the same time, gains may continue with the immigration of species on more southerly fronts with the net effect being higher biodiversity for Canada in the future than currently exists. Added to this, species resilience combined with highly diverse local environmental fabrics may well help to retain existing species complements, albeit in more local and more compressed settings. Owing to physiographic diversity at meso- and micro-scales, regional climates will continue to be ameliorated and attenuated by topography, slope, aspect and edaphic conditions, helping to retain more diverse mosaics than otherwise could persist under the more homogeneous conditions portrayed in this report.

Canada's commitments to the *Strategic Plan for Biodiversity 2011-2020*, specifically Aichi Target 11 (United Nations 2010), and the the United Nations *Paris Agreement* on Climate Change (United Nations 2015) to curb global warming present a timely opportunity to apply the results and conclusions in this report. Building on CCEA's earlier contributions on systems planning for protected area networks and climate change, the findings in this report can help provide a good vantage point for advancing spatial planning tailored to address Aichi Target 11 and the impact of global warming on protected areas. The inclusion of specific analysis and results in this study for the entire system of protected areas in Canada and the selected subsets of areas serves to enlighten understanding on the contributions of various jurisdictions. This may help to gel collective resolve and closer collaboration among federal, provincial and territorial agencies and non-governmental organizations working to overcome the challenges that climate change poses for protected areas and biodiversity conservation.

PHOTO ILLUSTRATIONS

The highly intricate ecological relationships underpinning romantic images of lush Carolinian forests present a complex tapestry for climate change to play out on efforts to conserve southern biodiversity, with changing environmental conditions likely to favour the representation of some species and ecosystems in protected areas while being detrimental to others. Location: Rondeau Provincial Park, Southern Ontario (Photo Credit: Tom Beechey).

This study demonstrates how climate change over the 21st century could induce shifts in the range of mammals, birds and amphibians to affect their representation in protected areas. Photos in the following categories illustrate and expand upon key findings of this study and their implications for protected areas and biodiversity conservation:

1. selected species in the modelled taxa that may be affected by or resilient to the environmental impacts attributed to climate change;
2. other species and taxonomic groups for which range shift modelling could reveal additional species vulnerable to climate change;
3. landscapes with inherent ecological integrity and resilience that may dampen the impact of climate change on species and protected areas;
4. discoveries and insights to inform future conservation efforts and adaptation in planning, designing and managing protected areas; and,
5. concepts and approaches that could enhance complementary conservation efforts around protected areas and across the wider landscape.

Photos are generally arranged in four regions: High Northern/Arctic; Pacific/Cordilleran; Prairies/Central/Southern; and Eastern/Atlantic. Photo credits are cited along with the location of the images as part of the photo captions.

Range shift scenarios for Peary Caribou (*Rangifer tarandus pearyii*), a small subspecies of barren ground caribou endemic to the insular tundra regions of Nunavut and Northwest Territories, can be used to prioritize field research and monitoring programmes for wildlife conservation in protected areas and greater area ecosystems. Location: Arctic Archipelago (Photo Credit: Kevin Kardynal, © Environment Canada and Climate Change).

The Peel River Watershed in Yukon and Northwest Territories is a vast wilderness tract of more than 77 000 km^2 featuring a mosaic of high northern ecosystems that support woodland and barren ground caribou, with sufficient size and integrity to accommodate modest range shifts for many resident species. Location: Greystone River, Peel River Watershed, Yukon (Photo Credit: Peter Mather, courtesy Yellowstone to Yukon Conservation Initiative).

A Pleistocene survivor that has endured climate change in it's distant past, Muskox (*Ovibus moschatos*) is once again having to confront the impact of climate-induced habitat modification and related environmental changes, this time possibly leading to the extirpation of the species from northern protected areas in Canada. Location: Auyuittuq National Park, Ellesmere Island, Nunavut (Photo Credit: Joyce Gould).

Thawing and collapse of permafrost in Arctic and tundra regions, induced by global warming, not only modifies existing tundra habitats but also fuels the process by releasing additional carbon, which feeds solar insulation and the acceleration of global warming, and which generates further thawing, carbon release and melting of permafrost. Location: Auyuittuq National Park, Ellesmere Island, Nunavut (Photo Credit: Joyce Gould).

Steep-sided valleys flanking coastal inlets, lowland expanses and floodplains provide a wide range of aspects and exposures that can attenuate or ameliorate varied topographic settings to maximize site, community and habitat diversity, which could help to buffer the effects of global warming on protected areas and species distributions in Arctic landscapes. Location: Auyuittuq National Park, Ellesmere Island, Nunavut (Photo Credit: Joyce Gould).

Despite being concentrated in Canada's largest migratory bird sanctuary, the very restricted range of Ross's Goose (*Anser rossii*) on Queen Maud Gulf in the high Arctic signals its vulnerability to climate change with range shift modelling revealing that it could be displaced from Canada's network of protected areas in the 21st century. Location: Karrak Lake, Queen Maud Gulf Migratory Bird Sanctuary, Nunavut (Photo Credit: Murray Gillespie).

Tundra Swan (*Cygnus columbianus*) is one of many North American migratory waterfowl that may experience changes in their summer residency in northern protected areas and more widely across their Canadian breeding range due to environmental perturbations associated with global warming. Location: Kendall Island Migratory Bird Sanctuary, Mackenzie Delta, Northwest Territories (Photo Credit: courtesy Canadian Wildlife Service).

The vulnerability of Collared Pika (*Ochotona collaris*) to climate change supports the designation of this species as being of 'Special Concern' by the Committee on the Status of Endangered Wildlife in Canada and has led biologists in Nahanni to develop a monitoring programme to track its distribution and status which may help to guide future conservation efforts. Location: Tlogotsho Plateau, Nahanni National Park, Yukon (Photo Credit: Doug Tate).

Although Murres (*Uria*) do not appear to be threatened by climate change, likely because of their wide distribution, large populations and adaptive nature, displacement of large breeding colonies of other less resilient species more vulnerable to global warming could have serious implications for such concentrations of wildlife. Location: Prince Leopold Island Migratory Bird Sanctuary, Nunavut (Photo Credit: courtesy Canadian Wildlife Service).

Species' range shifts associated with climate change happen incrementally, and in mountainous regions receding glaciers that expose new environments for primary succession and vegetative encroachment can lead to the development of new communities and habitats, which can enable wildlife to migrate and settle in new territory. Location: Mount Robson Provincial Park, British Columbia (Photo Credit: courtesy BC Parks).

Colourful alpine meadows provide important habitat for many species in the western cordillera and despite woody encroachment they may offer a somewhat resilient refuge against climate change due to their inherent diversity, their widespread distribution in and around protected areas, and their intricate patchwork and topographic amplitude. Location: Mount Robson Provincial Park, British Columbia (Photo Credit: courtesy BC Parks).

Changes in habitat may be a critical factor in range shifts for many small mammals that display turnover in modelling projections; however, generalized patterns are not always obviously apparent and many other wide-ranging species such as the Hoary Marmot (*Marmota caligata*) do not disclose any cause for immediate concern. Location: Mount Robson Provincial Park, British Columbia (Photo Credit: courtesy BC Parks).

Finer scale range shift modelling for Grizzly Bear (*Ursus arctos horribilis*) and other ursids may reveal gains or losses of subspecies in protected areas that were not disclosed by the coarser filter adopted in this study, which focused on providing an overview of broader patterns of species turnover in Canada's network of protected areas. Location: Khutzeymateen/K'tzim-a-deen Grizzly Sanctuary, British Columbia (Photo Credit: Tory Stevens).

Wildlife native to temperate Pacific rainforests have a wide latitude for secure movement and migration provided by the extensive contiguous forest habitats of mixed age and composition and the mature network of protected areas and other conserved lands and waters which characterize this globally significant ecological region. Location: Cathedral Grove, MacMillan Provincial Park, Vancouver Island, British Columbia (Photo Credit: Tom Beechey).

Monitoring of colonial seabirds, here involving researchers taking weight measurements of Rhinoceros Auklet (*Cerorhinca monocerata*) chicks, can provide valuable insights on changes in the condition and status of birds that could help to diagnose impacts of climate change and possible management intervention for conservation. Location: South Bay, Anne Vallée Triangle Island Ecological Reserve, British Columbia (Photo Credit: Blair Hammond).

Range shift modelling for Ancient Murrelet (*Synthilboramphus antiquus*), a burrowing colonial seabird confined to the islands of Haida Gwai, and designated as a species of 'Special Concern' by the Committee on the Status of the Endangered Wildlife in Canada due to high predation by introduced mammals, reveals the possible loss of colonies of this species in the 21st century. Location: Haida Gwaii, British Columbia (Photo Credit: Laurie Wilson).

Pelagic marine mammals, such as Steller's Sea Lion (*Eumetopias jubatus*), which has experienced serious population declines on the Pacific coast in recent years, require specific assessments to identify species that may experience range shifts that could trigger losses or gains in representation in protected areas. Location: Gitxaala Nii Luutiksm Kitkatla Conservancy, British Columbia (Photo Credit: Jamie Hahn).

The projected loss of Sage Thrasher (*Oreoscoptes montanus*) from some climate change scenarios reflects in part the already very limited distribution and scant representation of this rare species, and raises concern for its long-term viability, which may be jeopardized by the existing scarce habitat supply and the limited prospect for future habitat expansion. Location: Mainly southern interior, British Columbia (Photo Credit: Dick Cannings).

The compressed edaphic and topographic gradients in the prairie-foothills-cordilleran transition around Waterton Lakes National Park in south-western Alberta support striking ecological diversity and ideal habitat for deer (*Odocoileus*) and other large mammals that might offer some resilience to critical habitat losses and species turnover associated with climate change. Location: Pine Ridge, Alberta (Photo Credit: Bob Lee).

The Waldron tract, comprising more than 12 000 hectares of grasslands on the western slope of the Rockies, is one of many natural area conservation projects of the Nature Conservancy of Canada that is helping to protect key areas of biodiversity and wildlife habitats, often with critical linkages to other protected areas. Location: Waldron Natural Area, Alberta (Photo Credit: Kyle Marquardt, courtesy Nature Conservancy of Canada).

The Waterton-Glacier International Peace Park of 1932 comprised of Waterton Lakes National Park (Canada) and Glacier National Park (United States), both now designated as World Biosphere Reserves and a World Heritage Site, forms the 'Crown of the Continent' that provides a significant international wildlife corridor. Location: Glacier-Waterton peaks, Montana (Photo Credit: courtesy US National Park Service).

Work being supported by the Y2Y Conservation Initiative to track and map the distribution of the elusive Wolverine (*Gulo gulo*) is helping in trans-boundary conservation efforts and establishes a model for field studies of critical species for which range shift modelling could help to inform adaptive planning and management for protected area networks. Location: Y2Y corridor (Photo Credit: Stephen Legault, courtesy Yellowstone to Yukon Conservation Initiative).

The increased incidences of forest fires, insect infestations and invasive alien species are some of the disruptive agents commonly associated with climate change that can displace native wildlife, modify established habitats and reset successional pathways to alter the distribution of species and reduce species representation in protected areas. Location: Colin Cornwall Wildland Provincial Park (Photo Credit: Drajs Vujnovic).

Owing to its wider distribution and better representation in protected areas, the outlook for Western Grebe (*Aechmophorus occidentalis*), featured here, may be more favourable than that for the very similar but far scarcer Clark's Grebe (*Aechmophorus clarkii*), which range shift modelling projects as a species that could be extirpated from protected areas in the 21st century. Location: Manitoba (Photo Credit: © Ducks Unlimited Canada/Tye Gregg).

Projected warming trends with more extreme weather events in mid-western prairie regions could affect delicate ecological relationships that might necessitate increased monitoring and more active intervention management in order to meet biodiversity conservation objectives in and around protected areas. Location: Grasslands National Park, Saskatchewan (Photo Credit: Max Finkelstein, courtesy Parks Canada Agency).

Already highly susceptibility to sylvatic plague, and with almost its entire Canadian population centred in Grasslands National Park with little opportunity to colonize other sites, climate change projections of the loss of Black-tailed Prairie Dog (*Cynomys ludovicianus*) could create added stress for this species in Canada. Location: Grasslands National Park, Saskatchewan (Photo Credit: courtesy Parks Canada Agency).

Range shift modelling for reptiles as a group and in particular oppressed species such as Prairie Rattlesnake (*Crotalus viridis*) could help to identify opportunities for new habitats, assisted migration and adaptive management in highly settled prairie landscapes under future climate change scenarios. Location: Grasslands National Park, Saskatchewan (Photo Credit: Wayne Lynch, courtesy Parks Canada Agency).

Found from Atlantic Canada to the Pacific west coast, including much of the Boreal Forest, Wood Frog (*Lithobates sylvaticus*) is a highly adaptive ranid inhabiting wetlands and moist forests that may extend its already widespread representation in many northern protected areas through range expansions associated with climate change. Location: Fort Severn, Ontario (Photo Credit: Mike Oldham).

The proposed Pimachiowin Aki World Heritage Site endorsed by the Poplar River, Little Grand Rapids, Pauingassi, Pikaangikum and Bloodvein First Nations incporpoates Treaty lands together with Atikaki Provincial Park in Manitoba and Woodland Caribou Provincial Park in Ontario, forming a vast wilderness tract for woodland caribou and other wildlife. Location: Aikens Lake, Atikaki Provincial Park, Manitoba (Photo Credit: Morgan Hallett),

Reductions in northern sea ice attributed to global warming complicate the movement, hunting and feeding of Polar Bear (*Ursus maritimus*) range-wide with added stress for over-wintering bears in the Hudson Bay Lowlands, which hibernate and nurse their young on depleted food reserves in dens excavated in ancient beach strands. Location: Kaskatamagan Wildlife Management Area, Manitoba (Photo Credit: Daryll Hedman).

Floristic inventories and vegetation surveys conducted to describe and map ecosystems in many protected areas, such as the work undertaken here on the plateau of the Monts Groulx, now assume added value as baselines to monitor plant succession, wildlife habitats and species distributions associated with climate change. Location: Manicouagan-Uapishka World Biosphere Reserve, Quebec (Photo Credit: Dominic Boisjoly).

Like time capsules, post-glacial relicts of Alpine Woodsia (*Woodsia alpina*) and other Arctic-alpine plants persist in colder-than-normal micro-climates on cliffs and canyon walls around the northern coastline of Lake Superior, many now in protected areas and widely disjunct from their current centres of distribution in far northern and cordilleran regions. Location: Cavern Lake Canyon Provincial Nature Reserve, Ontario (Photo Credit: Tom Beechey).

The Thousand Islands Bridge connecting Canada with the United States symbolizes the Algonquin to Adirondacks Collaborative, which connects Algonquin Provincial Park in Ontario with the Adirondack Park in New York State, together with some 30 other conservation areas, to help to sustain the ecological integrity of the region. Location: Thousand Islands National Park, Ontario (Photo Credit: courtesy Thousand Islands National Park).

The patchwork of remnant woodland nodes and corridors threaded with fence lines and hedgerows in highly fragmented agricultural and rural landscapes, such as this example in the Greater Toronto Area, provides important linkages for the movement of plants and animals that can assist species migration today and under future climate change scenarios. Location: Rouge Valley, Southern Ontario (Photo Credit: Mike McMurtry).

Natural areas in municipal parks, open space and even storm-water ponds can contribute to the biodiversity fabric of urban and regional landscapes by providing habitat patches and linkages that can assist species migration among formally protected areas and thereby help to sustain critical ecological functions under future climate change scenarios. Location: Halton Hills storm-water pond, Southern Ontario (Photo Credit: Tom Beechey).

Beyond protected areas in many settled regions, wildlife such as this juvenile Bullfrog (*Lithobates catesbeiana*) and many other native species are afforded some protection through development restrictions on significant wetlands, woodlands and other environmentally sensitive areas in order to retain important natural areas and green space for both wildlife and citizens. Location: Georgian Bay wetland, Ontario (Photo Credit: Mike Oldham).

Lowland southern deciduous forests and swamps are among the most complex forest ecosystems in Canada often exhibiting diverse habitat stratification and intricate niche development with a range of internalized micro-climates that may provide some inherent resilience to climate change for many highly adapted species. Location: Rondeau Provincial Park, Southern Ontario (Photo Credit: Tom Beechey).

Assisted colonization of species, such as the re-introduction of Southern Flying Squirrel (*Glaucomys volans*) to Point Pelee in the 1930s, after its extirpation by feral animals in the early 20th century, could have application for trans-locating rare species and local populations confronted by migratory impediments associated with climate change. Location: Point Pelee National Park (Photo Credit: R. D. Robinson, courtesy Parks Canada Agency).

Peripheral bird species that currently breed in the United States near the Canadian border, such as Worm-eating Warbler (*Helmitheros vermivorum*), which is sometimes recorded in atlassing efforts and seasonal bird counts as a casual visitor, could be among the first species to assume breeding residency in Canada with emerging climate change scenarios. Location: Rondeau Provincial Park, Southern Ontario (Photo Credit: Allen Woodliffe).

Nature reserves on Pelee Island, the southernmost land mass in Canada, protect many rare Carolinian species including Small-mouth Salamander (*Ambystoma texanum*), which is confined here to a few wetlands and vernal ponds making it the most restricted vertebrate in Canada and possibly quite vulnerable to adverse environmental changes. Location: Fish Point Provincial Nature Reserve, Southern Ontario (Photo Credit: Mike Oldham).

As part of the work to restore savannahs at Point Pelee, efforts are being made to improve the habitat for Yellow-breasted Chat (*Icteria virens*), which suffered a serious decline in its population due to habitat loss associated with forest succession in the park, an example of intervention management of possible relevance to climate change. Location: Point Pelee National Park, Southern Ontario (Photo Credit: courtesy Point Pelee National Park).

Although protected areas play a vital role for Fowler's Toad (*Anaxyrus fowleri*), which is listed as 'Endangered' by the Committee on the Status of Wildlife in Canada, the species might not benefit from potential range expansions that may do little to enhance its conservation status, which is determined mainly by a fixed habitat supply and various human threats. Location: Rondeau Provincial Park, Southern Ontario (Photo Credit: Allen Woodliffe).

Field naturalists across Canada play important roles in conducting wildlife surveys and atlassing projects on birds, mammals, herptiles and other taxonomic groups that provide critical information on the distribution and status of species in and around protected areas and other conservation lands. Location: Essex Region Conservation Area, Southern Ontario (Photo Credit: courtesy Emma Rose Buck and Jeremy Bensette).

Nature reserves owned and managed by non-governmental organizations play important roles in protecting habitats and species, such as Eastern Newt (*Notophthalmus viridescens*), here featuring the Red Eft juvenile stage, which contribute to species representation in protected areas and in broader efforts to conserve biodiversity. Location: Sauble Dunes Nature Reserve (Photo Credit: Noah Cole, courtesy Ontario Nature).

With an elevation of 806 metres and located just five kilometres from the north Atlantic coast, Gros Morne Mountain exhibits striking bioclimatic gradients ranging from southern boreal to Arctic-alpine ecosystems, which provide some resilience and altitudinal amplitude for habitat adaptation to help counter the impact of climate change. Location: Gros Morne National Park, Newfoundland (Photo Credit: Darroch Whitaker).

This un-named lake in the Gros Morne highlands is surrounded by Arctic-alpine vegetation that provides habitat for southern breeding populations of Arctic Hare, Long-tailed Duck, Rock Ptarmigan and American Tree Sparrow, while isolated late summer snow-beds (*zabois*) support southern populations of Arctic plants. Location: Gros Morne National Park, Newfoundland (Photo Credit: Darroch Whitaker).

Orphan glaciers, some 100 in total in the Torngat Mountains, are the last vestiges of the Pleistocene ice cap in eastern Canada, remnants which may continue to ablate under ongoing global warming that is enabling the invasion of species and the development of new ecosystems in these once barren ice-mantled sites. Location: Caubvick Glacier, Torngat Mountains National Park, Labrador (Photo Credit: Darroch Whitaker).

Range shift modelling for Beluga Whale (*Delphinapterus leucas*) and other cetaceans could assist in selecting marine conservation areas around Canada's vast coastline to help to fulfill the national commitment to Aichi Target 11, which calls upon signatory nations to incorporate ten percent of their coastal waters within protected areas by 2020. Location: Saguenay Marine Park, Quebec (Photo Credit: Nelson Boisvert, courtesy Parks Canada Agency).

The highly varied site conditions in this deeply incised valley in the Torngat Mountains offer some resilience to climate change on sculpted valley walls and subtending slopes while the braided floodplain is being overwhelmed by expanding willow and alder thickets that are apparently being colonized by northern boreal songbirds. Location: Southwest, Torngat Mountains National Park, Labrador (Photo Credit: Darroch Whitaker).

Shrubification has been occurring throughout the Arctic, but the rate of shrub expansion is extremely high in the Torngat Mountains, as seen in this riparian willow (*Salix*) and alder (*Alnus*) thicket, likely due to the combined effects of climate change and reduced grazing pressure following the decline of caribou numbers. Location: Nakvak Brook, Torngat Mountains National Park, Labrador (Photo Credit: Darroch Whitaker).

Wilson's Warbler (*Cardellina pusilla*) and several other northern boreal songbirds are now nesting regularly in rapidly expanding riparian willow and alder thickets in the southern Torngat Mountains, 150 kilometres or more north of their previously documented range limits along the Labrador coast. Location: Komaktorvik River, Torngat Mountains National Park, Labrador (Photo Credit: Darroch Whitaker).

Trailing heath-like mats with patchy, severely contorted spruce (*Picea*) thickets on exposed maritime coastlines, that resemble displaced subarctic and alpine *krummholz* vegetation, illustrate how harsh localized micro-climates can sustain extreme 'outliers' of vegetation, communities and habitats within more temperate, regional ecological mosaics. Location: Peggy's Cove, Nova Scotia (Photo Credit: Tom Beechey).

The mobility of birds can make them 'first responders' to exploit environmental changes associated with climate change, which may help to explain the range expansions for Great Egret (*Ardea alba*) in the lower Great Lakes region in recent decades and which could act to extend its range and breeding population in Canada in future. Location: Southern Quebec (Photo Credit: ©Ducks Unlimited Canada/Michele Blachas and Carole Piché).

Environmental changes associated with climate change can happen at various temporal and spatial scales in different ecosystems and the impacts of global warming on maritime coastal systems such as tidal marshes are yet to be studied in depth to determine how they might affect the range and distribution of coastal plain flora and associated wildlife. Location: Tusket River Nature Reserve, Nova Scotia (Photo Credit: Sean Blaney).

Low-lying sandy shorelines and beaches that provide habitats for resident and migratory shorebirds and other wildlife may be affected by sea level rise projected to occur with climate change that could alter the extent and configuration of biotic communities and habitats, which could have implications for the distribution and abundance of native species. Location: Portage Island National Wildlife Area, New Brunswick (Photo Credit: Sean Blaney).

Irrespective of range shifts in breeding territories for migratory Arctic birds, shorebirds such as Baird's Sandpiper (*Calidris bairdii*) will remain reliant on maritime beaches and coastlines as corridors and stopovers for long distance travel to and from northern protected areas and surrounding regions important for nesting and foraging. Location: Protected beach, Prince Edward Island (Photo Credit: courtesy Island Nature Trust).

Extensive non-governmental efforts including those of nature trusts, naturalist clubs and private citizens have secured hundreds of natural areas across Canada, yet to be assessed through range shift modelling, which help to represent and protect habitats and species that contribute to governmental efforts on protected areas and biodiversity conservation. Location: Conway Sandhills Natural Area, Prince Edward Island (Photo Credit: Don Jardine, courtesy island Nature Trust).

Although amphibians exhibit potential for species gains associated with climate change, with possible additions such as Marbled Salamander (*Ambystoma opacum*) from the north-eastern United States, their colonization in Canada may be impaired by mobility and geographical barriers such as the Great Lakes and the St. Lawrence River. Location: South Fork, New York State (courtesy South Fork Natural History Museum and Nature Centre).

Among the smallest mammals in the world, Pygmy Shrew (*Sorex hoyi*) is widely distributed throughout the forested regions of Canada from the Maritimes to the Pacific Northwest where it is well represented and likely to persist in many protected areas in spite of climate change, much like it's diminutive ancestors, which triumphed in the Cretaceous. Location: Prince Edward Island (Photo Credit: courtesy PEI Forests, Fish and Wildlife).

Small size breeds success for many other vertebrates, such as the Spring Peeper (*Pseudacris cricifer*), one of Canada's smallest frogs, which is widely distributed in eastern and central Canada where it is represented in many protected areas, a demonstration of adaptive capacity and resilience that may help it to combat climate change. Location: Sauble Dunes Nature Reserve, Southern Ontario (Photo Credit: Noah Cole, courtesy Ontario Nature).

SELECTED REFERENCES

Anderson, M.G., M. Clark, and A. Olivero Sheldon. 2012. *Resilient Sites for Terrestrial Conservation in the Northeast and Mid-Atlantic Region*. The Nature Conservancy, Eastern Conservation Science. 168 pp.

Araújo, M.B., Pearson, R.G., Thuiller, W., Erhard, and M. 2005. Validation of species-climate impact models under climate change. *Global Change Biology*, 11: 1504-1513.

Baril, A., and K. Lindsay. 2009. *Vulnerability Assessment for Climate-induced Changes in Vertebrate Species Composition in Environment Canada Protected Areas.* Unpublished Technical Report, Canadian Wildlife Service, Environment Canada, Gatineau, QU.

Beier, P., and B. Brost. 2010. Use of Land Facets to Plan for Climate Change: Conserving the Arenas, Not the Actors. *Conservation Biology,* 24: 701-710.

Canadian Parks Council Climate Change Working Group. 2013. *Canadian Parks and Protected Areas: Helping Canada Weather Climate Change. Parks Canada Agency on behalf of the Canadian Parks Council.* 52 pp. http://www.parks-parcs.ca/english/CPC%20Climate%20Change%20Report%20FINAL%20engLR.pdf

Conservation Areas Reporting and Tracking System (CARTS)/Canadian Council on Ecological Areas (CCEA). 2011. http://www.ccea.org/download-carts-data/

Cheung, W. W. L., J. Dunne, J. L. Sarmiento, and D. Pauly. 2011. Integrating ecophysiology and plankton dynamics into projected maximum fisheries catch potential under climate change in the Northeast Atlantic. *ICES Journal of Marine Science*, 68: 1008–1018.

Cheung, W.L., V.W.Y. Lam, J.L. Sarmiento, K. Kearney, R. Watson, and D. Pauly. 2009. Projecting global marine biodiversity impacts under climate change scenarios. *Fish and Fisheries, DOI*: 10.1111/j.1467-2979.2008.00315.x

Game, E.T., G. Lipsett-Moore, E. Saxon, N. Peterson, and S. Sheppard. 2011. Incorporating climate change adaptation into national conservation assessments. *Global Change Biology*, 17: 3150-3160.

Gauthier, D. (Ed.). 1992. *Canadian Council on Ecological Areas Framework for Developing a Nationwide System of Ecological Areas, Part 1--A Strategy.* Report of the Systems Framework Task Force, CCEA Occasional Paper No. 12. Canadian Council on Ecological Areas, Ottawa, Ontario, Canada.

Gautier, D., K. Kavanaugh, T. Beechey, L. Goulet, and E. Wiken. 1995. *Canadian Council on Ecological Areas Framework for Developing a Nationwide System of Ecological Areas, Part 2-Ecoregion Gap Analysis*. CCEA Occasional Paper No. 13. Canadian Council on Ecological Areas, Ottawa, Ontario, Canada.

Gobeil, J. F., and M. A. Villard. 2002. Permeability of three boreal forest landscape types to bird movements as determined from experimental translocations. *Oikos*, 98:447-458.

Gobeil, J. F., J.L. Lawler, A. Baril, K. Lindsay, A. Fenech, and N. Comer. 2010. *Projected Range Shifts of Bird Species in Canadian Bird Conservation Regions under Climate Change*. Unpublished Technical Report, Canadian Wildlife Service, Environment Canada, Gatineau, QU. K1A 0H3.

Government of Canada. 2009. *Canada's Fourth Assessment Report to the Convention on Biological Diversity*. Available at: Environment Canada. 2006. National Inventory Report, 1990-2004 – Greenhouse gas sources and sinks in Canada. Available at: http://www.ec.gc.ca/pdb/ghg/inventory_report/2004_report/toc_e.cfm

Intergovernmental Panel on Climate Change (IPPC). 2007. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Core Writing Team, Pachauri, R.K. and Reisinger, A. (Eds.) IPCC, Geneva, Switzerland. 104 pp.

Intergovernmental Panel on Climate Change (IPPC). *Scenario Data for the Atmospheric Environment.* Data Distribution Centre. Available at: http://www.ipcc-data.org/sim/gcm_clim/SRES_TAR/ddc_sres_emissions.html. Content last modified: 02 April 2014. Accessed 16 January 2016.

Jessen, S., and S. Patton. 2008. Protecting marine biodiversity in Canada: Adaptation options in the face of climate change. *Biodiversity,* 9: 47-58.

Kennedy, J., and E. Krebs. 2010. *A Manual for Completing All-bird Conservation Plans in Canada.* Canadian Wildlife Service, Environment Canada, Gatineau, QU. K1A 0H3

Kharouba, H.M., and J.T Kerr. 2010. Just passing through: Global change and the conservation of biodiversity in protected areas. *Biological Conservation*, 143:1094–1101.

Lawler, J. J., D. White, R. P. Neilson, and A. R. Blaustein. 2006. Predicting climate-induced range shifts: model differences and model reliability. *Global Change Biology*, 12: 1568– 1584.

Lawler, J.J., S. L. Shafer, D. White, P. Kareiva, E. P. Maurer, A. R. Blaustein, and P. J. Bartlein. 2009. Projected climate-induced faunal change in the western hemisphere. *Ecology*, 90: 588-597.

Lemieux, C.J., and D.J. Scott. 2005. Climate change, biodiversity conservation and protected areas planning in Canada. *The Canadian Geographer*, 49: 384-399. doi: 10.1111/j.0008-3658.2005.00103.x

Lemieux, C.J., T.J. Beechey, D.J. Scott, and P.A. Gray. 2010. *Protected Areas and Climate Change in Canada: Challenges and Opportunities for Adaptation*. Canadian Council on Ecological Areas (CCEA) Occasional Paper No. 19. CCEA Secretariat, Ottawa, Ontario, Canada. K1A 0H3

Lemieux, C.J., T.J. Beechey, and P.A. Gray. 2011a. Prospects for Canada's protected areas in an era of rapid climate change. *Land Use Policy*, 28(4): 928-941. DOI: 10.1016/j.landusepol.2011.03.008.

Lemieux, C.J., T.J. Beechey, D.J. Scott, and P.A. Gray. 2011b. The state of climate change adaptation in Canada's protected areas sector. *The Canadian Geographer,* 55(3): 301-317. DOI: 10.1111/j.1541-0064.2010.00336.x

MacKinnon, D., C.J. Lemieux, K. Beazley, S. Woodley, R. Helie, J. Perron, J. Elliott, C. Haas, J. Langlois, H. Lazaruk, T. Beechey, and P. Gray. 2015. Canada and Aichi Biodiversity Target 11: understanding 'other effective area-based conservation measures' in the context of the broader target. *Biodiversity and Conservation*. DOI 10.1007/s10531-015-1018-1

McKenney, D., J.H. Pedlar, K. Lawrence, K. Campbell and M.F. Hutchinson. 2007a. Potential impacts of climate change on the distribution of North American trees. *Bioscience*, 57: 939-948.

McKenney, D.W., J.H. Pedlar, K. Lawrence, K. Campbell, and M.F. Hutchinson. 2007b. Beyond traditional hardiness zones: using climate envelopes to map plant range limits. *BioScience*, 57: 929-937.

National Audubon Society. 2014. *Audubon's Birds and Climate Change Report: A Primer for Practitioners*. National Audubon Society, New York. Contributors: Gary Langham, Justin Schuetz, Candan Soykan, Chad Wilsey, Tom Auer, Geoff LeBaron, Connie Sanchez, Trish Distler. Version 1.2.

New, M., D. Liverman, H. Schroder, and K. Anderson. 2011. Four degrees and beyond: the potential for a global temperature increase of four degrees and its implications. Philosophical Transactions of the *Royal Society, Series A*, 369 (1934): 6-19.

Nunavut Planning Commission. 2011-2012. *Nunavut Land Use Plan. Draft 2011-12*. http://www.nunavut.ca/files/DraftNunavutLandUsePlan_2011-2012.pdf

Olson, L., and K.F. Lindsay. 2009. Here today, gone tomorrow? Targeting conservation investment in the face of climate change. J. *Geography and Regional Planning*, 2: 20-29.

Parmesan, C., and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, 41: 37-42.

Patterson, B. D., G. Ceballos, W. Sechrest, M. F. Tognelli, T. Brooks, L. Luna, P. Ortega, I. Salazar, and B. E. Young. 2003. *Digital Distribution Maps of the Mammals of the Western Hemisphere, version 1.0*. NatureServe, Arlington, Virginia, USA.

Ridgely, R. S., T. F. Allnutt, T. Brooks, D. K. McNicol, D. W. Mehlman, B. E. Young, and J. R. Zook. 2003. *Digital Distribution Maps of Birds of the Western Hemisphere, version 1.0*. NatureServe, Arlington, Virginia, USA.

Stortini, C., N. L. Shackell, P. Tyedmers, and K. Beazley. 2015. Assessing marine species vulnerability to projected warming on the Scotian Shelf, Canada. *ICES Journal of Marine Science*, 72 (6): 1731-1743.

Trombulak, S., and R. Baldwin (Eds.) 2010. *Landscape-scale Conservation Planning*. Springer. New York, USA.

United Nations. 2015. *Paris Agreement*. Paris Climate Change Conference, 21st Meeting of the Conference of the Parties, November 30-December 12, 2015, Paris, France. http://unfccc.int/paris_agreement/items/9485.php

United Nations. 2010. *Strategic Plan for Biodiversity 2011-2020 including Aichi Biodiversity Targets*. 10th Meeting of the Conference of the Parties, October 18-29, 2010, Nagoya, Aichi Prefecture, Japan. https://www.cbd.int/sp/

United Nations. 1992a. *Convention on Biological Diversity*. The Earth Summit, June 3-14, 1992, Rio de Janeiro, Brazil. Secretariat of the Convention on Biological Diversity, Montreal, Canada. https://www.cbd.int/intro/default.shtml

United Nations. 1992b. *United Nations Framework Convention on Climate Change*. The Earth Summit, June 3-14, Rio de Janeiro, Brazil. Secretariat, United Nations Framework Convention, Born, Germany. http://unfccc.int/essential_background/convention/items/6036.php

Wiersma, Y. F. 2007. *Protected Areas in Northern Canada*. CCEA Occasional Paper No. 17. Canadian Council on Ecological Areas, Ottawa, Canada. Vii + 35 pp., illus.

Wiersma, Y. F., T. J. Beechey, B. M. Oosenbrug and J. C. Meickle. 2005. *Protected Areas in Northern Canada: Designing for Ecological Integrity*. CCEA Occasional Paper No. 16. Canadian Council on Ecological Areas, Ottawa, Canada. xiii + 110 pp., illus.

APPENDICES

Appendix 1: List of assessed species scientific and common names

Mammals

Scientific Name (total = 132)	Common Name
Alces alces	Moose
Alopex lagopus	Arctic Fox
Antrozous pallidus	Pallid Bat
Canis latrans	Coyote
Canis lupus	Gray Wolf
Castor canadensis	American Beaver
Clethrionomys gapperi	Southern Red-backed Vole
Clethrionomys rutilus	Northern Red-backed Vole
Condylura cristata	Star-nosed Mole
Corynorhinus townsendii	Townsends Big-eared Bat
Cryptotis parva	Least Shrew
Cynomys ludovicianus	Black-tailed Prairie Dog
Dicrostonyx groenlandicus	Northern Collared Lemming
Dicrostonyx hudsonius	Labrador Collared Lemming
Dicrostonyx richardsoni	Richardsons Collared Lemming
Didelphis virginiana	Virginia Opossum
Dipodomys ordii	Ords Kangaroo Rat
Eptesicus fuscus	Big Brown Bat
Erethizon dorsatum	North American Porcupine
Euderma maculatum	Spotted Bat
Geomys bursarius	Plains Pocket Gopher
Glaucomys sabrinus	Northern Flying Squirrel
Glaucomys volans	Southern Flying Squirrel
Gulo gulo	Wolverine
Lasiurus blossevillei	Western Red Bat
Lasiurus borealis	Eastern Red Bat
Lasiurus cinereus	Hoary Bat
Lasionycteris noctivagans	Silver-haired Bat
Lemmiscus curtatus	Sagebrush Vole
Lemmus trimucronatus	Brown Lemming
Lepus americanus	Snowshoe Hare
Lepus arcticus	Arctic Hare
Lepus othus	Alaskan Hare[1]
Lepus townsendii	White-tailed Jackrabbit
Lontra canadensis	Northern River Otter
Lynx canadensis	Canada Lynx
Lynx rufus	Bobcat
Marmota caligata	Hoary Marmot
Marmota flaviventris	Yellow-bellied Marmot
Marmota monax	Woodchuck

Mammals

Scientific Name (total = 132)	Common Name
Martes americana	American Marten
Martes pennanti	Fisher
Mephitis mephitis	Striped Skunk
Microtus chrotorrhinus	Rock Vole
Microtus longicaudus	Long-tailed Vole
Microtus miurus	Singing Vole
Microtus montanus	Montane Vole
Microtus ochrogaster	Prairie Vole
Microtus oeconomus	Tundra Vole
Microtus oregoni	Creeping Vole
Microtus pennsylvanicus	Meadow Vole
Microtus pinetorum	Woodland Vole
Microtus townsendii	Townsends Vole
Microtus xanthognathus	Taiga Vole
Mustela erminea	Ermine
Mustela frenata	Long-tailed Weasel
Mustela nivalis	Least Weasel
Mustela vison	American Mink
Myotis californicus	California Myotis
Myotis ciliolabrum	Western Small-footed Myotis
Myotis evotis	Long-eared Myotis
Myotis leibii	Eastern Small-footed Myotis
Myotis lucifugus	Little Brown Bat
Myotis septentrionalis	Northern Myotis
Myotis sodalis	Indiana Bat
Myotis thysanodes	Fringed Myotis
Myotis volans	Long-legged Myotis
Myotis yumanensis	Yuma Myotis
Napaeozapus insignis	Woodland Jumping Mouse
Neotoma cinerea	Bushy-tailed Woodrat
Neotoma magister	Allegheny Woodrat
Nycticeius humeralis	Evening Bat
Odocoileus hemionus	Mule Deer
Odocoileus virginianus	White-tailed Deer
Ondatra zibethicus	Muskrat
Onychomys leucogaster	Northern Grasshopper Mouse
Ovibos moschatus	Muskox
Ovis canadensis	Bighorn Sheep
Parascalops breweri	Hairy-tailed Mole
Perognathus fasciatus	Olive-backed Pocket Mouse

Appendix I (continued): List of assessed species scientific and common names

Mammals

Scientific Name (total = 132)	Common Name
Perognathus flavescens	Plains Pocket Mouse
Peromyscus maniculatus	Deer Mouse
Phenacomys ungava	Eastern Heather Vole
Pipistrellus subflavus	Eastern Pipistrelle
Procyon lotor	Northern Raccoon
Puma concolor	Puma
Rangifer tarandus	Caribou
Reithrodontomys megalotis	Western Harvest Mouse
Scalopus aquaticus	Eastern Mole
Scapanus townsendii	Townsends Mole
Sciurus carolinensis	Eastern Gray Squirrel
Sciurus niger	Eastern Fox Squirrel
Sigmodon hispidus	Hispid Cotton Rat
Sorex arcticus	Arctic Shrew
Sorex cinereus	Cinereus Shrew
Sorex fumeus	Smoky Shrew
Sorex haydeni	Prairie Shrew
Sorex hoyi	Pygmy Shrew
Sorex longirostris	Southeastern Shrew
Sorex merriami	Merriams Shrew
Sorex monticolus	Montane Shrew
Sorex palustris	Water Shrew
Sorex trowbridgii	Trowbridges Shrew
Sorex tundrensis	Tundra Shrew
Sorex ugyunak	Barren Ground Shrew
Sorex vagrans	Vagrant Shrew
Spermophilus franklinii	Franklins Ground Squirrel
Spermophilus parryii	Arctic Ground Squirrel
Spermophilus richardsonii	Richardsons Ground Squirrel
Spermophilus tridecemlineatus	Thirteen-lined Ground Squirrel
Spilogale gracilis	Western Spotted Skunk
Spilogale putorius	Eastern Spotted Skunk
Sylvilagus audubonii	Desert Cottontail
Sylvilagus floridanus	Eastern Cottontail
Sylvilagus nuttallii	Mountain Cottontail
Sylvilagus transitionalis	New England Cottontail
Synaptomys borealis	Northern Bog Lemming
Synaptomys cooperi	Southern Bog Lemming
Tamiasciurus douglasii	Douglass Squirrel
Tamiasciurus hudsonicus	Red Squirrel

Mammals

Scientific Name (total = 132)	Common Name
Tamias minimus	Least Chipmunk
Tamias striatus	Eastern Chipmunk
Taxidea taxus	American Badger
Thomomys talpoides	Northern Pocket Gopher
Urocyon cinereoargenteus	Gray Fox
Ursus americanus	American Black Bear
Ursus arctos	Brown Bear
Vulpes vulpes	Red Fox
Zapus hudsonius	Meadow Jumping Mouse
Zapus princeps	Western Jumping Mouse
Blarina brevicauda	Northern Short-tailed Shrew
Peromyscus leucopus	White-footed Mouse

Future species for Canada (n=9)

[1]Highlighted species, throughout Appendix 1, are those that do not currently exist in Canada. Future ranges for these species are predicted to occur in future scenarios.

Appendix I (continued): List of assessed species scientific and common names

Amphibians

Scientific Name (total = 39)	New Scientific Name	Common Name
Acris crepitans		Northern Cricket Frog
Ambystoma laterale		Blue-spotted Salamander
Ambystoma maculatum		Spotted Salamander
Ambystoma opacum		Marbled Salamander
Ambystoman texanum		Smallmouth Salamander
Ambystoma tigrinum		Eastern Tiger Salamander
Ascaphus truei		Pacific Tailed Frog
Bufo americanus	*Anaxyrus americanus*	American Toad
Bufo cognatus	*A. cognatus*	Great Plains Toad
Bufo fowleri	*A. fowleri*	Fowler's Toad
Bufo hemiophrys	*A. hemiophrys*	Canadian Toad
Bufo woodhousii	*A. woodhousii*	Woodhouse's Toad
Desmognathus fuscus		Northern Dusky Salamander
Eurycea bislineata		Northern Two-lined Salamander
Eurycea longicauda		Red salamander
Gyrinophilus porphyriticus		Spring Salamander
Hemidactylium scutatum		Four-toed Salamander
Hyla chrysoscelis		Cope's Gray Treefrog
Hyla versicolor		Eastern Gray Treefrog
Notophthalmus viridescens		Eastern Newt
Plethodon cinereus		Northern Red-backed Salamander
Plethodon glutinosus		Northern Slimy Salamander
Pseudacris crucifer		Spring Peeper
Pseudacris regilla		Upland Chorus Frog
Pseudacris triseriata		Midland Chorus Frog
Pseudotriton ruber		Red Sala
Rana aurora		Northern Red-legged Frog
Rana blairi	*Lithobates blairi*	Plains Leopard Frog
Rana catesbeiana	*L. catesbeiana*	Bullfrog
Rana clamitans	*L. clamitans*	Bronze Frog
Rana palustris	*L. palustris*	Pickerel Frog
Rana pipiens	*L. pipiens*	Northern Leopard Frog
Rana septentrionalis	*L. septentrionalis*	Mink Frog
Rana sphenocephala	*L. sphenocephala*	Florida Leopard Frog
Rana sylvatica	*L. sylvaticus*	Wood Frog
Rhyacotriton kezeri		Columbia torrent salamander
Scaphiopus holbrookii		Eastern Spadefoot
Spea bombifrons		Plains Spadefoot
Eleutherodactylus latidiscus		*Non, latin only*

Future species for Canada (n=9)

Appendix I (continued): List of assessed species scientific and common names

Birds

Scientific Name (total = 372)	Common Name
Accipiter cooperii	Coopers Hawk
Accipiter gentilis	Northern Goshawk
Accipiter striatus	Sharp-shinned Hawk
Actitis macularia	Spotted Sandpiper
Aechmophorus clarkii	Clarks Grebe
Aechmophorus occidentalis	Western Grebe
Aegolius acadicus	Northern Saw-whet Owl
Aegolius funereus	Boreal Owl
Aeronautes saxatalis	White-throated Swift
Agelaius phoeniceus	Red-winged Blackbird
Aix sponsa	Wood Duck
Ammodramus bairdii	Bairds Sparrow
Ammodramus henslowii	Henslows Sparrow
Ammodramus leconteii	Le Contes Sparrow
Ammodramus savannarum	Grasshopper Sparrow
Anas acuta	Northern Pintail
Anas americana	American Wigeon
Anas clypeata	Northern Shoveler
Anas crecca	Green-winged Teal
Anas cyanoptera	Cinnamon Teal
Anas discors	Blue-winged Teal
Anas platyrhynchos	Mallard
Anas rubripes	American Black Duck
Anas strepera	Gadwall
Anser albifrons	Greater White-fronted Goose
Anser rossii	Ross's Goose
Anthus rubescens	American Pipit
Anthus spragueii	Spragues Pipit
Aquila chrysaetos	Golden Eagle
Archilochus alexandri	Black-chinned Hummingbird
Archilochus colubris	Ruby-throated Hummingbird
Ardea alba	Great Egret
Ardea herodias	Great Blue Heron
Asio flammeus	Short-eared Owl
Asio otus	Long-eared Owl
Athene cunicularia	Burrowing Owl
Aythya affinis	Lesser Scaup
Aythya americana	Redhead

Birds

Scientific Name (total = 372)	Common Name
Aythya collaris	Ring-necked Duck
Aythya marila	Greater Scaup
Aythya valisineria	Canvasback
Baeolophus bicolor	Tufted Titmouse
Bartramia longicauda	Upland Sandpiper
Bombycilla cedrorum	Cedar Waxwing
Bombycilla garrulus	Bohemian Waxwing
Bonasa umbellus	Ruffed Grouse
Botaurus lentiginosus	American Bittern
Brachyramphus brevirostris	Kittlitzs Murrelet
Branta bernicla	Brant
Branta canadensis	Canada Goose Great
Bubo virginianus	Horned Owl
Bubulcus ibis	Cattle Egret
Bucephala albeola	Bufflehead
Bucephala clangula	Common Goldeneye
Bucephala islandica	Barrows Goldeneye
Buteo jamaicensis	Red-tailed Hawk
Buteo lagopus	Rough-legged Hawk
Buteo lineatus	Red-shouldered Hawk
Buteo platypterus	Broad-winged Hawk
Buteo regalis	Ferruginous Hawk
Buteo swainsoni	Swainsons Hawk
Butorides virescens	Green Heron
Calamospiza melanocorys	Lark Bunting
Calcarius lapponicus	Lapland Longspur
Calcarius mccownii	McCowns Longspur
Calcarius ornatus	Chestnut-collared Longspur
Calidris alba	Sanderling
Calidris alpina	Dunlin
Calidris bairdii	Bairds Sandpiper
Calidris canutus	Red Knot
Calidris fuscicollis	White-rumped Sandpiper
Calidris maritima	Purple Sandpiper
Calidris mauri	Western Sandpiper
Calidris melanotos	Pectoral Sandpiper
Calidris minuta	Little Stint
Calidris ptilocnemis	Rock Sandpiper

Appendix I (continued): List of assessed species scientific and common names

Birds

Scientific Name (total = 372)	Common Name
Calidris pusilla	Semipalmated Sandpiper
Caprimulgus vociferus	Northern Whip-poor-will
Carduelis flammea	Common Redpoll
Carduelis hornemanni	Hoary Redpoll
Carduelis pinus	Pine Siskin
Carduelis tristis	American Goldfinch
Carpodacus cassinii	Cassins Finch
Carpodacus mexicanus	House Finch
Carpodacus purpureus	Purple Finch
Catharus fuscescens	Veery
Catharus guttatus	Hermit Thrush
Catharus minimus	Gray-cheeked Thrush
Catharus ustulatus	Swainsons Thrush
Catoptrophorus semipalmatus	Willet
Centrocercus urophasianus	Greater Sage-Grouse
Certhia americana	Brown Creeper
Chaetura pelagica	Chimney Swift
Chaetura vauxi	Vauxs Swift
Charadrius melodus	Piping Plover
Charadrius semipalmatus	Semipalmated Plover
Charadrius vociferus	Killdeer
Chlidonias niger	Black Tern
Chondestes grammacus	Lark Sparrow
Chordeiles minor	Common Nighthawk
Cinclus mexicanus	American Dipper
Circus cyaneus	Northern Harrier
Cistothorus palustris	Marsh Wren
Cistothorus platensis	Sedge Wren
Clangula hyemalis	Long-tailed Duck
Coccyzus americanus	Yellow-billed Cuckoo
Coccyzus erythropthalmus	Black-billed Cuckoo
Coccothraustes vespertinus	Evening Grosbeak
Colaptes auratus	Northern Flicker
Colinus virginianus	Northern Bobwhite
Columba fasciata	Band-tailed Pigeon
Contopus cooperi	Olive-sided Flycatcher
Contopus sordidulus	Western Wood-Pewee
Contopus virens	Eastern Wood-Pewee

Birds

Scientific Name (total = 372)	Common Name
Corvus brachyrhynchos	American Crow
Corvus corax	Northern Raven
Corvus ossifragus	Fish Crow
Coturnicops noveboracensis	Yellow Rail
Cyanocitta cristata	Blue Jay
Cygnus columbianus	Tundra Swan
Dendroica aestiva	Yellow Warbler
Dendroica caerulescens	Black-throated Blue Warbler
Dendroica castanea	Bay-breasted Warbler
Dendroica cerulea	Cerulean Warbler
Dendroica coronata	Yellow-rumped Warbler
Dendroica discolor	Prairie Warbler
Dendroica fusca	Blackburnian Warbler
Dendroica magnolia	Magnolia Warbler
Dendroica nigrescens	Black-throated Gray Warbler
Dendragapus obscurus	Blue Grouse
Dendroica palmarum	Palm Warbler
Dendroica pensylvanica	Chestnut-sided Warbler
Dendroica pinus	Pine Warbler
Dendroica striata	Blackpoll Warbler
Dendroica tigrina	Cape May Warbler
Dendroica townsendi	Townsends Warbler
Dendroica virens	Black-throated Green Warbler
Dolichonyx oryzivorus	Bobolink
Dryocopus pileatus	Pileated Woodpecker
Dumetella carolinensis	Gray Catbird
Egretta thula	Snowy Egret
Empidonax alnorum	Alder Flycatcher
Empidonax flaviventris	Yellow-bellied Flycatcher
Empidonax hammondii	Hammonds Flycatcher
Empidonax minimus	Least Flycatcher
Empidonax oberholseri	Dusky Flycatcher
Empidonax traillii	Willow Flycatcher
Empidonax virescens	Acadian Flycatcher
Eremophila alpestris	Horned Lark
Euphagus carolinus	Rusty Blackbird
Falcipennis canadensis	Spruce Grouse
Falco columbarius	Merlin

Appendix I (continued): List of assessed species scientific and common names

Birds

Scientific Name (total = 372)	Common Name
Falco mexicanus	Prairie Falcon
Falco peregrinus	Peregrine Falcon
Falco rusticolus	Gyrfalcon
Falco sparverius	American Kestrel
Fulica americana	American Coot
Gallinula chloropus	Common Moorhen
Gavia adamsii	Yellow-billed Loon
Gavia immer	Great Northern Loon
Gavia pacifica	Pacific Loon
Gavia stellata	Red-throated Loon
Geothlypis trichas	Common Yellowthroat
Glaucidium gnoma	Northern Pygmy-Owl
Grus canadensis	Sandhill Crane
Gymnorhinus cyanocephalus	Pinyon Jay
Haliaeetus leucocephalus	Bald Eagle
Helmitheros vermivorus	Worm-eating Warbler
Heteroscelus incanus	Wandering Tattler
Himantopus mexicanus	Black-necked Stilt
Hirundo rustica	Barn Swallow
Histrionicus histrionicus	Harlequin Duck
Hylopezus dives	Thicket Antpitta
Hylocichla mustelina	Wood Thrush
Icterus bullockii	Bullocks Oriole
Icterus galbula	Baltimore Oriole
Icterus spurius	Orchard Oriole
Icteria virens	Yellow-breasted Chat
Ixobrychus exilis	Least Bittern
Ixoreus naevius	Varied Thrush
Junco hyemalis	Dark-eyed Junco
Lagopus lagopus	Willow Ptarmigan
Lagopus leucurus	White-tailed Ptarmigan
Lagopus mutus	Rock Ptarmigan
Lanius excubitor	Northern Shrike
Lanius ludovicianus	Loggerhead Shrike
Larus argentatus	Herring Gull
Larus californicus	California Gull
Larus canus	Mew Gull
Larus delawarensis	Ring-billed Gull

Birds

Scientific Name	Common Name
Larus glaucoides	Iceland Gull
Larus hyperboreus	Glaucous Gull
Larus philadelphia	Bonapartes Gull
Larus pipixcan	Franklins Gull
Larus thayeri	Thayers Gull
Leucosticte tephrocotis	Gray-crowned Rosy-Finch
Cardinalis cardinalis	Northern Cardinal
Catherpes mexicanus	Canyon Wren
Euphagus cyanocephalus	Brewers Blackbird
Gallinago gallinago	Common Snipe
Limnodromus griseus	Short-billed Dowitcher
Limnodromus scolopaceus	Long-billed Dowitcher
Limosa fedoa	Marbled Godwit
Lophodytes cucullatus	Hooded Merganser
Loxia curvirostra	Red Crossbill
Loxia leucoptera	White-winged Crossbill
Luscinia svecica	Bluethroat
Megaceryle alcyon	Belted Kingfisher
Melanerpes carolinus	Red-bellied Woodpecker
Melanerpes erythrocephalus	Red-headed Woodpecker
Melanitta fusca	White-winged Scoter
Melanerpes lewis	Lewiss Woodpecker
Melanitta nigra	Black Scoter
Melanitta perspicillata	Surf Scoter
Melospiza georgiana	Swamp Sparrow
Melospiza lincolnii	Lincolns Sparrow
Melospiza melodia	Song Sparrow
Mergus merganser	Common Merganser
Mergus serrator	Red-breasted Merganser
Mimus polyglottos	Northern Mockingbird
Mniotilta varia	Black-and-white Warbler
Molothrus ater	Brown-headed Cowbird
Motacilla alba	White Wagtail
Motacilla flava	Yellow Wagtail
Myadestes townsendi	Townsends Solitaire
Myiarchus crinitus	Great Crested Flycatcher
Nucifraga columbiana	Clarks Nutcracker
Numenius americanus	Long-billed Curlew

Appendix I (continued): List of assessed species scientific and common names

Birds

Scientific Name (total = 372)	Common Name
Numenius tahitiensis	Bristle-thighed Curlew
Nycticorax nycticorax	Black-crowned Night-Heron
Nyctea scandiaca	Snowy Owl
Oenanthe oenanthe	Northern Wheatear
Oporornis agilis	Connecticut Warbler
Oporornis formosus	Kentucky Warbler
Oporornis philadelphia	Mourning Warbler
Oporornis tolmiei	MacGillivrays Warbler
Oreoscoptes montanus	Sage Thrasher
Otus asio	Eastern Screech-Owl
Otus kennicottii	Western Screech-Owl
Oxyura jamaicensis	Ruddy Duck
Pagophila eburnea	Ivory Gull
Pandion haliaetus	Osprey
Parula americana	Northern Parula
Passerina amoena	Lazuli Bunting
Passerina caerulea	Blue Grosbeak
Passerina cyanea	Indigo Bunting
Passerella iliaca	Fox Sparrow
Passerculus sandwichensis	Savannah Sparrow
Perisoreus canadensis	Gray Jay
Petrochelidon pyrrhonota	Cliff Swallow
Phalacrocorax auritus	Double-crested Cormorant
Phalaropus fulicarius	Red Phalarope
Phalaropus lobatus	Red-necked Phalarope
Phalaenoptilus nuttallii	Common Poorwill
Phalaropus tricolor	Wilsons Phalarope
Pheucticus ludovicianus	Rose-breasted Grosbeak
Pheucticus melanocephalus	Black-headed Grosbeak
Phylloscopus borealis	Arctic Warbler
Pica hudsonia	Black-billed Magpie
Picoides arcticus	Black-backed Woodpecker
Picoides pubescens	Downy Woodpecker
Picoides tridactylus	Three-toed Woodpecker
Picoides villosus	Hairy Woodpecker
Pinicola enucleator	Pine Grosbeak
Pionopsitta pulchra	Rose-faced Parrot
Pipilo erythrophthalmus	Eastern Towhee

Birds

Scientific Name (total = 372)	Common Name
Pipilo maculatus	Spotted Towhee
Piranga ludoviciana	Western Tanager
Piranga olivacea	Scarlet Tanager
Piranga rubra	Summer Tanager
Plectrophenax nivalis	Snow Bunting
Plegadis chihi	White-faced Ibis
Pluvialis dominica	American Golden-Plover
Pluvialis fulva	Pacific Golden-Plover
Pluvialis squatarola	Gray Plover
Podiceps auritus	Horned Grebe
Podiceps grisegena	Red-necked Grebe
Podiceps nigricollis	Black-necked Grebe
Podilymbus podiceps	Pied-billed Grebe
Poecile atricapilla	Black-capped Chickadee
Poecile carolinensis	Carolina Chickadee
Poecile gambeli	Mountain Chickadee
Poecile hudsonica	Boreal Chickadee
Poecile rufescens	Chestnut-backed Chickadee
Polioptila caerulea	Blue-gray Gnatcatcher
Polysticta stelleri	Stellers Eider
Pooecetes gramineus	Vesper Sparrow
Porzana carolina	Sora
Progne subis	Purple Martin
Protonotaria citrea	Prothonotary Warbler
Psaltriparus minimus	Bushtit
Quiscalus quiscula	Common Grackle
Rallus elegans	King Rail
Rallus limicola	Virginia Rail
Recurvirostra americana	American Avocet
Regulus calendula	Ruby-crowned Kinglet
Regulus satrapa	Golden-crowned Kinglet
Riparia riparia	Sand Martin
Salpinctes obsoletus	Rock Wren
Sayornis phoebe	Eastern Phoebe
Sayornis saya	Says Phoebe
Scolopax minor	American Woodcock
Seiurus aurocapillus	Ovenbird
Seiurus motacilla	Louisiana Waterthrush

Appendix I (continued): List of assessed species scientific and common names

Birds

Scientific Name (total = 372)	Common Name
Seiurus noveboracensis	Northern Waterthrush
Setophaga ruticilla	American Redstart
Sialia currucoides	Mountain Bluebird
Sialia sialis	Eastern Bluebird
Sitta canadensis	Red-breasted Nuthatch
Sitta carolinensis	White-breasted Nuthatch
Sitta pygmaea	Pygmy Nuthatch
Somateria spectabilis	King Eider
Sphyrapicus nuchalis	Red-naped Sapsucker
Sphyrapicus varius	Yellow-bellied Sapsucker
Spiza americana	Dickcissel
Spizella arborea	American Tree Sparrow
Spizella breweri	Brewers Sparrow
Spizella pallida	Clay-colored Sparrow
Spizella passerina	Chipping Sparrow
Spizella pusilla	Field Sparrow
Stellula calliope	Calliope Hummingbird
Stelgidopteryx serripennis	Northern Rough-winged Swallow
Sterna hirundo	Common Tern
Stercorarius longicaudus	Long-tailed Jaeger
Sterna paradisaea	Arctic Tern
Stercorarius parasiticus	Parasitic Jaeger
Stercorarius pomarinus	Pomarine Jaeger
Strix nebulosa	Great Gray Owl
Strix varia	Barred Owl
Sturnella magna	Eastern Meadowlark
Sturnella neglecta	Western Meadowlark
Sturnus vulgaris	European Starling
Surnia ulula	Northern Hawk Owl
Synthliboramphus antiquus	Ancient Murrelet
Tachycineta bicolor	Tree Swallow
Tachycineta thalassina	Violet-green Swallow
Thryomanes bewickii	Bewicks Wren
Thryothorus ludovicianus	Carolina Wren
Toxostoma rufum	Brown Thrasher
Tringa flavipes	Lesser Yellowlegs
Tringa melanoleuca	Greater Yellowlegs
Tringa solitaria	Solitary Sandpiper

Birds

Scientific Name (total = 372)	Common Name
Troglodytes aedon	House Wren
Troglodytes troglodytes	Winter Wren
Turdus migratorius	American Robin
Tympanuchus phasianellus	Sharp-tailed Grouse
Tyrannus tyrannus	Eastern Kingbird
Tyrannus verticalis	Western Kingbird
Tyto alba	Barn Owl
Vermivora celata	Orange-crowned Warbler
Vermivora chrysoptera	Golden-winged Warbler
Vermivora peregrina	Tennessee Warbler
Vermivora pinus	Blue-winged Warbler
Vermivora ruficapilla	Nashville Warbler
Vireo bellii	Bells Vireo
Vireo cassinii	Cassins Vireo
Vireo flavifrons	Yellow-throated Vireo
Vireo gilvus	Warbling Vireo
Vireo griseus	White-eyed Vireo
Vireo olivaceus	Red-eyed Vireo
Vireo philadelphicus	Philadelphia Vireo
Vireo solitarius	Blue-headed Vireo
Wilsonia canadensis	Canada Warbler
Wilsonia citrina	Hooded Warbler
Wilsonia pusilla	Wilsons Warbler
Xanthocephalus xanthocephalus	Yellow-headed Blackbird
Xema sabini	Sabines Gull
Zenaida macroura	Mourning Dove
Zonotrichia albicollis	White-throated Sparrow
Zonotrichia atricapilla	Golden-crowned Sparrow
Zonotrichia leucophrys	White-crowned Sparrow
Zonotrichia querula	Harris' Sparrow

Future species for Canada (n=21)

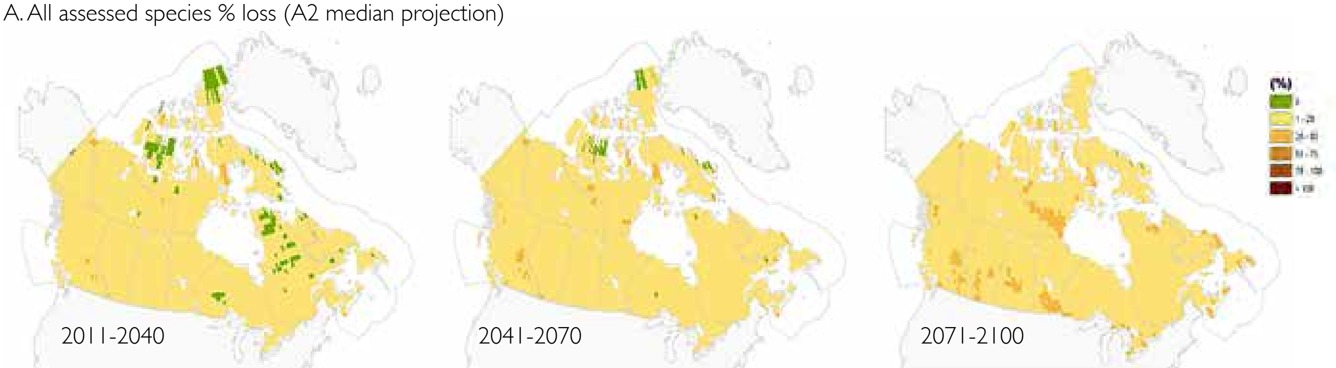
Appendix 2: Bioclimatic variables used in simulating species distributions

(from Lawler et al. 2009; Appendix B: Ecological Archives E090-041-A2)

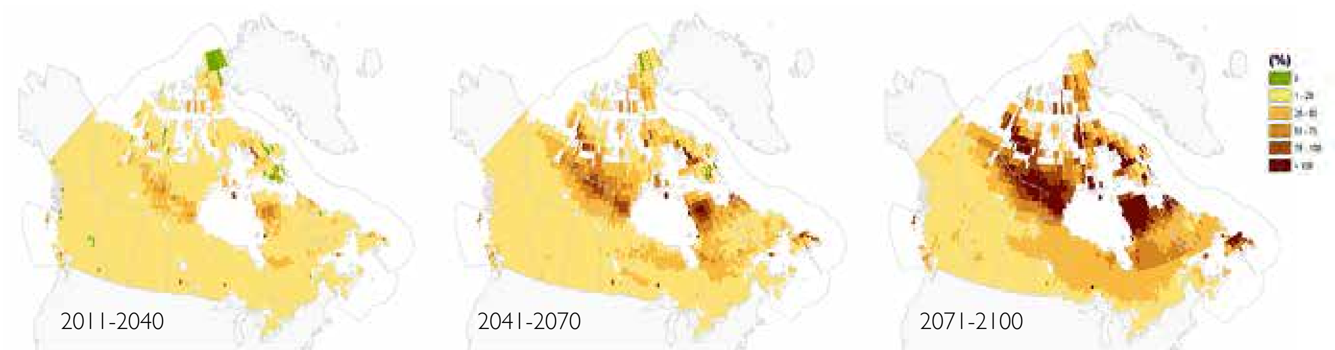
1	Growing degree days (5 °C base)
2	Chilling period (number of days in the year with a mean temperature <= 5 °C)
3	Mean temperature of the coldest month (°C)
4	Mean temperature of the warmest month (°C)
5	Mean annual temperature (°C)
6	Annual actual evapotranspiration (mm)
7	Annual potential evapotranspiraton (mm)
8	Moisture index (annual actual evapotranspiration/annual potential evapotranspiration)
9	Actual evapotranspiration (mm) for days with temperatures > -4 °C
10	Potential evapotranspiration (mm) for days with temperatures > -4 °C
11	Moisture index for days with temperatures > -4 °C (annual actual evapotranspiration/annual potential evapotranspiration)
12	Actual evapotranspiration (mm) for days with temperatures > 5 °C
13	Potential evapotranspiration (mm) for days with temperatures > 5 °C
14	Moisture index for days with temperatures > 5 °C (annual actual evapotranspiration/annual potential evapotranspiration)
15	Total annual snow (mm)
16	March - May actual evapotranspiration (mm)
17	March - May potential evapotranspiration (mm)
18	March - May moisture index (actual evapotranspiration/potential evapotranspiration)
19	June - August actual evapotranspiration (mm)
20	June - August potential evapotranspiration (mm)
21	June - August moisture index (actual evapotranspiration/potential evapotranspiration)
22	September - November actual evapotranspiration (mm)
23	September - November potential evapotranspiration (mm)
24	September - November moisture index (actual evapotranspiration/potential evapotranspiration)
25	December - February actual evapotranspiration (mm)
26	December - February potential evapotranspiration (mm)
27	December - February moisture index (actual evapotranspiration/potential evapotranspiration)
28	March - May total precipitation (mm)
29	June - August total precipitation (mm)
30	September - November total precipitation (mm)
31	December - February total precipitation (mm)
32	Total annual precipitation (mm)
33	Mean monthly precipitation (mm) for the driest month
34	Mean monthly precipitation (mm) for the wettest month
35	Annual temperature range (warmest month minus coldest month)
36	Annual precipitation range (wettest month minus driest month)

Appendix 3: Spatial distribution of species gains and losses by taxonomic grouping

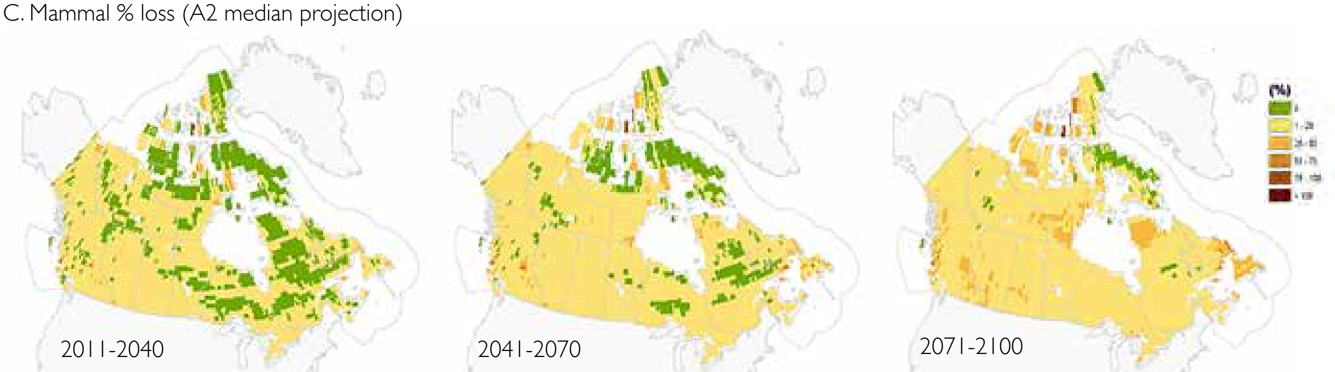
A. All assessed species % loss (A2 median projection)



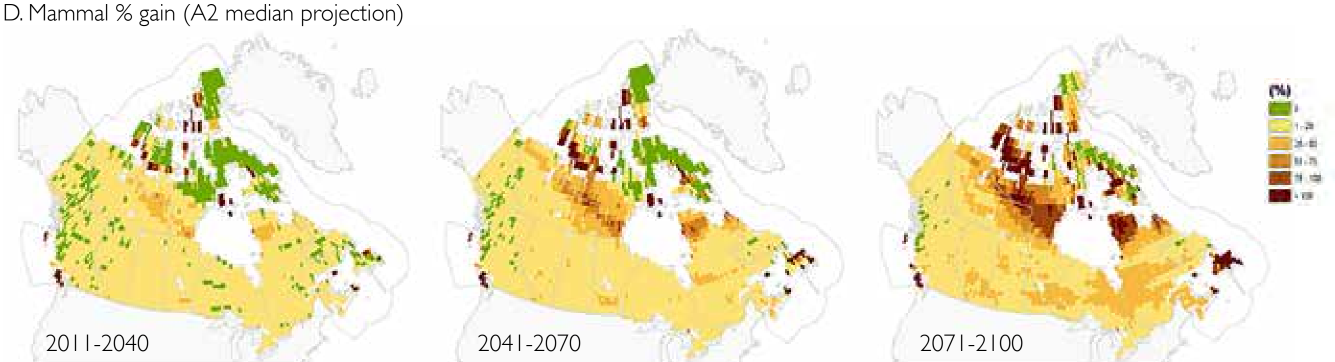
B. All assessed species % gain (A2 median projection)



C. Mammal % loss (A2 median projection)

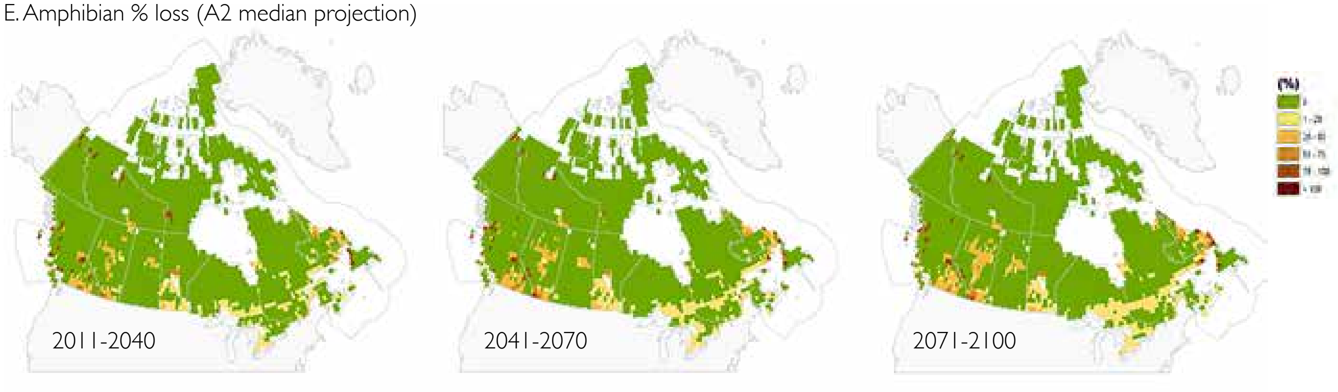


D. Mammal % gain (A2 median projection)

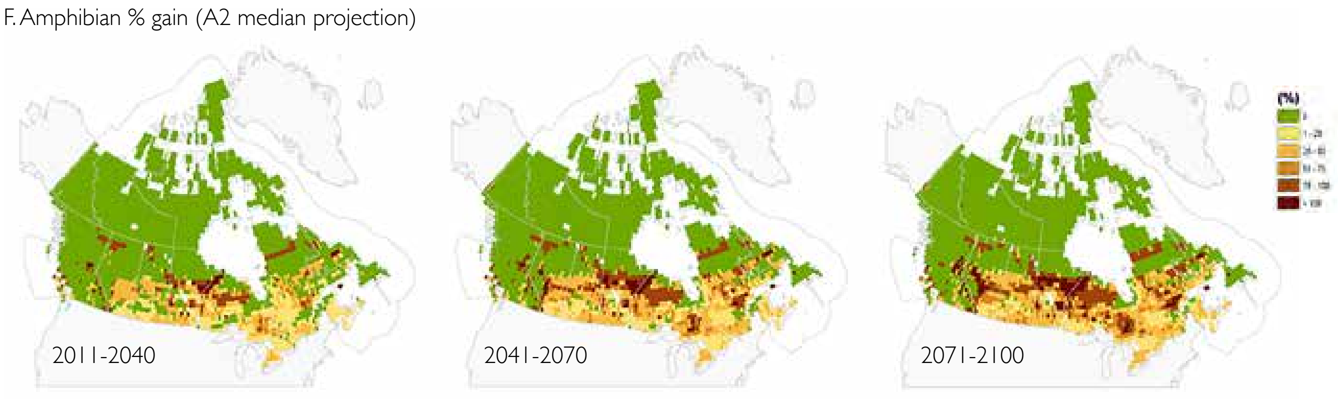


Appendix 3 (continued): Spatial distribution of species gains and losses by taxonomic grouping

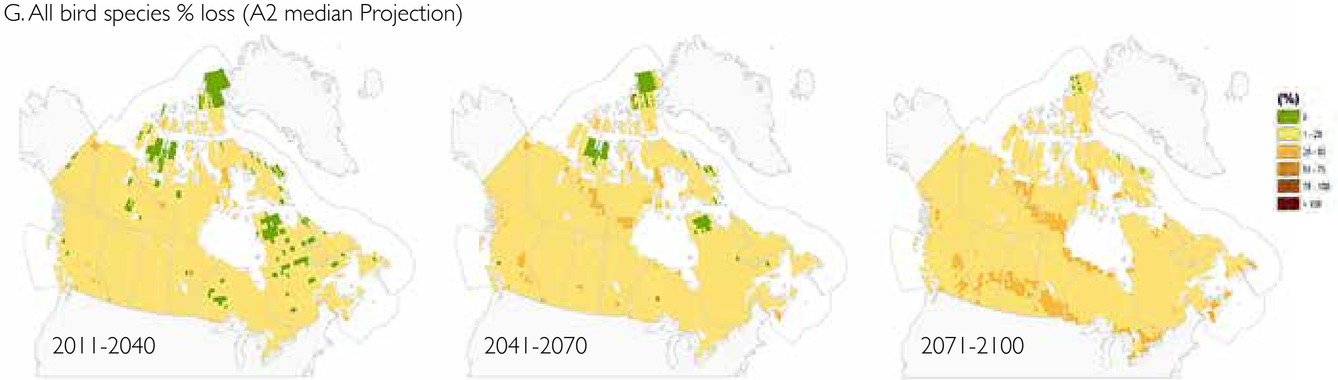
E. Amphibian % loss (A2 median projection)



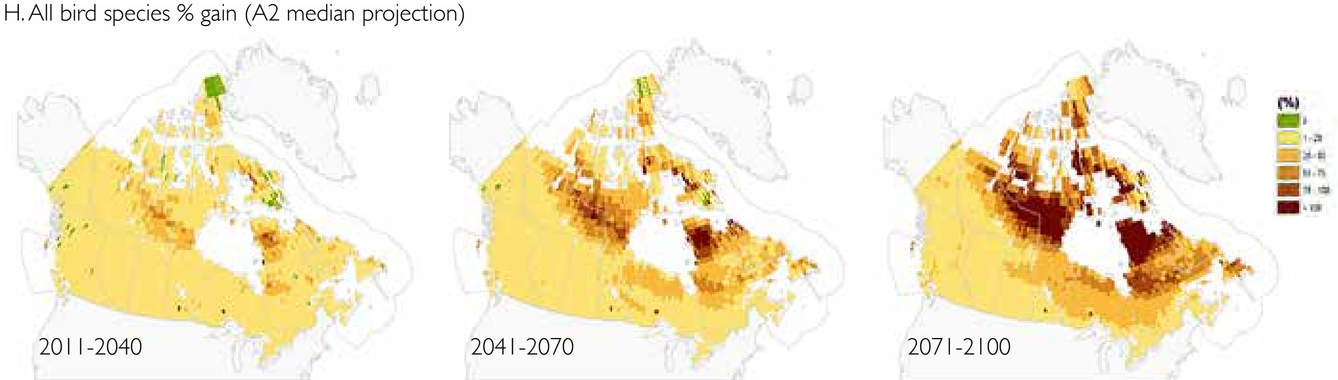
F. Amphibian % gain (A2 median projection)



G. All bird species % loss (A2 median Projection)

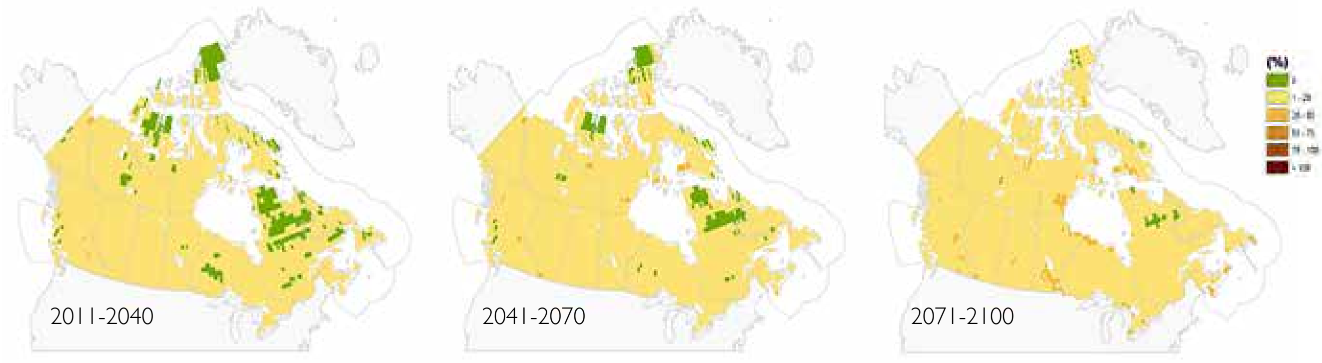


H. All bird species % gain (A2 median projection)

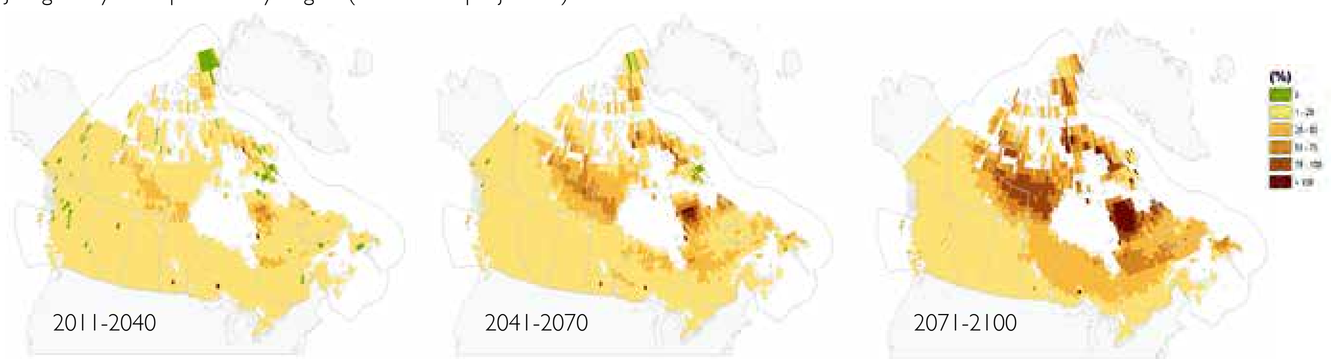


Appendix 3 (continued): Spatial distribution of species gains and losses by taxonomic grouping

I. Migratory bird species only % loss (A2 median projection)



J. Migratory bird species only % gain (A2 median projection)



Appendix 4: List of assessed species projected as a gain or loss in full-dispersal and no-dispersal scenarios for 30-year time periods to 2100 by taxa in Canada and in different protected area systems

Note: Results at the individual species level are less reliable than the general numbers and percentages and should be interpreted with caution.

Mammal Losses: No-dispersal scenario			
	Current to 2011-2040	**Current to 2041-2070**	**Current to 2071-2100**
Canada	Cynomys ludovicianus		
			Dicrostonyx richardsoni
			Myotis thysanodes
All protected areas	Cynomys ludovicianus		
			Dicrostonyx richardsoni
			Myotis thysanodes
			Ovibos moschatus
Federal protected areas	Cynomys ludovicianus		
			Dicrostonyx richardsoni
			Euderma maculatum
	Microtus oregoni		
	Myotis thysanodes	Myotis thysanodes	Myotis thysanodes
			Ovibos moschatus
Parks Canada Agency protected areas	Cynomys ludovicianus		
	Dicrostonyx richardsoni	Dicrostonyx richardsoni	Dicrostonyx richardsoni
			Euderma maculatum
	Microtus oregoni		
			Ovibos moschatus
Environment Canada protected areas	Cynomys ludovicianus		
			Dicrostonyx richardsoni
	Euderma maculatum	Euderma maculatum	Euderma maculatum
	Myotis thysanodes	Myotis thysanodes	Myotis thysanodes
			Ovibos moschatus
Other protected areas	Cynomys ludovicianus		
		Dicrostonyx richardsoni	Dicrostonyx richardsoni
			Myotis thysanodes
			Ovibos moschatus
Nunavut Settlement Area			Clethrionomys gapperi
			Dicrostonyx richardsoni
	Microtus xanthognathus	Microtus xanthognathus	Microtus xanthognathus
A/NA ecoregion	Canis lupus	Canis lupus	Canis lupus
	Mustela nivalis	Mustela nivalis	Mustela nivalis
	Rangifer tarandus	Rangifer tarandus	Rangifer tarandus
			Sorex arcticus
A/NA protected areas			Lynx canadensis
			Martes americana
	Sorex arcticus	Sorex arcticus	Sorex arcticus

Appendix 4 (continued): List of assessed species projected as a gain or loss in full-dispersal and no-dispersal scenarios for 30-year time periods to 2100 by taxa in Canada and in different protected area systems

Note: Results at the individual species level are less reliable than the general numbers and percentages and should be interpreted with caution.

Mammal Losses: Full-dispersal scenario			
	Current to 2011-2040	Current to 2041-2070	Current to 2071-2100
Canada			
All protected areas			Dicrostonyx richardsoni
			Ovibos moschatus
Federal protected areas	Cynomys ludovicianus		
			Dicrostonyx richardsoni
	Myotis thysanodes	Myotis thysanodes	Myotis thysanodes
			Ovibos moschatus
Parks Canada Agency protected areas	Cynomys ludovicianus		
	Dicrostonyx richardsoni	Dicrostonyx richardsoni	Dicrostonyx richardsoni
			Euderma maculatum
	Microtus oregoni		
			Ovibos moschatus
Environment Canada protected areas	Cynomys ludovicianus		
			Dicrostonyx richardsoni
	Euderma maculatum		
	Myotis thysanodes	Myotis thysanodes	Myotis thysanodes
			Ovibos moschatus
Other protected areas		Dicrostonyx richardsoni	Dicrostonyx richardsoni
			Ovibos moschatus
Nunavut Settlement Area			Clethrionomys gapperi
A/NA ecoregion	Canis lupus	Canis lupus	Canis lupus
	Rangifer tarandus	Rangifer tarandus	Rangifer tarandus
A/NA protected areas			Lynx canadensis
			Martes americana
	Sorex arcticus	Sorex arcticus	Sorex arcticus

Appendix 4 (continued): List of assessed species projected as a gain or loss in full-dispersal and no-dispersal scenarios for 30-year time periods to 2100 by taxa in Canada and in different protected area systems

Note: Results at the individual species level are less reliable than the general numbers and percentages and should be interpreted with caution.

Mammal Gains: Full-dispersal scenario			
	Current to 2011-2040	Current to 2041-2070	Current to 2071-2100
Canada	Lepus othus	Lepus othus	Lepus othus
	Myotis sodalis	Myotis sodalis	Myotis sodalis
			Neotoma magister
		Perognathus flavescens	Perognathus flavescens
			Sigmodon hispidus
			Sorex longirostris
			Sorex merriami
			Sylvilagus audubonii
	Sylvilagus transitionalis	Sylvilagus transitionalis	Sylvilagus transitionalis
All protected areas	Lepus othus	Lepus othus	Lepus othus
	Myotis sodalis	Myotis sodalis	Myotis sodalis
			Neotoma magister
	Nycticeius humeralis	Nycticeius humeralis	Nycticeius humeralis
		Perognathus flavescens	Perognathus flavescens
			Sorex longirostris
			Sorex merriami
			Sylvilagus audubonii
	Sylvilagus transitionalis	Sylvilagus transitionalis	Sylvilagus transitionalis
Federal protected areas	Geomys bursarius	Geomys bursarius	Geomys bursarius
	Lepus othus	Lepus othus	Lepus othus
	Myotis sodalis	Myotis sodalis	Myotis sodalis
	Nycticeius humeralis	Nycticeius humeralis	Nycticeius humeralis
			Perognathus flavescens
		Scapanus townsendii	Scapanus townsendii
		Spilogale putorius	Spilogale putorius
	Sylvilagus transitionalis	Sylvilagus transitionalis	Sylvilagus transitionalis
Parks Canada Agency protected areas			Antrozous pallidus
	Corynorhinus townsendii	Corynorhinus townsendii	Corynorhinus townsendii
	Cryptotis parva	Cryptotis parva	Cryptotis parva
	Geomys bursarius	Geomys bursarius	Geomys bursarius
	Lepus othus	Lepus othus	Lepus othus
	Myotis sodalis	Myotis sodalis	Myotis sodalis
			Nycticeius humeralis
			Perognathus flavescens
	Reithrodontomys megalotis	Reithrodontomys megalotis	Reithrodontomys megalotis
	Scalopus aquaticus	Scalopus aquaticus	Scalopus aquaticus
	Sciurus niger	Sciurus niger	Sciurus niger
			Sorex haydeni
	Spilogale gracilis	Spilogale gracilis	Spilogale gracilis
		Spilogale putorius	Spilogale putorius
	Sylvilagus transitionalis	Sylvilagus transitionalis	Sylvilagus transitionalis
		Tamiasciurus douglasii	Tamiasciurus douglasii
Environment Canada protected areas		Geomys bursarius	Geomys bursarius
		Lepus othus	Lepus othus
	Microtus miurus	Microtus miurus	Microtus miurus

Appendix 4 (continued): List of assessed species projected as a gain or loss in full-dispersal and no-dispersal scenarios for 30-year time periods to 2100 by taxa in Canada and in different protected area systems

Note: Results at the individual species level are less reliable than the general numbers and percentages and should be interpreted with caution.

Mammal Gains: Full-dispersal scenario (continued)			
	Current to 2011-2040	**Current to 2041-2070**	**Current to 2071-2100**
Environment Canada protected areas	Microtus oregoni	Microtus oregoni	Microtus oregoni
	Myotis sodalis	Myotis sodalis	Myotis sodalis
	Nycticeius humeralis	Nycticeius humeralis	Nycticeius humeralis
			Perognathus flavescens
		Scapanus townsendii	Scapanus townsendii
			Spilogale putorius
		Sylvilagus transitionalis	Sylvilagus transitionalis
Other protected areas	Lepus othus	Lepus othus	Lepus othus
	Myotis sodalis	Myotis sodalis	Myotis sodalis
			Neotoma magister
	Nycticeius humeralis	Nycticeius humeralis	Nycticeius humeralis
		Perognathus flavescens	Perognathus flavescens
			Sorex longirostris
			Sorex merriami
			Sylvilagus audubonii
	Sylvilagus transitionalis	Sylvilagus transitionalis	Sylvilagus transitionalis
Nunavut Settlement Area	Alces alces	Alces alces	Alces alces
	Castor canadensis	Castor canadensis	Castor canadensis
		Dicrostonyx hudsonius	Dicrostonyx hudsonius
	Erethizon dorsatum	Erethizon dorsatum	Erethizon dorsatum
			Lasionycteris noctivagans
	Lepus americanus	Lepus americanus	Lepus americanus
		Lepus othus	Lepus othus
	Marmota caligata	Marmota caligata	Marmota caligata
		Marmota monax	Marmota monax
			Mephitis mephitis
	Microtus miurus	Microtus miurus	Microtus miurus
		Myotis lucifugus	Myotis lucifugus
			Peromyscus maniculatus
		Sorex hoyi	Sorex hoyi
		Sorex monticolus	Sorex monticolus
			Sorex palustris
	Sorex tundrensis	Sorex tundrensis	Sorex tundrensis
		Tamias minimus	Tamias minimus
		Zapus hudsonius	Zapus hudsonius
A/NA ecoregion			Microtus ochrogaster
	Nycticeius humeralis	Nycticeius humeralis	Nycticeius humeralis
			Sorex longirostris
	Taxidea taxus	Taxidea taxus	Taxidea taxus
A/NA protected areas	Cryptotis parva	Cryptotis parva	Cryptotis parva
	Mustela nivalis	Mustela nivalis	Mustela nivalis
			Nycticeius humeralis
			Scalopus aquaticus
	Sylvilagus floridanus	Sylvilagus floridanus	Sylvilagus floridanus
		Sylvilagus transitionalis	Sylvilagus transitionalis

Appendix 4 (continued): List of assessed species projected as a gain or loss in full-dispersal and no-dispersal scenarios for 30-year time periods to 2100 by taxa in Canada and in different protected area systems

Note: Results at the individual species level are less reliable than the general numbers and percentages and should be interpreted with caution.

Amphibian Losses: No-dispersal scenario			
	Current to 2011-2040	**Current to 2041-2070**	**Current to 2071-2100**
Canada	Ambystoma texanum	Ambystoma texanum	
	Bufo cognatus	Bufo cognatus	
		Plethodon glutinosus	Plethodon glutinosus
	Pseudotriton ruber	Pseudotriton ruber	Pseudotriton ruber
All protected areas	Bufo cognatus	Bufo cognatus	
		Plethodon glutinosus	Plethodon glutinosus
	Pseudotriton ruber	Pseudotriton ruber	Pseudotriton ruber
Federal protected areas		Ascaphus truei	Ascaphus truei
	Bufo cognatus	Bufo cognatus	
	Pseudotriton ruber	Pseudotriton ruber	Pseudotriton ruber
Parks Canada Agency protected areas			Pseudacris triseriata
Environment Canada protected areas		Ascaphus truei	Ascaphus truei
	Bufo cognatus	Bufo cognatus	
Other protected areas	Bufo cognatus	Bufo cognatus	
		Plethodon glutinosus	Plethodon glutinosus
Nunavut Settlement Area			
A/NA ecoregion			
A/NA protected areas	Hemidactylium scutatum		

Amphibian Losses: Full-dispersal scenario			
	Current to 2011-2040	**Current to 2041-2070**	**Current to 2071-2100**
Canada	Ambystoma texanum	Ambystoma texanum	
	Pseudotriton ruber	Pseudotriton ruber	
All protected areas	Pseudotriton ruber	Pseudotriton ruber	
Federal protected areas	Bufo cognatus	Bufo cognatus	
	Pseudotriton ruber	Pseudotriton ruber	
Parks Canada Agency protected areas			
Environment Canada protected areas			Ascaphus truei
	Bufo cognatus	Bufo cognatus	
Other protected areas			
Nunavut Settlement Area			
A/NA ecoregion			
A/NA protected areas			

Appendix 4 (continued): List of assessed species projected as a gain or loss in full-dispersal and no-dispersal scenarios for 30-year time periods to 2100 by taxa in Canada and in different protected area systems

Note: Results at the individual species level are less reliable than the general numbers and percentages and should be interpreted with caution.

Amphibian Gains: Full-dispersal scenario			
	Current to 2011-2040	Current to 2041-2070	Current to 2071-2100
Canada		Ambystoma opacum	Ambystoma opacum
	Bufo woodhousii	Bufo woodhousii	Bufo woodhousii
	Eurycea longicauda	Eurycea longicauda	Eurycea longicauda
			Rana blairi
			Rana sphenocephala
		Rhyacotriton kezeri	Rhyacotriton kezeri
		Scaphiopus holbrookii	Scaphiopus holbrookii
			Eleutherodactylus latidiscus
All protected areas	Acris crepitans	Acris crepitans	Acris crepitans
		Ambystoma opacum	Ambystoma opacum
			Ambystoma texanum
	Bufo woodhousii	Bufo woodhousii	Bufo woodhousii
	Eurycea longicauda	Eurycea longicauda	Eurycea longicauda
			Rana blairi
			Rana sphenocephala
		Rhyacotriton kezeri	Rhyacotriton kezeri
			Scaphiopus holbrookii
			Eleutherodactylus latidiscus
Federal protected areas	Acris crepitans	Acris crepitans	Acris crepitans
			Ambystoma opacum
	Bufo fowleri	Bufo fowleri	Bufo fowleri
	Bufo woodhousii	Bufo woodhousii	Bufo woodhousii
	Eurycea longicauda	Eurycea longicauda	Eurycea longicauda
	Plethodon glutinosus	Plethodon glutinosus	Plethodon glutinosus
			Rana blairi
		Rhyacotriton kezeri	Rhyacotriton kezeri
Parks Canada Agency protected areas		Acris crepitans	Acris crepitans
	Ascaphus truei	Ascaphus truei	Ambystoma opacum
			Ascaphus truei
			Bufo cognatus
		Bufo fowleri	Bufo fowleri
	Bufo woodhousii	Bufo woodhousii	Bufo woodhousii
Environment Canada protected areas	Acris crepitans	Acris crepitans	Acris crepitans
			Ambystoma opacum
	Bufo fowleri		Bufo fowleri
	Bufo woodhousii	Bufo woodhousii	Bufo woodhousii
	Eurycea longicauda	Eurycea longicauda	Eurycea longicauda
	Gyrinophilus porphyriticus	Gyrinophilus porphyriticus	Gyrinophilus porphyriticus
	Plethodon glutinosus	Plethodon glutinosus	Plethodon glutinosus
			Pseudotriton ruber
			Rana blairi

Appendix 4 (continued): List of assessed species projected as a gain or loss in full-dispersal and no-dispersal scenarios for 30-year time periods to 2100 by taxa in Canada and in different protected area systems

Note: Results at the individual species level are less reliable than the general numbers and percentages and should be interpreted with caution.

Amphibian Gains: Full-dispersal scenario (continued)			
	Current to 2011-2040	**Current to 2041-2070**	**Current to 2071-2100**
Environment Canada protected areas		Rhyacotriton kezeri	Rhyacotriton kezeri
Other protected areas	Acris crepitans	Acris crepitans	Acris crepitans
		Ambystoma opacum	Ambystoma opacum
			Ambystoma texanum
	Bufo woodhousii	Bufo woodhousii	Bufo woodhousii
	Eurycea longicauda	Eurycea longicauda	Eurycea longicauda
			Pseudotriton ruber
			Rana blairi
			Rana sphenocephala
		Rhyacotriton kezeri	Rhyacotriton kezeri
			Scaphiopus holbrookii
			Eleutherodactylus latidiscus
Nunavut Settlement Area	Bufo americanus	Bufo americanus	Bufo americanus
Acadian/Northern Appalachian (A/NA) ecoregion	Acris crepitans	Acris crepitans	Acris crepitans
			Rana sphenocephala
A/NA protected areas			Ambystoma opacum
			Bufo fowleri
			Eurycea longicauda
		Plethodon glutinosus	Plethodon glutinosus

Appendix 4 (continued): List of assessed species projected as a gain or loss in full-dispersal and no-dispersal scenarios for 30-year time periods to 2100 by taxa in Canada and in different protected area systems

Note: Results at the individual species level are less reliable than the general numbers and percentages and should be interpreted with caution.

Bird Losses: No-dispersal scenario			
	Current to 2011-2040	**Current to 2041-2070**	**Current to 2071-2100**
Canada	Aechmophorus clarkii	Aechmophorus clarkii	
	Anser rossii	Anser rossii	Anser rossii
	Bubulcus ibis	Bubulcus ibis	Bubulcus ibis
	Dendroica discolor	Dendroica discolor	
		Egretta thula	Egretta thula
		Oreoscoptes montanus	Oreoscoptes montanus
		Plegadis chihi	Plegadis chihi
	Synthliboramphus antiquus	Synthliboramphus antiquus	Synthliboramphus antiquus
All protected areas	Aechmophorus clarkii	Aechmophorus clarkii	
	Anser rossii	Anser rossii	Anser rossii
	Bubulcus ibis	Bubulcus ibis	Bubulcus ibis
	Dendroica discolor	Dendroica discolor	
		Egretta thula	Egretta thula
		Oreoscoptes montanus	Oreoscoptes montanus
		Plegadis chihi	Plegadis chihi
	Synthliboramphus antiquus	Synthliboramphus antiquus	Synthliboramphus antiquus
			Zonotrichia querula
Federal protected areas	Anser rossii	Anser rossii	Anser rossii
	Bubulcus ibis	Bubulcus ibis	Bubulcus ibis
		Egretta thula	Egretta thula
	Oreoscoptes montanus	Oreoscoptes montanus	Oreoscoptes montanus
	Plegadis chihi	Plegadis chihi	Plegadis chihi
			Psaltriparus minimus
	Synthliboramphus antiquus	Synthliboramphus antiquus	Synthliboramphus antiquus
			Zonotrichia querula
Parks Canada Agency protected areas	Anser rossii	Anser rossii	Anser rossii
	Bubulcus ibis	Bubulcus ibis	Bubulcus ibis
	Calidris alpina	Calidris alpina	
			Charadrius melodus
		Egretta thula	Egretta thula
	Icterus bullockii		Icterus bullockii
	Plegadis chihi	Plegadis chihi	Plegadis chihi
			Psaltriparus minimus
	Spiza americana		
	Synthliboramphus antiquus	Synthliboramphus antiquus	Synthliboramphus antiquus
			Zonotrichia querula
Environment Canada protected areas	Anser rossii	Anser rossii	Anser rossii
	Bubulcus ibis	Bubulcus ibis	Bubulcus ibis
	Calidris canutus	Calidris canutus	
		Calidris maritima	Calidris maritima
			Dendroica cerulea

Appendix 4 (continued): List of assessed species projected as a gain or loss in full-dispersal and no-dispersal scenarios for 30-year time periods to 2100 by taxa in Canada and in different protected area systems

Note: Results at the individual species level are less reliable than the general numbers and percentages and should be interpreted with caution.

Bird Losses: No-dispersal scenario (continued)			
	Current to 2011-2040	**Current to 2041-2070**	**Current to 2071-2100**
Environment Canada protected areas	Egretta thula	Egretta thula	Egretta thula
	Heteroscelus incanus	Heteroscelus incanus	Heteroscelus incanus
		Larus glaucoides	Larus glaucoides
	Oreoscoptes montanus	Oreoscoptes montanus	Oreoscoptes montanus
		Psaltriparus minimus	Psaltriparus minimus
			Zonotrichia querula
Other protected areas	Aechmophorus clarkii	Aechmophorus clarkii	
	Anser rossii	Anser rossii	Anser rossii
	Bubulcus ibis	Bubulcus ibis	Bubulcus ibis
		Calidris alba	Calidris alba
		Calidris alpina	Calidris alpina
	Calidris canutus	Calidris canutus	Calidris canutus
	Dendroica discolor	Dendroica discolor	
		Egretta thula	Egretta thula
		Larus thayeri	Larus thayeri
		Oreoscoptes montanus	Oreoscoptes montanus
		Plegadis chihi	Plegadis chihi
			Pluvialis squatarola
	Synthliboramphus antiquus	Synthliboramphus antiquus	Synthliboramphus antiquus
			Zonotrichia querula
Nunavut Settlement Area	Agelaius phoeniceus	Agelaius phoeniceus	Agelaius phoeniceus
	Anser rossii	Anser rossii	Anser rossii
			Coturnicops noveboracensis
		Limnodromus scolopaceus	
			Melospiza georgiana
		Mergus merganser	
			Spizella passerina
		Sterna hirundo	Sterna hirundo
A/NA ecoregion		Anas strepera	Anas strepera
	Anthus rubescens	Anthus rubescens	Anthus rubescens
		Aquila chrysaetos	Aquila chrysaetos
	Bubulcus ibis	Bubulcus ibis	Bubulcus ibis
		Calidris minuta	Calidris minuta
			Charadrius semipalmatus
	Corvus ossifragus	Corvus ossifragus	
		Egretta thula	
			Fulica americana
	Histrionicus histrionicus	Histrionicus histrionicus	Histrionicus histrionicus
		Passerella iliaca	Passerella iliaca
			Phalaropus tricolor
			Picoides tridactylus

Appendix 4 (continued): List of assessed species projected as a gain or loss in full-dispersal and no-dispersal scenarios for 30-year time periods to 2100 by taxa in Canada and in different protected area systems

Note: Results at the individual species level are less reliable than the general numbers and percentages and should be interpreted with caution.

Bird Losses: No-dispersal scenario (continued)			
	Current to 2011-2040	Current to 2041-2070	Current to 2071-2100
A/NA ecoregion		Spizella pallida	Spizella pallida
			Surnia ulula
A/NA protected areas	Aquila chrysaetos	Aegolius funereus	Aegolius funereus
		Aquila chrysaetos	
			Anas acuta
			Aquila chrysaetos
	Bubulcus ibis	Bubulcus ibis	Bubulcus ibis
	Calidris minuta	Calidris minuta	Calidris minuta
			Catoptrophorus semipalmatus
	Charadrius semipalmatus	Charadrius semipalmatus	Charadrius semipalmatus
			Chlidonias niger
			Cistothorus platensis
			Dendroica palmarum
			Dendroica striata
	Empidonax virescens	Empidonax virescens	Empidonax virescens
	Fulica americana	Fulica americana	Fulica americana
	Ixobrychus exilis	Ixobrychus exilis	Ixobrychus exilis
	Mergus merganser	Mergus merganser	Mergus merganser
			Mergus serrator
			Perisoreus canadensis
	Phalacrocorax auritus	Phalacrocorax auritus	Phalacrocorax auritus
		Phalaropus tricolor	Phalaropus tricolor
			Picoides tridactylus
			Pinicola enucleator
			Poecile hudsonica
	Spizella pallida	Spizella pallida	Spizella pallida
	Sterna paradisaea	Sterna paradisaea	Sterna paradisaea
		Surnia ulula	Surnia ulula
	Thryothorus ludovicianus		
		Tringa solitaria	Tringa solitaria
			Vireo philadelphicus
			Wilsonia pusilla

Appendix 4 (continued): List of assessed species projected as a gain or loss in full-dispersal and no-dispersal scenarios for 30-year time periods to 2100 by taxa in Canada and in different protected area systems

Note: Results at the individual species level are less reliable than the general numbers and percentages and should be interpreted with caution.

Bird Losses: Full-dispersal scenario			
	Current to 2011-2040	Current to 2041-2070	Current to 2071-2100
Canada	Aechmophorus clarkii		
		Anser rossii	Anser rossii
	Bubulcus ibis	Bubulcus ibis	
		Plegadis chihi	Plegadis chihi
	Synthliboramphus antiquus	Synthliboramphus antiquus	
All protected areas	Aechmophorus clarkii		
		Anser rossii	Anser rossii
	Bubulcus ibis	Bubulcus ibis	
		Plegadis chihi	Plegadis chihi
	Synthliboramphus antiquus	Synthliboramphus antiquus	Synthliboramphus antiquus
			Zonotrichia querula
Federal protected areas	Anser rossii	Anser rossii	Anser rossii
	Bubulcus ibis	Bubulcus ibis	
	Oreoscoptes montanus	Oreoscoptes montanus	Oreoscoptes montanus
	Plegadis chihi	Plegadis chihi	Plegadis chihi
			Psaltriparus minimus
	Synthliboramphus antiquus	Synthliboramphus antiquus	Synthliboramphus antiquus
			Zonotrichia querula
Parks Canada Agency protected areas	Anser rossii	Anser rossii	Anser rossii
	Bubulcus ibis	Bubulcus ibis	Bubulcus ibis
	Plegadis chihi	Plegadis chihi	Plegadis chihi
			Psaltriparus minimus
	Synthliboramphus antiquus	Synthliboramphus antiquus	Synthliboramphus antiquus
			Zonotrichia querula
Environment Canada protected areas	Anser rossii	Anser rossii	Anser rossii
	Bubulcus ibis	Bubulcus ibis	
	Egretta thula	Egretta thula	Egretta thula
	Heteroscelus incanus	Heteroscelus incanus	
		Larus glaucoides	Larus glaucoides
	Oreoscoptes montanus	Oreoscoptes montanus	Oreoscoptes montanus
		Psaltriparus minimus	Psaltriparus minimus
			Zonotrichia querula
Other protected areas	Aechmophorus clarkii		
	Anser rossii	Anser rossii	Anser rossii
	Bubulcus ibis	Bubulcus ibis	
		Calidris alba	Calidris alba
	Calidris canutus		
		Larus thayeri	Larus thayeri
		Plegadis chihi	Plegadis chihi
	Synthliboramphus antiquus	Synthliboramphus antiquus	Synthliboramphus antiquus
			Zonotrichia querula

Appendix 4 (continued): List of assessed species projected as a gain or loss in full-dispersal and no-dispersal scenarios for 30-year time periods to 2100 by taxa in Canada and in different protected area systems

Note: Results at the individual species level are less reliable than the general numbers and percentages and should be interpreted with caution.

Bird Losses: Full-dispersal scenario (continued)			
	Current to 2011-2040	**Current to 2041-2070**	**Current to 2071-2100**
Nunavut Settlement Area	Agelaius phoeniceus	Agelaius phoeniceus	
	Anser rossii	Anser rossii	Anser rossii
		Mergus merganser	
		Sterna hirundo	Sterna hirundo
A/NA ecoregion		Anas strepera	Anas strepera
	Anthus rubescens	Anthus rubescens	Anthus rubescens
		Aquila chrysaetos	Aquila chrysaetos
	Bubulcus ibis	Bubulcus ibis	Bubulcus ibis
		Calidris minuta	Calidris minuta
	Corvus ossifragus		
	Histrionicus histrionicus	Histrionicus histrionicus	Histrionicus histrionicus
			Phalaropus tricolor
			Picoides tridactylus
			Spizella pallida
			Surnia ulula
A/NA protected areas		Aegolius funereus	Aegolius funereus
	Aquila chrysaetos	Aquila chrysaetos	Aquila chrysaetos
	Bubulcus ibis	Bubulcus ibis	Bubulcus ibis
	Calidris minuta	Calidris minuta	Calidris minuta
	Charadrius semipalmatus	Charadrius semipalmatus	Charadrius semipalmatus
			Cistothorus platensis
			Dendroica palmarum
			Dendroica striata
	Empidonax virescens		
		Fulica americana	Fulica americana
	Mergus merganser	Mergus merganser	Mergus merganser
			Mergus serrator
			Perisoreus canadensis
	Phalacrocorax auritus	Phalacrocorax auritus	Phalacrocorax auritus
		Phalaropus tricolor	Phalaropus tricolor
			Picoides tridactylus
			Pinicola enucleator
			Poecile hudsonica
		Spizella pallida	Spizella pallida
	Sterna paradisaea	Sterna paradisaea	Sterna paradisaea
		Surnia ulula	Surnia ulula
	Thryothorus ludovicianus		
			Tringa solitaria
			Vireo philadelphicus
			Wilsonia pusilla

Appendix 4 (continued): List of assessed species projected as a gain or loss in full-dispersal and no-dispersal scenarios for 30-year time periods to 2100 by taxa in Canada and in different protected area systems

Note: Results at the individual species level are less reliable than the general numbers and percentages and should be interpreted with caution.

Bird Gains: Full-dispersal scenario			
	Current to 2011-2040	**Current to 2041-2070**	**Current to 2071-2100**
Canada			Ardea alba
	Calidris mauri	Calidris mauri	Calidris mauri
	Calidris ptilocnemis	Calidris ptilocnemis	Calidris ptilocnemis
			Corvus ossifragus
			Gymnorhinus cyanocephalus
			Helmitheros vermivorus
			Himantopus mexicanus
			Hylopezus dives
	Luscinia svecica	Luscinia svecica	Luscinia svecica
	Motacilla alba	Motacilla alba	Motacilla alba
			Numenius tahitiensis
			Oporornis formosus
			Passerina caerulea
	Phylloscopus borealis	Phylloscopus borealis	Phylloscopus borealis
			Pionopsitta pulchra
			Piranga rubra
	Pluvialis fulva	Pluvialis fulva	Pluvialis fulva
			Poecile carolinensis
			Polysticta stelleri
		Vireo bellii	Vireo bellii
		Vireo griseus	Vireo griseus
All protected areas			Ardea alba
	Calidris mauri	Calidris mauri	Calidris mauri
	Calidris ptilocnemis	Calidris ptilocnemis	Calidris ptilocnemis
			Corvus ossifragus
			Gymnorhinus cyanocephalus
			Helmitheros vermivorus
			Himantopus mexicanus
			Hylopezus dives
	Luscinia svecica	Luscinia svecica	Luscinia svecica
	Motacilla alba	Motacilla alba	Motacilla alba
			Oporornis formosus
	Phylloscopus borealis	Phylloscopus borealis	Phylloscopus borealis
			Pionopsitta pulchra
			Piranga rubra
	Pluvialis fulva	Pluvialis fulva	Pluvialis fulva
			Poecile carolinensis
		Vireo bellii	Vireo bellii
		Vireo griseus	Vireo griseus
Federal protected areas			Ardea alba
	Calidris mauri	Calidris mauri	Calidris mauri

Appendix 4 (continued): List of assessed species projected as a gain or loss in full-dispersal and no-dispersal scenarios for 30-year time periods to 2100 by taxa in Canada and in different protected area systems

Note: Results at the individual species level are less reliable than the general numbers and percentages and should be interpreted with caution.

Bird Gains: Full-dispersal scenario (continued)			
	Current to 2011-2040	Current to 2041-2070	Current to 2071-2100
Federal protected areas		Calidris ptilocnemis	Calidris ptilocnemis
		Dendroica discolor	Dendroica discolor
			Helmitheros vermivorus
	Luscinia svecica	Luscinia svecica	Luscinia svecica
	Motacilla alba	Motacilla alba	Motacilla alba
			Oporornis formosus
	Phylloscopus borealis	Phylloscopus borealis	Phylloscopus borealis
			Piranga rubra
	Pluvialis fulva	Pluvialis fulva	Pluvialis fulva
			Poecile carolinensis
		Vireo bellii	Vireo bellii
			Vireo griseus
Parks Canada Agency protected areas	Baeolophus bicolor	Baeolophus bicolor	Baeolophus bicolor
		Calidris mauri	Calidris mauri
		Calidris ptilocnemis	Calidris ptilocnemis
		Colinus virginianus	Colinus virginianus
			Dendroica discolor
		Empidonax virescens	Empidonax virescens
	Luscinia svecica	Luscinia svecica	Luscinia svecica
		Melanerpes carolinus	Melanerpes carolinus
	Motacilla alba	Motacilla alba	Motacilla alba
	Phylloscopus borealis	Phylloscopus borealis	Phylloscopus borealis
	Pluvialis fulva	Pluvialis fulva	Pluvialis fulva
	Protonotaria citrea	Protonotaria citrea	Protonotaria citrea
	Rallus elegans	Rallus elegans	Rallus elegans
	Wilsonia citrina	Wilsonia citrina	Wilsonia citrina
Environment Canada protected areas			Ardea alba
		Brachyramphus brevirostris	Brachyramphus brevirostris
		Calidris mauri	Calidris mauri
			Calidris ptilocnemis
			Dendroica discolor
		Luscinia svecica	Luscinia svecica
	Motacilla alba	Motacilla alba	Motacilla alba
	Motacilla flava	Motacilla flava	Motacilla flava
			Oporornis formosus
	Phylloscopus borealis	Phylloscopus borealis	Phylloscopus borealis
			Piranga rubra
	Pluvialis fulva	Pluvialis fulva	Pluvialis fulva
			Poecile carolinensis
		Vireo bellii	Vireo bellii
			Vireo griseus

Appendix 4 (continued): List of assessed species projected as a gain or loss in full-dispersal and no-dispersal scenarios for 30-year time periods to 2100 by taxa in Canada and in different protected area systems

Note: Results at the individual species level are less reliable than the general numbers and percentages and should be interpreted with caution.

Bird Gains: Full-dispersal scenario (continued)			
	Current to 2011-2040	Current to 2041-2070	Current to 2071-2100
Other protected areas			Ardea alba
	Calidris mauri	Calidris mauri	Calidris mauri
	Calidris ptilocnemis	Calidris ptilocnemis	Calidris ptilocnemis
			Corvus ossifragus
			Gymnorhinus cyanocephalus
			Helmitheros vermivorus
			Himantopus mexicanus
			Hylopezus dives
	Luscinia svecica	Luscinia svecica	Luscinia svecica
	Motacilla alba	Motacilla alba	Motacilla alba
			Oporornis formosus
	Phylloscopus borealis	Phylloscopus borealis	Phylloscopus borealis
			Pionopsitta pulchra
			Piranga rubra
	Pluvialis fulva	Pluvialis fulva	Pluvialis fulva
			Poecile carolinensis
		Vireo bellii	Vireo bellii
		Vireo griseus	Vireo griseus
Nunavut Settlement Area		Accipiter striatus	Accipiter striatus
	Ammodramus leconteii	Ammodramus leconteii	
			Asio otus
	Aythya affinis	Aythya affinis	Aythya affinis
			Aythya collaris
	Aythya valisineria	Aythya valisineria	Aythya valisineria
		Bonasa umbellus	Bonasa umbellus
	Botaurus lentiginosus	Botaurus lentiginosus	Botaurus lentiginosus
	Brachyramphus brevirostris	Brachyramphus brevirostris	Brachyramphus brevirostris
	Bucephala albeola	Bucephala albeola	Bucephala albeola
			Bucephala islandica
	Buteo jamaicensis	Buteo jamaicensis	Buteo jamaicensis
	Calidris mauri	Calidris mauri	Calidris mauri
			Calidris ptilocnemis
			Carduelis pinus
	Catharus ustulatus	Catharus ustulatus	Catharus ustulatus
			Certhia americana
		Charadrius vociferus	Charadrius vociferus
		Chordeiles minor	Chordeiles minor
		Cinclus mexicanus	Cinclus mexicanus
	Colaptes auratus	Colaptes auratus	Colaptes auratus
	Contopus cooperi	Contopus cooperi	Contopus cooperi
			Contopus sordidulus

Appendix 4 (continued): List of assessed species projected as a gain or loss in full-dispersal and no-dispersal scenarios for 30-year time periods to 2100 by taxa in Canada and in different protected area systems

Note: Results at the individual species level are less reliable than the general numbers and percentages and should be interpreted with caution.

Bird Gains: Full-dispersal scenario (continued)			
	Current to 2011-2040	Current to 2041-2070	Current to 2071-2100
Nunavut Settlement Area	Corvus brachyrhynchos	Corvus brachyrhynchos	Corvus brachyrhynchos
			Dendroica castanea
		Dendroica magnolia	Dendroica magnolia
			Empidonax flaviventris
			Empidonax minimus
			Falco sparverius
		Heteroscelus incanus	Heteroscelus incanus
		Ixoreus naevius	Ixoreus naevius
	Leucosticte tephrocotis	Leucosticte tephrocotis	Leucosticte tephrocotis
			Loxia curvirostra
	Luscinia svecica	Luscinia svecica	Luscinia svecica
	Megaceryle alcyon	Megaceryle alcyon	Megaceryle alcyon
	Melanitta nigra	Melanitta nigra	Melanitta nigra
	Melanitta perspicillata	Melanitta perspicillata	Melanitta perspicillata
	Melospiza lincolnii	Melospiza lincolnii	Melospiza lincolnii
	Melospiza melodia	Melospiza melodia	Melospiza melodia
			Mniotilta varia
	Motacilla alba	Motacilla alba	Motacilla alba
	Motacilla flava	Motacilla flava	Motacilla flava
			Petrochelidon pyrrhonota
	Phylloscopus borealis	Phylloscopus borealis	Phylloscopus borealis
			Pica hudsonia
	Picoides arcticus	Picoides arcticus	Picoides arcticus
		Picoides pubescens	Picoides pubescens
		Picoides villosus	Picoides villosus
	Pinicola enucleator	Pinicola enucleator	Pinicola enucleator
	Pluvialis fulva	Pluvialis fulva	Pluvialis fulva
	Podiceps grisegena	Podiceps grisegena	Podiceps grisegena
		Poecile atricapilla	Poecile atricapilla
			Polysticta stelleri
	Porzana carolina	Porzana carolina	Porzana carolina
			Regulus satrapa
	Riparia riparia	Riparia riparia	Riparia riparia
	Sayornis phoebe	Sayornis phoebe	Sayornis phoebe
			Sitta canadensis
		Sphyrapicus varius	Sphyrapicus varius
	Strix nebulosa	Strix nebulosa	Strix nebulosa
			Tachycineta thalassina
		Tringa melanoleuca	Tringa melanoleuca
			Troglodytes troglodytes
	Tympanuchus phasianellus	Tympanuchus phasianellus	Tympanuchus phasianellus

Appendix 4 (continued): List of assessed species projected as a gain or loss in full-dispersal and no-dispersal scenarios for 30-year time periods to 2100 by taxa in Canada and in different protected area systems

Note: Results at the individual species level are less reliable than the general numbers and percentages and should be interpreted with caution.

Bird Gains: Full-dispersal scenario (continued)			
	Current to 2011-2040	**Current to 2041-2070**	**Current to 2071-2100**
Nunavut Settlement Area	Vermivora celata	Vermivora celata	Vermivora celata
	Vermivora peregrina	Vermivora peregrina	Vermivora peregrina
			Zonotrichia atricapilla
A/NA ecoregion	Colinus virginianus	Colinus virginianus	Colinus virginianus
			Coragyps atratus
	Melanerpes carolinus	Melanerpes carolinus	Melanerpes carolinus
		Oporornis formosus	Oporornis formosus
			Piranga rubra
			Poecile carolinensis
	Protonotaria citrea	Protonotaria citrea	Protonotaria citrea
	Rallus elegans	Rallus elegans	Rallus elegans
	Spiza americana	Spiza americana	Spiza americana
	Sturnella neglecta	Sturnella neglecta	Sturnella neglecta
		Vireo griseus	Vireo griseus
A/NA protected areas	Baeolophus bicolor	Baeolophus bicolor	Baeolophus bicolor
			Charadrius melodus
		Dendroica cerulea	Dendroica cerulea
			Dendroica discolor
	Icterus spurius	Icterus spurius	Icterus spurius
			Icteria virens
			Melanerpes carolinus
	Protonotaria citrea	Protonotaria citrea	Protonotaria citrea
		Rallus elegans	Rallus elegans
	Spiza americana		Spiza americana
	Tyto alba	Tyto alba	Tyto alba
	Vermivora chrysoptera	Vermivora chrysoptera	Vermivora chrysoptera
	Vermivora pinus	Vermivora pinus	Vermivora pinus
		Wilsonia citrina	Wilsonia citrina

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Canadian Guidebook for the Application of IUCN Protected Area Categories. CCEA Occasional Paper No. 18. 2008. Canadian Council on Ecological Areas

Protected Areas in Northern Canada: Identifying Ecological Areas to Represent Mammals. CCEA Occasional Paper No. 17. 2007. Y. F. Wiersma

Protected Areas in Northern Canada: Designing for Ecological Integrity. CCEA Occasional Paper No. 16. 2005. Y. F. Wiersma, T. J. Beechey, B. M. Oosebrug and J. C. Meickle

Guidelines for Annual Jurisdictional Reports to the Canadian Council on Ecological Areas. CCEA Occasional Paper No. 15. 2002. Canadian Council on Ecological Areas

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