DISPONIBLE EN FRANÇAIS

ABORIGINALS

ECOSYSTEMS

PROTECTED AREAS

ECOLOGICAL CORRIDORS

IMPACTS OF CLIMATE CHANGE ON THE BIODIVERSITY OF QUÉBEC

LITERATURE REVIEW SUMMARY

CSBQ QCBS

OURANOS

Ministère du Développement durable, de l'Environnement et des Parcs
Québec

IMPACTS OF CLIMATE CHANGE ON THE BIODIVERSITY OF QUÉBEC

ecosystems
protected areas
aboriginals
ecological corridors

LITERATURE REVIEW SUMMARY

Context

In 2009, initiated by the Prince Albert II of Monaco Foundation, the Government of Quebec and the Ouranos Consortium launched an Atlas project on the biodiversity of northern Quebec. This project aims to develop a tool to integrate knowledge of northern Quebec's biodiversity, taking into account the impacts of climate change.

The Northern Quebec Biodiversity Atlas is an ambitious and multifaceted project which should be able to support implementation of various governmental projects, in particular, the development of a protected areas network for Quebec, adapted to climate change. While the section on biodiversity knowledge is based largely on inventory data gathered by the Ministère du Développement durable de l'Environnement et des Parcs (MDDEP) and the Ministère des Ressources naturelles et de la Faune (MRNF), the climate section relies on the skills and funding of the Ouranos Consortium, given its ideal fit within the "Ecosystems and Biodiversity" theme, one of the priorities of the Government of Quebec's Climate Change Action Plan (PACC–26), administered by Ouranos.

Many studies have shown that northern and arctic regions are being, and will continue to be, strongly affected by climate change. These regions in particular will undergo changes to their temperature and precipitation averages, as well as modifications to temperature and precipitation ranges and extremes. In Québec, these changes will have impacts affecting various sectors of society and the environment.

In order to better understand the scale of future impacts of climate change, the Quebec Centre for Biodiversity Science (QCBS-CSBQ) was given the task of creating a literature review[1] consisting of four chapters, with a particular focus on the impacts to Northern Quebec. From April to October 2010, under supervision of four QCBS researchers, eleven students created an extensive bibliographic database (1892 citations) that will be able to be accessed through the QCBS website. Individual review of these documents allowed the most relevant to be selected (916 references) for inclusion in the four thematic chapters of the literature review.

The summary presented here is a synthesis of this literature review presented by the QCSB to the MDDEP in 2011. A French version of this document is also available.

Document preparation and editing:

- Philippe Auzel, QCBC-CSBQ coordinator, McGill University
- Hélène Gaonac'h, Communications Coordinator, Ouranos
- Frédéric Poisson, Northern Québec Biodiversity Atlas Project Manager, Direction du patrimoine écologique et des parcs, MDDEP
- Robert Siron, PACC-26 Scientific Coordinator, and Ecosystems, Biodiversity and Climate Change (EcoBioCC) Program Coordinator, Ouranos

[1] Biodiversity and climate change literature review (Revue de littérature en lien avec la biodiversité et les changements climatiques). 2011. QCBS. 279 pp (http://qcbs.ca/research/adapting-to-cc/)

Compilation of the original document: researchers in charge* and students

- Ecosystems of Québec - Sophie Calmé*, Michel Belanger, Marie-Michèle Bourassa: Université Sherbrooke; Asa Kestrup: McGill University.
- Protected areas - Fanie Pelletier*, Jennifer Chambers: Université Sherbrooke; Annie Ève Gagnon, Melanie Louise Le Blanc : Université Laval; Marie-Claire Bédard, Yanick Gendreau : UQAR.
- Northern Aboriginals - Alain Cuerrier*: Institut de Recherche en Biologie Végétale; Ashleigh Downing: Université de Montréal; Charlène Lavallée: UQTR.
- Ecological corridors and their contributions to ecosystem services - Andrew Gonzalez*, Matthew Mitchell, Jonathan Whiteley, Alan Larocque: McGill University.

This literature review was made possible through the financial support of the Fonds Verts du Gouvernment du Québec and FRQNT.

Fondsvert Québec

Fonds de recherche
Nature et
technologies
Québec

ISBN paper : 978-2-923292-09-0
ISBN web : 978-2-923292-10-6

Legal deposit-Bibliothèque nationale du Québec, 2010
Legal deposit-Natiobal Library of Canada, 2010

Bibliographic reference

P. Auzel, H. Gaonac'h, F. Poisson, R. Siron, S. Calmé, M. Belanger, M.M. Bourassa, A. Kestrup, Cuerrier, A., A. Downing, C. Lavallée, F. Pelletier, J. Chambers, A.E, Gagnon, M.C. Bedard, Y. Gendreau, A. Gonzalez, M. Mitchell, J. Whiteley & A. Larocque. *Impacts of Climate Change on the Biodiversity of Quebec: Literature review summary.* 2012. CSBQ, MDDEP, Ouranos. 29 p.

Graphical conception: François Landry, MDDEP.

Table of contents

List of sections

List of sections	Page
Impacts of climate change on the Quebec's ecosystems and proposed adaptation measures	1
Impacts of climate change on protected areas and proposed adaptation measures	7
Impacts of climate change on Northern Aboriginals	15
Ecological corridors and their role in the mitigation of the impacts of climate change	23
Editors	29

List of tables

	List of tables	Page
1	List of recommendations relevant to the management of protected areas for biodiversity adaptation to climate change	9
2	Similarities of observations made by Inuit's from Northern Canada and impacts and possible adaptations	19

List of figures

	List of figures	Page
1	Schematic diagram of alley cropping agroforestry	4
2	Relationship between ecosystem conservation, human well-being, and impacts of climate change	5
3	Protected areas management strategy in the context of climate change	12
4	Diagram showing the interrelationship between science and traditional knowledge regarding adaptation to climate change by First Nations	20
5	Considerations and steps to take to facilitate the collaboration of Inuit communities in scientific research	21
6	Example of a corridor formed by a waterway with its different zones and their respective functions	23
7	Example of a segmented forest corridor in an agricultural landscape	25
8	Graphical representation of the links between networks resilient to climate change	26

List of boxes

	List of boxes	Page
1	Definition of adaptive capacity	18
2	Corridor functions	24

Impacts of climate change on the Quebec's ecosystems and proposed adaptation measures

Introduction

Climate change causes modifications in temperature and precipitation values, two important factors contributing to the distribution of biomes. Since ecosystems occur within biomes, this means that they are also directly affected by climate change. Numerous anthropogenic factors also complicate how ecosystems respond to climate change. Conversely, global climate could also be strongly affected by changes in ecosystem functions, caused in turn by human activities and climate change. Man-made developments that take over primary production are directly dependant on the characteristics of those ecosystems. This situation makes an ecosystems-based approach, placing importance on ecosystem functions, vital for effective lands management.

Impacts on nutrient and carbon cycles

One of the best-known impacts of greenhouse gas build-up is global warming. At the level of nutrient-cycling, warmer temperatures cause a thinning of winter snow cover, thereby affecting the periods of freezing and thawing, as well as an increase in the rates of mineralization. These changes will have significant impacts on deciduous forests. Rates of litter decomposition will also be affected by changes in the amount of precipitation.

In the boreal forest, increases in annual temperature will not only lead to increased photosynthesis and respiration, but also to a shift toward earlier-starting growing seasons. Accelerated nutrient cycling, causing an increase in the rate of soil organic matter decomposition and thus decreasing the amount of carbon stored in the soil, will lead to an increase in levels of mineralized nitrogen under climate change. On a global scale, increases in primary production, forest cover expansion, and increases in local biomass will increase carbon sinks. Aquatic ecosystems also play an important role. The boreal forest in humid zones is a significant carbon sink compared to when it is found in more arid zones, but climate change could reverse this advantage. Since climate change will cause both gains and losses of carbon, it is difficult to predict whether the boreal forest will act as a significant carbon sink. The annual carbon budget in the clean cut forestry sector is itself affected more strongly by age-class distribution of trees than by variability in climate. Indeed, the amount of carbon stored due to growth does not only depend on climate changes, but also on how forests are managed.

Methane emissions are characteristic of arctic ecosystems due to the anaerobic decomposition of organic matter. Emission of methane is reduced in well-drained soil, resulting in an increased carbon flux in the ecosystem. Vegetation also plays a role in methane and carbon flux. Accordingly, in the context of climate change, fluctuations in carbon will be more strongly modulated by changes to vegetation and soil parameters than by direct effects of temperature. Globally in the tundra and taiga, changes to temperature and nutrients will cause a decline in species richness due to rare species being overtaken by more abundant species. Specifically, the addition of nutrients and acceleration of nutrient cycles will increase biomass and growth of deciduous shrubs, but diminish the growth of evergreen shrubs and non-vascular plants. Thawing of permafrost will result in increased transportation of dissolved organic carbon (DOC) to aquatic environments and a release of methane. An increase in DOC concentration will have an impact on aquatic ecosystems since it influences both the carbon cycle and the availability of nutrients and mercury. Thawing also releases toxins previously locked in permafrost, ice, and snow, and produces a high level of mobility of mercury and other contaminants, causing a significant export of these compounds towards rivers and lakes.

Impacts on vegetation

Climate warming could create temperatures to which local vegetation is not adapted, and which would not be synchronized to local photoperiods. Predicted phenological changes allow anticipation of disturbances in the life cycles of many species and eventually local extinctions for species with less adaptation flexibility. Various studies predict a northern migration of southern plant species, altering the plant composition of forests. For this reason, forest ecosystems located at the northern and southern limits of their distribution will be most strongly affected by changes to climate. Species with wide ranges and high reproductive rates should be able to adapt fairly quickly over several generations. Production of large quantities of seeds and pollen with high dispersal capacities should also facilitate colonization of new environments having recently become more favorable.

In North America, the boreal forest is characterized by significant snow cover during the winter and low light due to dense cloud cover during the growing season. At the southern limit of the boreal forest, conifers will be replaced by deciduous trees. The vegetation changes expected in the boreal-taiga transition zone, due to individual morphological modifications, could cause a loss of taxa and a reorganization of northern communities. The extent of the boreal-tundra ecotone also seems to be related to winter precipitation. Recent climate warming has meant an increase in snow cover in northern Québec. Accumulation of snow in places where seedlings could grow diminishes the chances of plants establishing themselves. Additionally, even despite these expected increases in precipitation, the continuous heat in the summer will have negative impacts (although for some individuals this could be beneficial).

Three factors that define the composition and distribution of species at high latitudes are: climate conditions, permafrost patterns, and fire regimes. Warming will cause an increase in the size and cover of deciduous shrubs and graminoids, but a decrease in moss and lichen cover. Thus, it will have a positive effect on plant biomass in the arctic tundra. However, the establishment of trees in the tundra could be restricted by competition and by the limited resources available, in addition to a decreased survival rate of seed germination. In the short term, this would mean a decline in plant species diversity in the tundra. The loss of trees due to disturbances caused by climate (e.g., fire) will also play a role in the ecotone's future composition. Finally, increased concentration of CO_2 in bogs will also favour increased abundance of vascular plants at the expense of mosses.

Impacts on fauna

Different elements of the food chain will be affected by climate change at different rates, necessarily causing mispairings and imbalances in species interactions. For example, birds that migrate long distances could undergo impacts from climate change, such as being forced to change their breeding and overwintering spots.

Climate change could have serious consequences on species demography. For example, plant-pollinator interactions could become de-synchronized, negatively impacting effective pollination and pollinator survival. Predator-prey cycles could also undergo transformations due to climate change, although some species will likely be able to adapt quickly to an unstable climate. The most significant changes to climate will occur during the winters, meaning that the survival, distribution and abundance of hibernating mammals, amphibians, non-migrating birds, and insects undergoing diapause could be affected.

One of the impacts of climate change in northern regions is the appearance of new species. The fauna of northern Canada will undergo major changes in the future due to a modified temperature regime, but also due to changes in precipitation, snow and ice cover, and biological factors such as abundance and distribution of primary resources and predators. Extreme climate events will also change how populations react. Global warming will increase plant cover in the Arctic, and consequently lead to increased reproductive levels in animal species further north than their previous limits. As with any trophic relationship, one species cannot incur changes without simultaneously affecting trophic levels above and/or below itself. Compounding the effects of climate change, human activity could also contribute to the migration of insects, with more frequent and severe disease outbreaks. Animal and plant species present in the north with large populations and high reproductive rates will persist and adapt to disease epidemics, but will suffer an adaptive disadvantage for several generations. Conversely, species with small populations, fragmented distributions, low reproductive rates, or suffering a decline due to introduced insects or diseases, will have to migrate or face extinction. In wetlands and bogs, negative consequences of climate change will be significant for species native to cold waters, whereas species native to warmer waters and exotics previously limited by the low temperatures will be able to establish themselves further north depending on their thermal tolerance. The reduction in water levels in rivers due to droughts will impact aquatic organisms living in these habitats.

Impacts of natural and anthropogenic disturbances

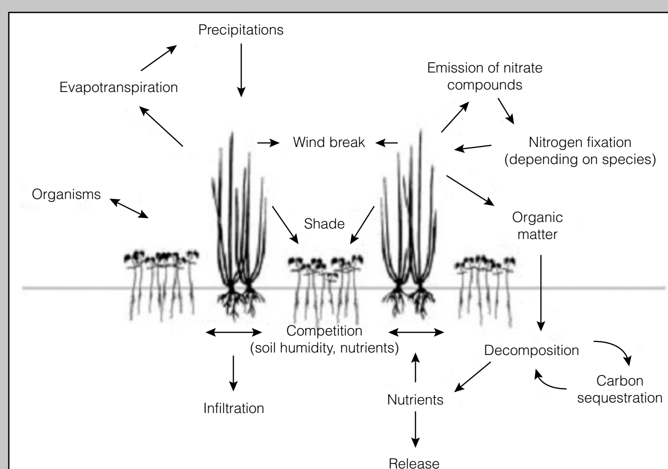
The appearance and spread of invasive species could be compounded by changes to the climate in deciduous forests. Those changes could be especially influenced both directly and indirectly by various human activities. Roads are one such typical anthropogenic disturbance that can aggravate the effects of climate change, for example, by facilitating the spread of invasive species.

The disturbances that most strongly affect the dynamics of boreal vegetation are those due indirectly to climate, in particular, fires and insect infestations. A higher frequency of fires, provoked by climate change, will cause a replacement of boreal species, leading to a dominance of deciduous and mixed forest species above the current southern limit of the boreal forest. Changes to present-day climate will increase the frequency of disturbances caused by fire, reduce timber volume and landscape diversity, and increase the total availability of wildlife habitats in dense forest. Climate change may also increase the frequency and duration of epidemic insect outbreaks, while at the same time extending insect migrations to higher altitudes and latitudes. The boreal forest will not only be affected by changes to the climate, but also by land conversion. Further north, permafrost thawing will reduce the depth of the water table, and the stress caused by lowered water availability in the soil will reduce the physiological activity of wetland plants. The exploitation of different resources and the presence of people (e.g. urbanization, tourism, etc.) currently have a major impact on the environment, and this will only continue to increase over the coming decades.

Methods of Adaptation to Climate Change

Climate change is inevitable, and although we should make as many efforts as possible to slow its progress, we should also develop measures that will help us to adapt to these changes. A good option to facilitate climate change adaptation is to maintain a network of trees dispersed throughout modified landscapes. Management of public forests should also be based on adaptive strategies in order to ensure their sustainability. For the southern part of the province, where cultivated lands form a significant component of the ecosystem mosaic, one of the agroforestry methods that allows food and biomass production while at the same time improving ecological functions is called "alley cropping", or strip cultivation. As its name suggests, this is a practice in which rows of crop are interspersed with rows of hedges composed of species that will create a more favourable microclimate for the entire crop (Figure 1).

Figure 1 : Schematic diagram of alley cropping agroforestry (Quinkenstein *et al.*, 2009)



The challenge ahead to mitigate the effects of climate change on the flora and fauna of the boreal forest will be to maintain the complex structure of mature forests, while promoting post-harvest productivity in order to maintain harvest volume. One way to minimize the impacts would be to accelerate the successional rates of tree populations and to create or maintain uneven-aged stands (composed of trees of different ages). Partial cutting and site preparation techniques to prevent soil from being severely burned are examples of strategies to follow in order to continue operations, while maximizing the resilience of ecosystems to climate change. Natural disturbances like fire and insect outbreaks play a major role in the evolution of forest structure and composition, and a management plan taking these into account can maintain a certain level of resilience. Diversifying silvicultural practices and proposing alternatives to keep up with the stresses of climate change are essential adaptation strategies in the forestry sector to maintain ecological functions and services of the boreal forest, and to reduce the risks that measures taken will not be cancelled out by natural disturbances. Priorities must be restructured regarding the protection of habitats, with greater emphasis placed on small areas with high value, and a return to the normal fire regime in larger areas. It is this type of ecosystems approach that will be most beneficial in managing areas being influenced by global changes. Furthermore, indicator species can be used as a frame of reference, given the impossibility of assessing the responses to climate change of every single taxon. Although nature reserves are essential to the management of forests due to their sustainability on a landscape scale, protected areas will not be sufficient by themselves to ensure species conservation and the protection of global biodiversity. It will also be necessary to protect and restore vegetation along waterways since riparian and coastal vegetation can effectively protect against erosion and reduce the movement of nutrients originating from agricultural lands. To reduce the damage caused by floods, it will be important to identify sites vulnerable to landslides and flooding.

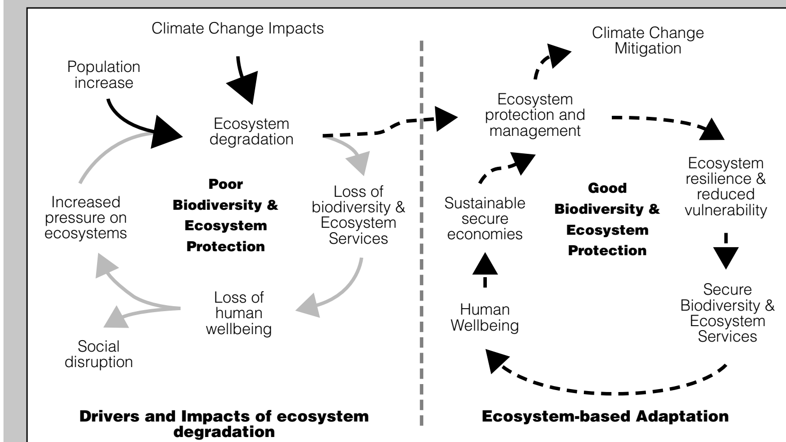


Figure 2 : Relationship between ecosystem conservation, human well-being, and impacts of climate change (Munang *et al.*, 2010).

In order to implement adaptation measures to increase resilience in northern Quebec, traditional values of indigenous communities will need to be incorporated along with scientific knowledge, since effective and respectful management of a territory cannot be done without consideration of all parties involved. Flexibility is key, because although models and simulations can give us good predictions of climate change, only time will allow accurate evaluation of different management strategies. Finally, climate change will also affect infectious diseases in arctic regions, and adaptive measures should be adopted in order to reduce adverse impacts.

Conclusions

Given the complexity of food chain communities, several problems related to phenological changes will appear, or continue to grow, in the coming decades as climate change progresses. Species will therefore have two options: to either adapt to the changes or move to other environments where conditions are more favorable. An ecosystems approach toward climate change adaptation strategies is therefore most appropriate. Any action taken in the context of global adaptation and generalized to the scale of ecosystems in the face of climate change should be considered as a positive step toward the well-being of humankind (Figure 2).

References

Munang R., Rivington M., Liu J., Thiaw I and Kasten T. 2010. *Integrated solutions for biodiversity, climate change and poverty.* Nairobi, Kenya: United Nations Environment Programme.

Quinkenstein A., Wollecke J., Böhm C., Grünewald H., Freese D., Schneider B.U. and Hüttl R.F. 2009. *Ecological benefits of the alley cropping agroforestry system in sensitive regions of Europe.* Environmental Science and Policy, 12: 1112-1121.

Impacts of climate change on protected areas and proposed adaptation measures

Introduction

Since the publication of the first report by the Intergovernmental Panel on Climate Change (IPCC-GIEC, 1990), studies on the impacts of climate change on populations, communities, and ecosystems have multiplied. It is now recognized that climate change is primarily a result of anthropogenic activities, and it is estimated that from now until 2100, the planet will undergo global warming on the scale of 2 to 3°C.

Some authors argue that this increase in temperature could cause the disappearance of 20 to 30% of the Earth's species. Climate change thus adds itself to the long list of threats to biodiversity (including loss of habitat, pollution, overexploitation of living resources, etc.), and at a global scale. The effects of these threats to biodiversity are often synergistic, which makes predictions on the medium and long-term scale even more complex.

Within this context, protected areas can help reduce the impacts of climate change on biodiversity (species, ecosystems, and habitats). They can play a role in reducing the impacts of climate change in two distinct ways:

Mitigation i.e., they can reduce the speed and intensity at which changes to climate will occur as well as the impacts on affected ecosystems.

For example, by acting as sinks for carbon - one of the main greenhouse gases responsible for climate change.

Adaptation: i.e., "An adjustment by natural or human systems faced with a new or changing environment….. […] in order to reduce adverse effects or to exploit beneficial opportunities." (IPCC, 2007)

- by maintaining ecosystem integrity and essential ecological services that will help humans adjust to climate change;
- by acting as a buffer to the local climate;
- by reducing the vulnerability of ecosystems and the risks and impacts of extreme climate events to them.

In this literature review, we have focused mainly on the role that protected areas play in terms of adaptation in the context of climate change, paying particular attention to issues relevant to Quebec.

Threats of climate change to protected areas and the ecological services they provide

The specific threats to protected areas and their ecological services are both numerous and varied in the context of climate change. Threats addressed in this review are:

- changes in the frequency of forest fires;
- increases in insect outbreaks;
- increases in extreme weather events (e.g., ice storms, floods, droughts, hurricanes, and wind storms);
- changes to species distributions (e.g., expansion, contraction, displacement northward or in altitude, extinction);
- arrival of exotic and/or invasive species;
- non-linear changes to the environment;
- acidification, shoreline erosion, and rise in seawater levels;
- reduced water flow and concentration of pollutants in fresh water;
- drying and physicochemical changes to wetlands.

Adaptive measures

The scientific literature makes several recommendations to assist established protected areas to better cope with the impacts of climate change and to permit adaptation and maintenance of biodiversity (Table 1).

Among these recommendations are: the creation of ecological corridors, the use of buffer zones, matrix management (i.e., regions outside of the protected areas), and the restoration of disturbed areas.

Another way to improve the abilities of the network of protected areas to counter climate change is to increase both their number and surface area. In order for the network to be effective, the selection methodology for the sites to be protected must be optimized so as to meet the pre-defined objectives for the network. To do this, we can build on approaches already in use (ecosystems approach, species approach, importance of representativeness), in complement with approaches specifically adapted for the establishment of protected areas in a context of global warming. The main problem with management approaches used until now has been that the protected areas were selected with the goal of conserving elements considered to be stable in space and time, i.e., typical ecosystems of a country, distribution ranges of vulnerable species, etc. Consequently, parks and reserves are mandated to preserve the site in their current states for perpetuity. This vision represents a serious flaw in light of the predicted effects of climate change, particularly with regards to changes predicted to occur in certain protected areas, such as changes to biomes and the distributional ranges of animal species. In order to modify this vision and to improve the selection of protected areas in the context of climate change, the following recommendations have been proposed in the scientific literature and are addressed in this review:

- integration of small scale climate projections during site selection;
- preferential protection of zones at risk and climate refugia;
- promotion of diversity protection at all levels (bioclimatic variation, genetic diversity, high heterogeneity, transition zones);
- use of the full range of categories and governance of reserves available.

Table 1 : List of recommendations relevant to the management of protected areas for biodiversity adaptation to climate change. Inspired from the paper by Heller and Zavaleta (2009) based on 112 scientific papers on the management of biodiversity in the context of climate change.

Conservation measures	[Number of articles referenced]
Increase connectivity (establish corridors, remove barriers to dispersion, reduce the distance between reserves, reforestation)	[23]
Increase the number of reserves	[13]
Protect large areas, enlarge protected areas	[11]
Establish networks of reserves – large reserves linked by smaller ‘stepping stone’ reserves	[8]
Protect the full range of bioclimatic variation	[8]
Re-evaluate the goals of conservation (i.e., move away from the concept of ‘natural’, adopt the idea of ‘process’ rather than ‘pattern’)	[7]
Protect current and anticipated refugia	[5]
Ensure species are represented in more than one reserve (i.e., increase the number of occurrences of a species in a network of reserves)	[4]
Preserve the genetic diversity of populations	[4]
Keep flexible limits around reserves	[3]
Select reserves in areas of high heterogeneity and endemism	[3]
Establish several smaller reserves rather than a single large reserve	[2]
Establish reserves on the northern border of the distributional range of species	[2]
Adjust the borders of parks to take into account the predicted movements of species	[1]
Increase protection of wetlands	[1]
Target the protection of sensitive biomes	[1]
Target annual plants rather than perennials on climatic boundaries	[1]
Create linear reserves oriented on a north-south axis	[1]

Conservation measures (Continuation)	[Number of articles]
Establish reserves at the heart of distribution ranges	[1]
Establish reserves so that vegetation transition zones are located centrally	[1]
Protect urban green zones	[1]
Protect primary forests	[1]
Protect functional groups and key species	[1]
Protect mountains	[1]
Use simple rules in the planning of reserves	[1]

Modelling	[Number of articles]
Study the physiological, behavioural and demographic responses of species to climate change	[15]
Establish and maintain monitoring programs	[11]
Do studies that incorporate multiple factors of global changes	[8]
Identify indicator species	[5]
Model future distributional ranges of species	[5]
Initiate long-term studies of species' responses to natural climate fluctuations	[5]
Use predictive modelling for the selection of new protected areas	[3]
Anticipate complex changes over time, and not only unidirectional changes, in the design of reserves	[2]
Study and protect metapopulations	[2]
Use GIS to study the distribution of species and landscape structure	[2]
Study the response of undisturbed areas to climate change	[1]
Quantify environmental susceptibility versus adaptive capacity in the planning of conservation action	[1]
Use caution when using predictive modelling, as the responses of some species are not easily predicted	[1]

Development outside of and within protected areas	[Number of articles]
Integrate climate change into planning exercises (reserves, invasive species, harvesting schedules, grazing limits, incentives programs)	[19]
Reduce other threats to biodiversity within reserves	[17]
Assisted migration; transportation of individuals to more favourable locations	[16]
Practice intensive management to ensure the survival of populations	[15]
Create and manage buffer zones around reserves	[10]

Moderate use of lands in the matrix	[8]
Improve techniques for restoration of wetlands, rivers, and areas outside of the reserves (of the matrix)	[8]
Increase genetic and species diversity in restoration projects and forestry	[8]
Do not implement CO2 emissions reduction projects that will have negative effects on biodiversity	[6]
Limit CO2 emissions	[4]
Maintain natural disturbance regimes of ecosystems	[3]
Manage the matrix	[2]

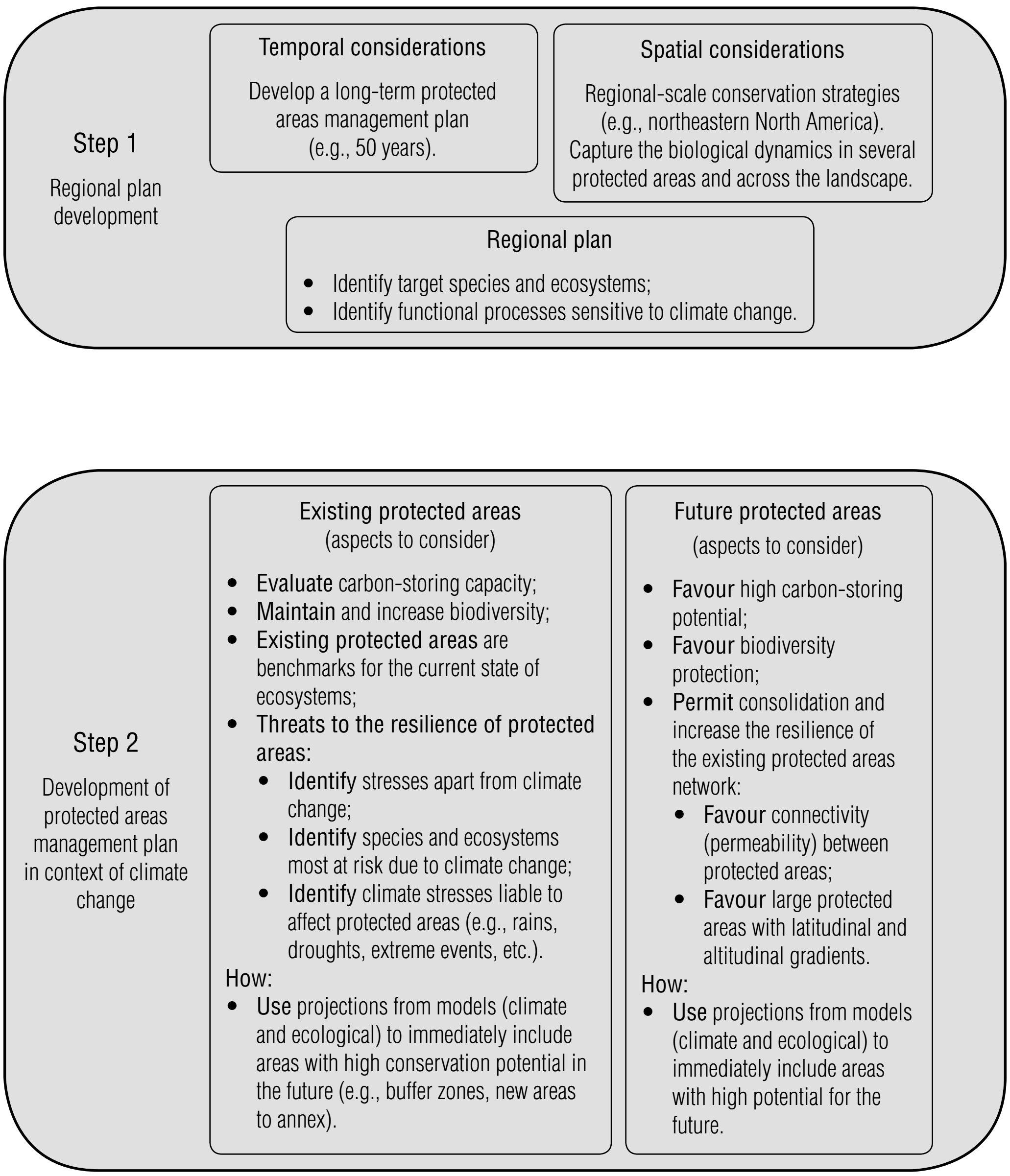
Governance	[Number of articles]
Improve interagency and regional coordination	[12]
Adopt a regional and long-term perspective for planning, modelling, and management	[11]
Practice adaptive management	[11]
Increase multidisciplinary collaborations	[8]
Develop adaptation managament strategies immediately, not later	[6]
Build collaborations between nations	[1]

Education	[Nombre d'articles]
Encourage training of managers by making available workshops and summaries of literature reviews addressing climate change	[2]
Create educational programs for the public on land use and effects on climate	[3]

Management of protected areas

Lastly, it is absolutely necessary to adopt a management structure for established protected areas networks in order to react appropriately to the specific challenges posed by climate change. The current absence of such a structure in the management of protected areas networks may potentially account for the fact that few of the adaptation solutions discussed in this review, as much for existing protected areas as for their selection, have yet to be put into practice. We present in this review a five step adaptation management methodology in order to fully integrate protected areas into a strategy to fight climate change (Figure 3, from Dudley et al., 2010; Hannah et Salm, 2005; Mawdsley et al., 2009; Welch, 2005). We are on the verge of the implementation of such a management strategy; it must be done soon and will need the support and involvement of government, both at the human as well as financial level, to ensure that the network of protected areas can fully assume its role in long-term conservation, by means of mitigation and adaptation to climate change.

Figure 3 : Protected areas management strategy in the context of climate change (based on Dudley *et al.*, 2010; Hannah et Salm, 2005; Mawdsley *et al.*, 2009; Welch, 2005).



Step 3

Measures for adaptive management of protected areas in the context of climate change (plan execution)

- **Shift** from the traditional static mode of protected areas management to a dynamic one. Be flexible with regards to the method of management and implement modifications as the ecosystems change (use predictive climate and ecological modelling);
- **Management** should be more “aggressive”, proactive, and innovative:
    - Restriction of public access to some parts of the protected area;
    - Habitat restoration;
    - Assisted migration;
    - Water-level control;
    - Fire control;
    - Control measures for invasive species;
    - Collaboration with authorities outside of protected areas;
    - Etc.

Step 4

Ensure monitoring and research

- **Improve** and evaluate existing monitoring programs for species and ecosystems to ensure they are meeting the challenges posed by climate change. Protected areas act as benchmarks for the state of ecosystems;
- **Monitoring programs** should cover species, ecosystems, and genes. Monitored elements should be designated within the framework of the regional plan and monitoring should be continued long term;
- **Species** at the northern limit of their distributional ranges or those on mountaintops are good indicators to monitor the effects of climate change;
- **Implement** research projects to better respond to the challenges of adaptive management and better understand the past and future effects of climate change.

Implications for managers of protected areas

- Training and education:
    - **Ensure** training of protected areas personnel so that they have the knowledge required for the implementation of management plans and so they are able to educate the public;
    - **Protected areas**, as their mission, can educate the public about the effects of climate change on the environment.
- Plan evaluation:
    - **Know** the benefits and environmental services provided by protected areas, and how these can help mitigation of and adaptation to climate change (e.g., regulatory, supply, and sociocultural services);
    - **Know** the implications of adaptive management of protected areas in the context of climate change. This knowledge will be necessary to make the best management decisions to maximize the cost-benefit ratio of the implementation and realization of the action plan.

Author of the figure: Yanick Gendreau

References

Dudley N., Stolton S., Belokurov A., Krueger L., Lopoukhine N., Mackinnon K., Sandwith T. and Sekhran N. 2010. *Natural solutions: Protected areas helping people cope with climate change*. Gland (Switzerland),Washington DC and New York (USA): IUCN-WCPA, TNC, UNDP, WCS, The World Bank, WWF.

GIEC. 2007. *Climate Change 2007 : Impacts, adaptation and vulnerability : contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge ; New York, Cambridge University Press.

Hannah L. and Salm R. 2005. *Protected areas management in a changing climate.* In: Lovejoy T. E. et Hannah L. (eds.) Climate change and biodiversity. New Haven and London: Yale University press, 440p.

Heller N. E. and Zavaleta E. 2009. *Biodiversity management in the face of climate change: A review of 22 years of recommendations.* Biological Conservation, 142: 14-32.

Mawdsley J. R., O'Malley R. and Ojima D. S. 2009. *A Review of Climate-Change Adaptation Strategies for Wildlife Management and Biodiversity Conservation.* Conservation Biology, 23: 1080-1089.

Welch D. 2005. *What should protected area managers do in the face of climate change?* The George Wright forum 22: 75-93.

Impacts of climate change on Northern Aboriginals

Introduction

Presently, throughout the world, more than 26 million people have been displaced due to climate change, and it is estimated that by 2050, this number will be closer to 200 million.

Polar regions risk undergoing the most dramatic changes and consequently, inhabitants of northern regions risk being severely affected by impacts associated with climate disruptions. First Nations, Inuit communities and other local populations will all be affected. Thus, contrary to some misconceptions, it is not only polar regions that will be affected, but also regions further south. This situation is not without consequences for these regions whose populations will find themselves caught in spiral of economic and political instability that could be detrimental to their health, and more generally to the sustainability of their models of society.

Ice melt

For several decades, scientists have been observing a reduction in sea ice cover throughout the Arctic basin, with early thawing, late freezing, and an overall reduction in ice thickness. Greater absorption of solar rays due to a reduction in albedo and, therefore, increased temperatures and duration of the warm season are all partly responsible for this phenomenon.

The majority of Inuit communities around the polar circle depend on ice for different needs, such as travel; seal, bear, and whale hunting, and fishing, all important food sources; revenue (tourism, fabrication of clothing, various objects); and for sporting activities. Their calendar is based on observed environmental conditions and on predictable recurring events, such as the progression of ice or animal migrations. Climate change will thus contribute to an erosion of cultural traits by modifying their subsistence economy and their ability to survive in their vast ice-based environment.

People living in polar regions have always had to live in difficult climate conditions, but they will have much more to deal with given the unpredictability of weather events and changing environmental conditions.

Snow cover

In arctic regions, snow comprises up to 80% of the precipitation. A reduction in precipitation in the form of snow will reduce the protection of both soil permafrost and plants, and modify the absorption of solar rays, thereby also affecting thermal and hydrological regimes. Variability of snow conditions and temperatures have forced Inuit to adapt their winter camps. The construction of igloos is now more difficult and uncertain, having led them to replace their traditional shelters with tents.

Communities can travel across the tundra only with great difficulty in December and January due to strong winds that blow the snow away, leaving the ground bare. As such, the use of snowmobiles becomes highly impractical.

Snow protects the ice in bays and lakes, and reduces melting in the springtime. The loss of ice during this period of makes daily travel during hunting excursions increasingly difficult.

Permafrost melting

In addition to ice melt, caused by increased temperatures and longer warm seasons, climate warming is also responsible for the degradation of soils.

The recent sedentarization of Inuit and other northern indigenous communities has forced the establishment of permanent communities, complete with housing, schools, airports, and businesses. Most infrastructures have been built on ground that is permanently frozen. The degradation of permafrost threatens the integrity of these infrastructures, and forces the communities to address the challenge of construction on unstable ground and to rethink their existing development plans, to the point of even relocating existing structures.

When relocations are necessary, they can have serious repercussion on the health of the people involved. These people must adapt to a new environment as well as new hunting territories, increasing stress on both individuals and on the community as a whole.

Health of northern populations

Climate change has both direct and indirect effects on the health of northern populations.

Direct effects on health are due to unusual climate conditions, such as elevated temperatures, heavy precipitation, and natural disasters (e.g., landslides).

Indirect effects are numerous. Most apparent is the increase in number of accidents and the resulting physical injuries. Food resources are less abundant and of lower quality, and local foods are being replaced by imported products. More sedentary lifestyles with increased use of motorized vehicles, along with poor nutrition, are leading to widespread degradation in quality of life, contributing to increasing rates of obesity and diabetes.

The number of biting insects is increasing and new species are appearing. It is becoming necessary to protect oneself with the help of appropriate protective gear, mosquito nets, insect repellants, and insecticides. Exposure to water- and foodborne pathogens is another aspect that can compromise the health of northern communities. Traditional methods of meat preparation (raw or fermented), are no longer adapted to new environmental conditions. Communities are therefore more exposed to the development of various zoonoses and parasitic diseases.

Food security: hunting, fishing, and gathering

Wildlife is also subject to the effects of climate change. The behaviour of animals can be affected, as well as their distributional ranges and migrations. This challenges the food security of populations that depend heavily on the use of natural resources. Members of some communities have noticed an increase in diseased animals, without being certain of the cause of the problem: pollution and/or climate change. Some trappers have observed changes at the level of fur quality, which they take to be an indication of the animal's health as a response to climate change.

Northern communities must coordinate their hunting seasons with the seasonal abundance of different prey, while making sure that environmental conditions are safe for the necessary activities, especially for those that take place on the ice. We know that the migration of caribou depends on the availability of the plants and lichens on which they feed. Modifications to plant phenology will change the migratory behaviour of animals as well as their abundance. Warming during winter can create a layer of ice which, by covering lichens and mosses, can deprive caribou of their food of choice, and cause widespread mortality in their populations. Hunting of snow geese is a traditional practice that provides an important source of food for the Cree. Climate change may affect geese populations (e.g., quantity, quality, migration) and their use.

Throughout northern Québec, hunters are observing lower rates of success in their normal hunting grounds. They must adapt their practices and in some cases, may be forced to reduce their consumption of caribou meat.

Nevertheless, hunters do recognize that there are some advantages to the changing climate, for example, an increase in muskox populations. Another positive aspect noticed by hunters is a lengthening in the duration of the ice-free period, facilitating fishing and marine mammal hunting in open-water, as well as water travel. Like hunting, fishing is a subsistence activity culturally rooted in the daily lives of northern communities.

River systems depend on ice melt as well as on precipitation in the form of snow, and these therefore influence the presence and abundance of sought-after species. Inuit have stated that some of their lakes and rivers have very low levels, to the point of even disappearing completely.

Declines in water levels negatively affect fish health and the movement of species returning in rivers, such as Arctic char and salmon. Rising temperatures in aquatic environments are modifying the distribution of fish species. Cold-water species may face difficulties surviving the changing environmental conditions, whereas species preferring more temperate waters could be favoured.

Furthermore, climate warming could also have a major impact on the production of fruits, an important food source for many animal species and human communities. Berry picking is undoubtedly a food source of high nutritional quality, as well as being an important cultural and economic activity for northern communities. Northern peoples who use plants for various purposes (medicinal, food, and others) will have to adapt their practices based on changing vegetation.

Furthermore, Inuit are finding that sources of potable water are becoming scarce and of poorer quality. These days, most people planning their travels think about taking drinking water and extra food rations with them because of the unpredictability of weather conditions.

Adaptation to climate change

If governmental action plans are designed, elaborated, and implemented at international, national, and provincial levels to facilitate adaptations to climate change, specific measures will still need to be adopted at a more local scale, given the diversity of environmental, historical, social, political, and economic contexts. Because of their close ties to the environment, Inuit are best placed to recognize the magnitude of disturbances affecting the Arctic.

As the Arctic environment undergoes significant changes due to climate change, there will be important repercussion on community lifestyles. Inuit have no choice but to adapt their way of life, especially their hunting and fishing practices. This will inevitably lead to loss of traditions and current local knowledge, as they fade with the disappearance of the past environmental conditions on which they were based.

The capacity for adaptation depends on multiple factors, such as geographic, social, economic and institutional, to mention but a few (Table 2).

Definition of adaptive capacity

Adaptive capacity corresponds to the potential, means, or capacity of a system (country, region, community, economic sector, private enterprise) to adapt to environmental changes and their effects and impacts (Lemmen *et al.*, 2008).

Table 2 : Similarities of observations made by Inuit of northern Canadian regions with possible impacts and adaptations (adapted from Nickels *et al*., 2005).

Observations	Impacts	Adaptations
Unpredictable weather	• Elders lose confidence in their abilities to predict temperatures • Travel and hunting have become more dangerous • Difficulty obtaining certain species (less hunting, meaning less traditional foods)	• Increased communication when travelling (itineraries, dangerous routes) • Use of community freezers • Rise in number of camps outside of villages • Exchange and sharing of traditional foods
Some marine and terrestrial species are leaner, more animals are sick and have abnormalities	• Fewer animals are available as food sources	• Selection must be made regarding which individuals are fit for consumption • Exchange and sharing of traditional foods among communities
Reduced precipitation in the form of snow	• Makes travel by snowmobile difficult • Construction of igloos more difficult • Difficulties travelling to certain places • Impacts on lakes and rivers	• New routes, sometimes longer, must be sought out
Lower water levels (in all regions except Nunavut)	• Increased algae in the water • Increased sedimentation • Concerns about drinking water from natural sources • Increased difficulty of travel • Difficulties for some fish (e.g., Arctic char) • Drying of some waterways and wetlands	• Snow is melted for consumption rather than using lake water • Improved water-treatment systems are necessary • Dredging and river diversions for char (in Nunavik)
Rise in winter temperatures	• Permafrost melting • Observations of bird and other animal species from “the south” • Food doesn’t keep as long • Lower quality of animal furs • Less snow, thinner ice, early thawing and late freezing of ice	• Longer routes must be taken, longer time required for travel (less snow, early melting of ice and permafrost) • Food must be stored more quickly

Integrating communities in the decision-making process remains of utmost importance in order to target different issues and to develop tools to allow communities to manage their adaptation to climate change.

Research is essential to the adaptation process of Inuit communities to target their short- and long-term needs. It is important to acquire environmental, historical, and social knowledge, and to develop tools in collaboration with the communities involved (Figure 4).

Furthermore, education is as much a priority for the dissemination of acquired information as it is to permit communities to take charge of their process of adaptation. Governments thus have some significant challenges ahead of them in matters of education as well as in the conservation of natural resources, and co-management of wildlife and its sustainable use (Figure 5).

The challenges of resilience

More concretely, Inuit are modifying their daily practices with respect to the many environmental changes northern regions are undergoing: replacing use of igloos with tents; use of GPS for navigation during outings and for hunting; use of larger and more powerful boats in order to be able to change location more quickly in high wind conditions; use of snowmobiles for winter travel; and freezing hunted meat in specialized facilities because of the uncertainty of outside freezing temperatures.

This represents both a loss of cultural practices and a significant economic impact which some families cannot afford, although these technologies are necessary to ensure their food security.

With environmental conditions becoming more and more unpredictable, traditional knowledge becomes less reliable with regards to its predictive ability. Outings on the land are more dangerous because of the risk of accidents. According to research by search and rescue groups, a rapid intervention between 24 to 48 hours can mean the difference between life or death. Reduction in the frequency of being out on the land also has grave repercussions on communities (alcoholism, depression, and suicide). Thus, the use of modern methods of weather prediction is becoming more widespread, despite gaps in existing meteorological data for northern regions.

Figure 4 : Diagram showing the interrelationship between science and traditional knowledge regarding adaptation to climate change by First Nations. It identifies the importance of the link and intergenerational transfer between Elders and youth for maintenance of their cultural identity and in order to better respond to changes (Downing & Cuerrier, 2011).

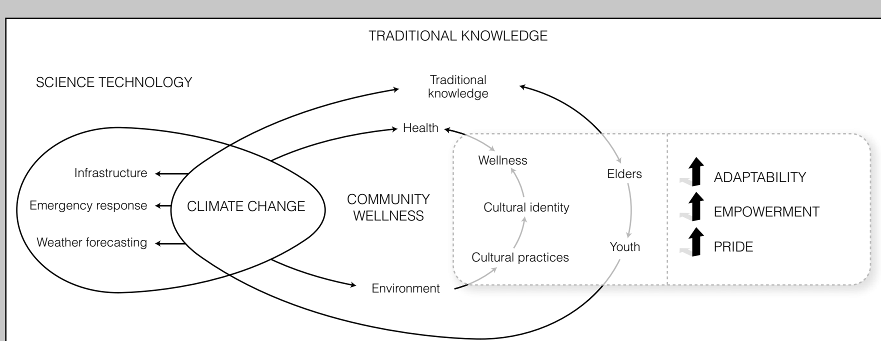
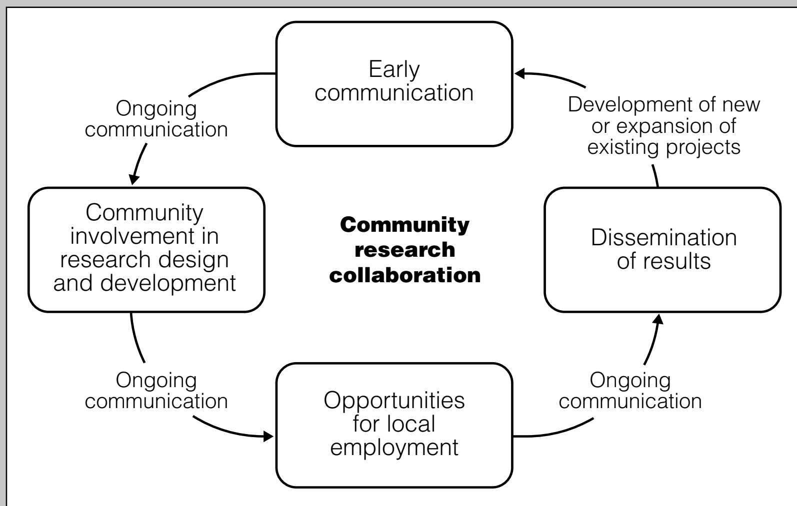


Figure 5 : Considerations and steps to take to facilitate the collaboration of Inuit communities in scientific research (adapted from Pearce *et al.* 2009).



At present, there is consensus that the resilience of traditional practices is essential for northern communities. However, this is a tall order given that adaptation must take place in a context where, although necessary to help communities adapt to the changes facing them, the use of modern technologies comes at the expense of traditional practices.

Conclusions

The impacts of climate change will have significant effects on entire ecosystems, and will directly and indirectly affect Inuit and aboriginal communities that depend on the use of natural resources.

Climatic variations will influence the availability and quality of various animal and plant species. Furthermore, changes to ecosystem functions, ice melt, permafrost deterioration, and changes to snow cover will have significant impacts on built infrastructures.

All these disturbances affect the lifestyles of northern populations, who must adapt their traditional practices. The direct and indirect impacts of warming are leading to the emergence of new social, cultural, economic, and human health problems. To address this crisis, communication between different stakeholders is fundamental to elaborate plans for intervention and to take effective measures to minimize the impacts of climate change on northern communities.

In order to ensure the success of different adaptation schemas that could be adopted by First Nations and Inuit, their participation remains essential.

It is by forming a close collaboration between parties, while developing a feeling of autonomy and responsibility in their own governance that the Inuit, Innu, Naskapi, and Cree people, as well as other local populations will be able to persist and remain resilient to the changes at work in what has been dubbed “la nordicité québécoise”.

References

Downing A. and Cuerrier A.. 2011. *A synthesis of the impacts of climate change on the First Nations and Inuit of Canada.* Indian Journal of Traditional knowledge. 10 (1): 57-70.

Ford J.D., Pearce T., Prno J., Duerden F., Berrang Ford L., Beaumier M. and Smith T. 2010. *Perceptions of climate change risks in primary resource use industries: a survey of the Canadian mining sector.* Regional Environment Change, 10:65–81

Lemmen D. S., Warren F. J., Lacroix, J. et Bush, E. 2008. Vivre avec les changements climatiques au Canada: édition 2007. 2007 ed. Ottawa (Ontario): Gouvernement du Canada.

Nickels S., Furgal C., Buell M. and Moquin H. 2005. *Unikkaaqatigiit – Putting the Human Face on Climate Change: Perspectives from Inuit in Canada.* Ottawa: Joint publication of Inuit Tapiriit Kanatami, Nasivvik Centre for Inuit Health and Changing Environments at Université Laval and the Ajunnginiq Centre at the National Aboriginal Health Organization.

Pearce T. D., Ford J. D., Laidler G.J., Smit B., Duerden F., Allarut M., Andrachuk M., Baryluk S., Dialla A., Elee P., Goose A., Ikummaq T., Joamie E., Kataoyak F., Loring E., Meakin S., Nickels S., Shappa K., Shirley J., and Wandel J. 2009. *Community collaboration and climate change research in the Canadian Arctic.* Polar Research 28: 10–27

Tyler N.J.C, Turi J.M., Sundset M.A., Strøm Bull K., Sara M.N., Reinert E., Oskal N., Nellemann C., McCarthy J.J., Mathiesen, S.D., Martello M.L., Magga O.H., Hovelsrud G.K., Hanssen-Bauer I., Eira N.I., Eira I.M.G., and Corell R.W. 2007. *Saami reindeer pastoralism under climate change: Applying a generalized framework for vulnerability studies to a sub-arctic social–ecological system.* Global Environmental Change 17: 191–206

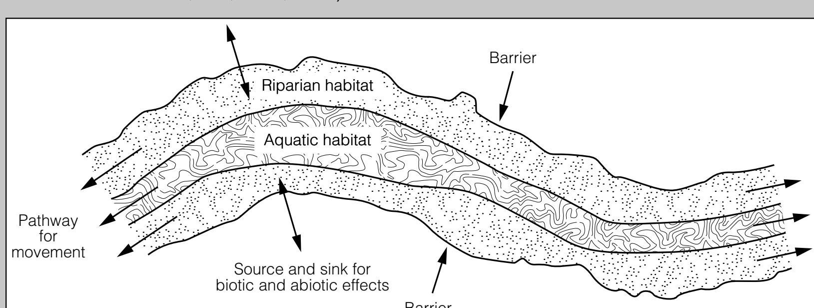
Ecological corridors and their role in the mitigation of the impacts of climate change

Roles and functions of ecological corridors

The creation of ecological corridors is a key element ensuring landscape connectivity, especially in environments disturbed by anthropogenic activities and land use (e.g., forestry, agriculture) or in the creation of protected areas. Sometimes these activities lead to loss of habitat, fragmenting the landscape and reducing community connectivity. Corridors can act as bridges between large expanses of similar or different habitats. There are countless examples of the effects of corridors, but the most common are habitat effects and creation of “passages” for mammals, birds, and terrestrial insects. Corridors thus have the potential to influence the migration and dispersal success of animal and plant species by facilitating their movement across the landscape. For animal species, this includes daily movements between areas used for nesting and for food, as well as longer-distance annual migrations, and even migrations intrinsic to the life cycles of certain species. For non-mobile species, such as plants, corridors can affect their dispersion in two ways: they influence the movement of animal species important to the life cycles of plants and to the dispersion of their seeds, such as insect pollinators; and they can create environmental conditions and habitat types necessary for seed germination and survival of the plant. River banks play the same role; these riparian habitats facilitate the dispersion of aquatic plants along streams and rivers (Figure 6).

Anthropogenic structures, such as roads, power lines, drainage ravines, dams, artificial wetlands, and all other linear networks can also be considered to be “corridors”. That is, these types of structures can act as dispersal corridors, particularly for species with rapid successional rates and for exotic invasive species. However, these artificial corridors seem to be in complete opposition to the concept of ecological corridors as fragments linking habitat patches, since they often have a disruptive rather than beneficial effect on the natural environment.

Figure 6 : Example of a corridor formed by a waterway with its different zones and their respective functions: riparian habitat suitable for plants and animals; pathway effects that influence movement trajectories of some animals; and source or sink effects on interactions with the surrounding environment. The fence effect of corridors is not shown here. (based on Bennett, A.F., 1998, 2003)



Generally, corridors allow individuals to access a greater area of habitat, potentially providing better access to necessary resources. The influence of corridors on individual survival, reproduction, and mortality can increase the persistence of populations in fragmented habitats. Ideally, in a conservation context, improvements brought to landscapes by corridors due to their favourable effects on the persistence of populations also reduce the risks of extinction of the species present. Conversely, corridors can also have negative effects. For example, they may facilitate the spread of invasive exotic species and disease vector species. Additionally, corridors influence the spread of fire and other abiotic disturbances between habitat patches, exposing native species to predation, domestic animals, and poaching.

Corridor functions

Corridors – linear patches of habitat that link large areas of the same habitat – can have several effects:

- At the most basic level, corridors can act directly as habitat patches, without even taking into account their role of providing connectivity to the landscape. This habitat effect depends on the characteristics of the species and of the corridor.
- Pathway effects favour and increase the rate at which individuals of a species can move between habitat patches within a territory.
- Barrier effects act in a manner opposite to pathway effects. In this case, natural or anthropogenic corridors block or hinder the movements of individuals in a territory between patches of suitable habitat.
- Corridors can also act as fences; when individuals encounter these fences, they are directed by the corridors toward connected habitat patches. In this case, the corridor is not directly used by the individual, but it does influence the individual's movement.
- Corridors interact with the surrounding matrix as sources or sinks for environmental or biological effects, often acting as both source and sink for different species and effects.

Corridors and land use

Changes in land use have the most important direct impacts on biodiversity and landscape connectivity. In agricultural landscapes, the usefulness of corridors depends on the types of agricultural practice and on historic patterns of land use. In these regions, corridors often represent strips of relatively stable land in a changing matrix of agricultural land (Figure7). The agro-ecosystemic approach incorporates non-productive areas as windbreaks and recognizes the importance of ecological services and the direct benefits on agricultural productivity provided by the biodiversity associated with these corridors.

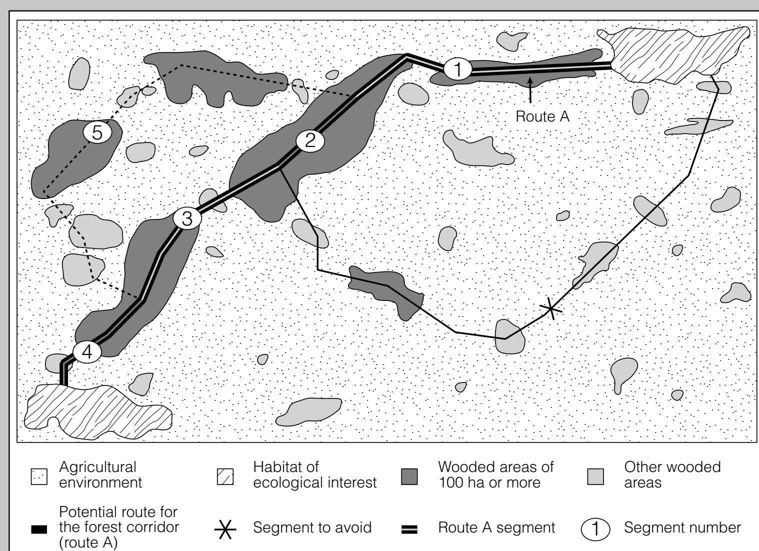
Several initiatives for planning and protecting corridors are underway in Québec, particularly in the south of the province, which is dominated by farmland and urban areas (see the Monteregian example cited below). Southern Quebec contains both the highest levels of biodiversity as well as the greatest number of species threatened by fragmentation and land use of the whole province.

In urban and semi-urban landscapes, corridors sometimes represent the only natural habitats available for many species. These corridor networks have been dubbed “greenbelts” and are often managed for various uses, such as conservation, recreational and tourism activities, and for their aesthetic value. Greenbelts increase the rate of contact between humans and wildlife, while at the same time playing their role as habitat for wildlife. These corridors have the tendency to increase the quality of life of residents, as well as nearby property value. However, some conflicts may arise due to the negative impacts caused by recreational use of corridors and the potential threats to the safety of residents living close by.

In order to ensure successful establishment of new corridors, as well as the maintenance of the environmental role of existing corridors, several recommendations and procedures to follow have been suggested:

- Establish objectives for corridor projects, including their function, priority species, and interactions with adjacent lands;
- Analyze and integrate geographic, ecological, social, economic, and climate projection data to identify potential sites;
- Apply the concept of "corridor design" with formal methodologies, such as graph theory, least-cost path analysis, multipath analysis, redundancy analysis, and multi-criteria decision analysis;
- Take into account the age of existing corridors, as well as their physical characteristics (size, width, length, presence of interruptions, level of connectivity, general structure) in order to assess their usefulness and functionality;
- Identify key partners; encourage their participation as well as the participation of involved local parties, and publicize the benefits of the presence of the corridor.
- Establish monitoring programs to evaluate the short term effectiveness of the corridor network, and allow long term adaptive management.

Figure 7 : Example of a segmented forest corridor in an agricultural landscape (based on Duchesne, 1999)



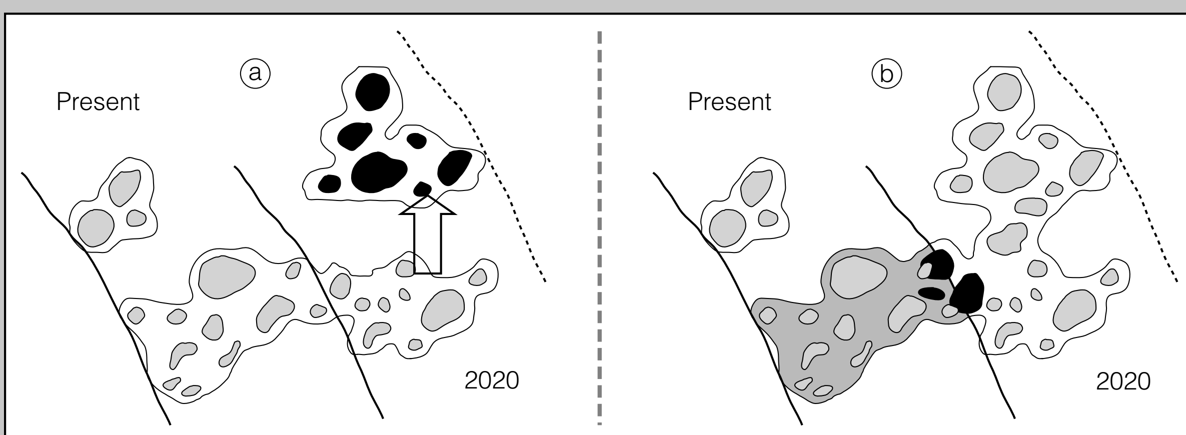
Corridors in the context of climate change

Corridors can promote the diversity of species present in landscapes and in fragmented patches, leading to a general increase in the biodiversity, resilience and stability of ecosystems, and in return, allow ecosystem services to be maintained under changing environmental conditions.

The value of corridors can be measured in both economic and ecological terms. The conservation value of a corridor can vary depending on its intended purpose and how its success is measured. The potential benefits are even more important today in the context of climate change, given the negative effects that anthropogenic disturbances are having on natural systems and their functions. It is predicted that the distributional ranges of most species will shift towards the poles and to higher altitudes in response to climate change. Such a shift in species ranges requires the movement of individuals across the territory, a process made more difficult when habitats are fragmented. Thus, corridors are often proposed as a remedial strategy against the effects of climate change on biodiversity and on ecosystems, since they have potential to facilitate the migrations of individuals (Figure8). The "pathway" effect of corridors is therefore important at a very large scale, and in this case they must be oriented parallel to the predicted gradients of climate change in order to fully fulfill their role (of facilitating the movement of species) and to achieve the targeted goal (mitigation of climate change). Corridors may equally serve on a smaller scale by facilitating the movement of less-mobile species between different habitats or local microclimates.

The effectiveness of corridors as mitigators of climate change will depend strongly on how the distributional ranges of species change, based on changes to the processes and directions of dispersal, and how these ranges will be affected by corridors. Large-scale changes in species distributions, associated with past and present climate changes, will likely require a reorganization of communities and will result in changes in biodiversity. This has implications for conservation goals and how these are measured. If we accept the role human activities play in such changes to biodiversity, corridors should be established using local species, or those thought to be able to adapt to future conditions.

Figure 8 : Graphical representation of the links between networks resilient to climate change: (a) Although the network in black becomes available in 2020, it is not resilient to climate change because it is too isolated to become colonized. The arrow indicates the area for study of adaptation measures. (b) The shaded zones indicate overlap in the habitat network between two successive climate situations. The colonizing capacity is improved by creation of new habitat patches or by enlarging the existing patches in the overlapping zones (areas in black). (Based on Vos *et al.*, 2008)



Use of lands in the context of climate change necessarily means the loss and fragmentation of habitats, limiting the capacity of species to move in search of more optimal conditions. For this reason, large-scale landscape planning is crucial. This planning must include the elaboration of local and regional projects, with the support of the local communities involved, so that the creation of the corridor serves as a management tool and fully fills its role in reducing the impacts of climate change and preventing the negative impacts of landscape fragmentation on ecosystems and biodiversity.

Examples of corridor projects at the regional scale

Two Countries, One Forest (Canada and United States)

Two Countries, One Forest (2C1Forest) is a major Canada-U.S. collaborative, involving more than 50 conservation organizations, whose primary goal is to maintain the Northern Appalachian Acadian Ecoregion. The ecoregion spans two countries, five states, and four provinces; it contains rare alpine vegetation, at-risk species, old-growth forests and 5.4 million people. The main concern in terms of conservation is that the region risks being separated into a series of ecological islands. This project aims to reduce negative effects through establishment of habitat corridors.

Southern Ontario Greenbelt

The Southern Ontario Greenbelt initiative was launched in 2005 and aims to prevent urban sprawl, protect farmland and watersheds, and to provide recreational activities. It covers approximately 7300 km^2 (1.8 million acres) of countryside and over 7000 of the most productive farms in Ontario. The greenbelt roughly consists of a ring around the Golden Horseshoe region of Lake Ontario, a region noteworthy for its size and proximity to the most populous urban area in Canada.

La Mauricie (Québec)

The *Mouvement vert Mauricie* submitted a report to the Mauricie Regional Conference of Elected Officials (Conférence Régionale des élus de la Mauricie - CRÉ-Mauricie) outlining proposed protected areas and biodiversity corridors in the region of Mauricie. This proposal complemented and improved upon the existing protected areas of the region, such as the Parc national de la Mauricie, and its surrounding areas. The corridors were specifically identified to link existing and proposed protected areas, taking into account built infrastructures such as aquatic corridors, elevated areas and railroads, while avoiding anthropogenic disturbances.

La Montérégie (Québec)

Various conservation groups, as well as government ministries and regional and municipal authorities, are in an active phase of research, planning, and exploration regarding the role of corridors in this southern rural region of Québec. Corridors have been proposed to increase the quality and quantity of forest habitats and to improve connectivity between protected areas, including Mont Saint-Hilaire, Mont Saint-Bruno, and others. Many groups have identified a minimum threshold of 30% forest cover to avoid severe loss of biodiversity, while the current forest cover is estimated to only be between 20 to 30%, and even lower in some municipalities. Recently the Nature Centre of Mont Saint-Hilaire produced a forest corridor plan for the Richelieu River region, linking the Gault Nature Reserve and Lac Saint-Pierre. This plan not only outlines the main methodologies for use of GIS in the selection of priority sites, but also recommends actions for the various levels of government as well as local community stakeholders.

A unified "Blue-Green Network" in the Metropolitan Community of Quebec (Communauté métropolitaine de Québec)

The *Communauté métropolitaine de Québec* (CMQ) recently planned a project described as a "blue-green network", referring to the combination of watersheds and green spaces. The goal of such a network is to continue the development of the city of Quebec as a "cultural and environmental capital" of the province, with an emphasis on sustainable development. The report uses a hierarchical classification of important elements; the network would include "blue" elements (streams, rivers, lakes, wetlands, etc.) as well as "green" ones (forests, farmlands, recreational parks, protected areas, etc.), in addition to recreational pathways (pedestrian and cycling trails, canals, and waterways). One of the explicit goals is to develop the recreational and tourism potential of green spaces by developing points of access to the network for the public, and by linking the existing recreational parks to a larger network of "green" and "blue" spaces.

References

Bennett, A.F. 2003. *Linkages in the Landscape: The Role of Corridors and Connectivity in Wildlife Conservation.* IUCN, Gland, Switzerland and Cambridge, UK. 254 pp.

Duchesne S., Bélanger L., Grenier M. et Hone, F. 1999. *Guide to Conserving Forest Corridors in an Agricultural Environment.* Saint-Nicolas, Québec: Fondation Les oiseleurs du Québec Inc.

Vos, C.C., Berry P., Opdam P., Baveco H., Nijhof B., O'Hanley J., Bell C. et Kuipers H. 2008. *Adapting landscapes to climate change: examples of climate-proof ecosystem networks and priority adaptation zones.* Journal of Applied Ecology, 45: 1722-1731.

Editors

Quebec Centre for Biodiversity Science (QCBS)

The QCBS is an inter-university network of more than 80 researchers from 8 academic institutions (Bishop's University, Concordia University, McGill University, l'Université de Montréal, l'Université du Québec à Montréal, l'Université du Québec à Rimouski, l'Université Laval, and l'Université de Sherbrooke) and two public organizations (Montreal Botanical Garden and Agriculture and Agri-Food Canada).

The objective of the QCBS is to foster the development of an integrated biodiversity science within Quebec by ensuring the promotion of an international research program at all academic levels (undergraduate, masters, PhD, and post-doctorate), and by facilitating scientific cooperation within a multidisciplinary group of researchers, in order to assume a leading role in academic and public debates on the loss of biodiversity in Quebec, Canada, and abroad. As a result, the QCBS is currently and will continue to be a natural partner of the MDDEP in the form of research projects, as future leaders in biodiversity science continue to be trained in the labs of QCSB researchers.

OURANOS, Consortium on Regional Climatology and Adaptation to Climate Change

Created in 2001, Ouranos was born out of a common vision between the Gouvernement du Québec, Hydro-Québec, and Environment Canada, with financial support from Valorisation-Recherche-Québec, to provide Quebec and Canada with an organization capable of ensuring the complementarity of climate science and the adaptation needs of a society faced with increasing climatic change. La mission d'Ouranos consiste à acquérir et développer les connaissances sur les changements climatiques et sur leurs impacts, ainsi que sur les vulnérabilités socioéconomiques et environnementales. L'objectif est d'informer les décideurs sur l'évolution du climat et de les conseiller pour identifier, évaluer, promouvoir et mettre en œuvre des stratégies d'adaptation locales et régionales. Ouranos' mission is to acquire and develop knowledge on climate change, its impact and related socioeconomic and environmental vulnerabilities, The objective is to inform decision makers about probable climate trends and advise them on identifying, assessing, promoting and implementing local and regional adaptation strategies. For the mission to be completed, Ouranos implemented various research programs regarding impacts and adaptation, including a program on ecosystems and biodiversity (EcoBioCC).

Ministère du Développement durable, de l'Environnement et des Parcs (MDDEP)

The mission of the Ministère du Développement durable, de l'Environnement et des Parcs (MDDEP) is the protection of the environment and the conservation of biodiversity in order to improve the quality of life of its citizens. As one of its major responsibilities to citizens and partners, the MDDEP is committed to fostering respect for the environment (land, water, and air) and natural heritage (ecosystems and species) in order to contribute to sustainable development, in collaboration with its partners.

EDITORS

Québec Centre for Biodiversity Science (QCBS)

McGill University, Department of Biology, W6/19
Stewart Biological Sciences Building
1205, Dr. Penfield Avenue
Montréal (Québec) H3A 1B1
Telephone : (514) 398-8719
Fax : (514) 398-5069
E-mail : philippe.auzel@mcgill.ca
Web Site : http://qcbs.ca/

OURANOS

550, Sherbrooke West Road
West Tower, 19th Floor
Montréal (Québec) H3A 1B9
Telephone : (514) 282 6464
Fax : (514) 282 7131
Web Site : http://www.ouranos.ca/

Ministère du Développement Durable, de l'Environnement et des Parcs (MDDEP)

Direction du Patrimoine Écologique et des Parcs (DPÉP)
Service de l'Expertise en Biodiversité (SEB)
Marie-Guyart Building, 4th Floor, Box 21
675, René-Lévesque East Boulevard
Québec (Québec) G1R 5V7
Telephone : (418) 521-3907
Fax : (418) 646-6169
Web Site : http://www.mddep.gouv.qc.ca/