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SPECIES AND AREAS UNDER PROTECTION: CHALLENGES AND OPPORTUNITIES FOR THE CANADIAN NORTHERN CORRIDOR

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FOREWORD

THE CANADIAN NORTHERN CORRIDOR RESEARCH PROGRAM PAPER SERIES

This paper is part of a special series in *The School of Public Policy Publications,* investigating a concept that would connect the nation's southern infrastructure to a new series of corridors across middle and northern Canada. This paper is an output of the Canadian Northern Corridor Research Program.

The Canadian Northern Corridor Research Program at The School of Public Policy, University of Calgary, is the leading platform for information and analysis on the feasibility, desirability, and acceptability of a connected series of infrastructure corridors throughout Canada. Endorsed by the Senate of Canada, this work responds to the Council of the Federation's July 2019 call for informed discussion of pan-Canadian economic corridors as a key input to strengthening growth across Canada and "a strong, sustainable and environmentally responsible economy." This Research Program will benefit all Canadians, providing recommendations to advance the infrastructure planning and development process in Canada.

This paper, "Species and Areas Under Protection: Challenges and Opportunities for the Canadian Northern Corridor", falls under theme *Environmental Impact* of the program's eight research themes:

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KEY MESSAGES

The key findings and recommendations of this review are:

There is a global biodiversity crisis, and many of the threats to biodiversity are present in northern Canada. At a high level, these include habitat loss, degradation and fragmentation, climate change, overharvesting, pollution and the spread of non-native species.

A multi-modal transportation corridor will likely exacerbate many of these threats. For example, roads, pipelines and railways physically fragment ecosystems and habitats, lead to significant mortality in diverse animal groups (road and railways), indirectly contribute to climate change through the transport of non-renewable resources, increase salt, heavy metal, and/or sediment loads on nearby habitats and facilitate the arrival and spread of exotic species.

Some species, such as the boreal caribou, will require special consideration by CNC proponents. The current range of boreal caribou significantly overlaps with the proposed route, and many of the identified threats are relevant to the CNC, including increased predation facilitated by anthropogenic habitat disturbance (e.g., forestry, roads and other linear features), illegal and unregulated hunting, noise and light disturbance, vehicle collisions and pollution.

Federal Acts relevant to the CNC from a biodiversity conservation perspective include the *Canadian Wildlife Act*, *Species at Risk Act*, and *Impact Assessment Act*. The domains of these Acts are protected areas and critical habitats, protection of threatened species and mitigation of adverse environmental impacts of projects, respectively.

The extent of intact forests and roadless areas is shrinking around the world. The proposed route is (unsurprisingly) mostly within Canada's reservoir of roadless areas. Accordingly, the CNC stands to negatively impact Canada's status as holding a significant portion of the world's remaining ecologically intact areas.

The development of the CNC will likely lead to the proliferation of other infrastructure. This phenomenon of growth-inducing infrastructure means that the realized extent of negative cumulative impacts on biodiversity will only grow with time.

The opportunities associated with the CNC are largely in the areas of mitigating its impacts on biodiversity and increasing Western science's knowledge of the health of northern ecosystems. There is a real opportunity for decades of research on wildlife crossing structures to be implemented in a deliberate and data-informed way, for increased monitoring of ecosystems and species in the North, and further research on a large number of topics (e.g., the efficacy of the *Impact Assessment Act* in protecting habitats and species at risk).

Indigenous Peoples must be equal partners throughout the entire CNC process. Without this, biodiversity conservation/ecosystem-based management will be unsuccessful. Wherever the CNC is not desired, deemed irrelevant, or unable to positively support culture and livelihoods, it should not be developed.

EXECUTIVE SUMMARY

The Canadian Northern Corridor (CNC) is a proposed multimodal transportation right-of-way, with accompanying infrastructure, that would run largely through northern Canada, with the goal of connecting all three coasts. Given the magnitude of the project, there are many implications for the lands and waterways, as well as for humans and other species in those areas, that the CNC will either intersect directly or affect indirectly through cascading effects.

This study used literature searches focused on the intersection of biodiversity, conservation research, government policies and engagement with Indigenous knowledge systems. Given the diversity of topics and the amount of research available in some areas (e.g., entire reviews have been written solely focused on the ecological effects of roads), this study highlights, rather than comprehensively treats, potential biodiversity challenges associated with the CNC. Biodiversity is a term that refers to the diversity (variability or complexity) of life, typically at one or more of the following levels: genes, species and ecosystem. Major development projects may: 1) reduce genetic diversity within species, 2) increase odds of species loss in the region, and 3) degrade the quality and extent of a variety of ecosystems.

Wetlands will be an important consideration for the CNC project. Wetlands are a globally threatened ecosystem, disappearing at roughly three times the rate as forests. Canada is known as a significant reservoir of fresh water, holding approximately 20 percent of the world's freshwater supply. Relevant to the CNC, more than half of this water drains northward into the Arctic Ocean and Hudson Bay. The dominant habitat that the CNC will traverse is the boreal forest, which holds 25 percent of the world's wetlands and 85 percent of Canada's wetlands. Geographical regions of concern are northern Ontario and northern Manitoba. The specific risks to wetlands from the CNC project include habitat loss and habitat fragmentation, which creates smaller populations isolated from other populations, leading to reduced probability of persistence through time, ultimately reducing biodiversity. Given their reliance on wetlands for breeding and early life development, amphibians may also be negatively impacted. Globally, amphibians are the most threatened vertebrates, mitigated somewhat by the fact that presently only two at-risk amphibian species have ranges projected to overlap with the CNC.

Connecting Canada's three coasts, and especially increasing traffic to three ports in the Arctic Ocean, carries with it the significant risk of increased opportunities for the invasion and spread of exotic (i.e., non-native) species. Globally, exotic species are recognized to be one of the main threats to native biodiversity, through their ability to introduce disease, prey on native species and compete for space, food and other resources. One major threat to the North would be via oceanic shipping from Atlantic and Pacific regions. Over land, increased traffic from southern locales, including the USA, would also pose a significant risk.

A critical potential negative impact of the CNC will be the suite of direct and indirect effects on plants and wildlife of roads, railways, powerlines, pipelines, culverts and bridges: direct mortality from collisions, reductions in movement associated with avoiding or having trouble crossing linear features (e.g., pipelines), and reductions in amount and quality of habitat. Mitigating these effects will be challenging because, for example, there is evidence that not only are different major groups of species differentially represented in vehicle collisions, but these rates can also differ significantly among closely related species. For impacts on movement patterns, there is evidence for contributions of sex, age and life history stage (e.g., juvenile vs. adult) of individuals. Finally, there are various road-related features that further degrade adjacent habitats, including noise, light and contaminant pollution. Powerlines and pipelines present the risk of electrocution and oil spills, respectively. Powerline cutlines may also be dominated by exotic plant species and lead to increased encounters between predators and prey, such as wolves and caribou.

The goal of the CNC is to better connect Canada's North and near-North regions to the rest of the country. However, in doing so, it runs the risk of reducing the total extent of roadless areas. A recent analysis of this issue concluded that Canada has a global responsibility to maintain and manage roadless areas, pointing out that keeping regions largely devoid of roads is one of the most effective ways to achieve our biodiversity-protection and climate-change commitments.

A related concern is a phenomenon dubbed "growth-inducing infrastructure"—namely, the tendency for an initial development to be the catalyst for additional non-incremental and transformative changes to the surrounding environment. For example, creating a cutline for a powerline may lead to the development of mines using the local and cheap electricity, which subsequently leads to increased logging and other activities. Similarly, a highway creates a need for gas stations, restaurants and lodging, which make legal and illicit hunting and angling more viable. The existence of a major corridor will also encourage connecting existing roads to the CNC, further reducing the extent of roadless areas.

Canada has a series of acts and regulations in place at federal, provincial and territorial levels to identify and protect species at risk of extinction, create wildlife areas for the preservation of wildlife, and assess and mitigate the environmental impacts of development projects. Through the process of searching the literature, I primarily encountered three federal Acts, although there are others relevant to the CNC, notably the *Migratory Birds Convention Act* and the *Fisheries Act*. The *Canada Wildlife Act* (*CWA 2017*) oversees the creation, management and protection of areas for wildlife research activities and conservation. Working together with the *Species at Risk Act* (*SARA 2002*), *CWA 2017* protects habitats critical for the long-term persistence of species, especially those that are considered at risk. Although the proposed CNC route does not look to intersect with many

Migratory Bird Sanctuaries or National Wildlife Areas, one notable area for consideration will be Edéhzhíe Protected Area in the Dehcho region of the Northwest Territories. Established in partnership between the Dehcho First Nations and the Government of Canada in 2018, it is noted for its great ecological, cultural and spiritual significance. The mandate of *SARA 2002* is to prevent the loss of wildlife species, guide the recovery of species that are locally extinct or at risk of being so and manage species of concern before their status further worsens. With reference to lists of species at risk for the various provinces and territories, I highlight seventy-nine at-risk wildlife species (primarily birds, mammals and fish) with ranges that potentially intersect with the CNC. Some of the more well-known species include the boreal caribou, polar bear, peregrine falcon, whooping crane and bull trout. A complication for the protection of species at risk in Canada is that *SARA 2002* provisions apply only to federally owned lands. Additionally, an independent assessment found that the federal government, provinces and territories are consistently underperforming in their obligations to protect species at risk. I recommend that CNC proponents treat such provisions as minimum but incomplete and go beyond them through engaging with local communities and Indigenous Peoples. Finally, the *Impact Assessment Act* (*IAA 2019*) is a federal process for assessing the potential impacts and preventing significant negative environmental effects of major projects. Given its scope and extent, the CNC will likely be a "designated activity," meaning that it will be subject to the *IAA 2019* five-phase process, which includes significant engagement with Indigenous Peoples and knowledge.

Indeed, authentic engagement and partnerships with Indigenous Peoples will be needed for all aspects of the CNC project to be a success, including biodiversity conversation and protection. Insights from Western science and Indigenous knowledge need to be treated as equally valid. In some areas, the two will be well aligned, whereas more dialogue will be needed in other instances. The former may apply in the case of preserving and protecting boreal caribou, whereas the latter is more likely with the tendency for Western science to prioritize areas based on various metrics (e.g., total evolutionary history present among the species in a region), which is not prevalent among Indigenous perspectives on biodiversity. Following the success of the Scientific Panel for Sustainable Forest Practices in Clayoquot Sound, I advocate the creation of an oversight scientific panel with strong representation from Elders and Knowledge Keepers as well as Western science practitioners.

While the proposed CNC presents a significant number of challenges for biodiversity conservation and preservation in Canada's North and near North, there are some potential opportunities. First, the CNC project will create opportunity and need to minimize wildlife-vehicle collisions and maintain connections between previously contiguous habitat patches. There is a very large amount of literature that can inform the correct use of fencing and wildlife crossings (e.g., highway overpasses); if utilized well, this evidence-based approach could yield additional insights and establish the CNC as a standard for similar projects. Second, it will create opportunities to monitor species and ecosystems. While it is hard to quantify the extent of data deficiency for species, watersheds in the North and near North appear overrepresented among those in Canada that are poorly monitored. Third, the development of the CNC potentially opens many avenues for research in the North, including insights into how best to mitigate effects of multimodal corridors on biodiversity. For example, additional research could be conducted on the efficacy of specialized overpasses in minimizing impacts on bats, with existing efforts to date largely based in

Europe. Finally, two interrelated major opportunities are that of improving Canada's poor record of action towards protecting biodiversity at all levels of government and suggesting revisions to various legislation, such as *IAA 2019* processes.

1. INTRODUCTION

Canada, a settler colonial state, is the second largest country by land area. There are approximately eighty thousand species of plants and animals, representing less than one percent of the estimated 8.7 million species worldwide. Of these, 308 plant and animal species are endemic to Canada (i.e., not naturally found elsewhere in the world). This diversity of species is supported in part by the great diversity of habitats, which includes deserts, temperate rainforests, prairies, high-elevation meadows and roughly 20 percent of the world's freshwater habitats (from puddles and bogs to some of the largest lakes in the world). Additionally, Canada's coastline is the longest in the world. Conversely, human population density is quite low. Furthermore, densities vary greatly in different parts of the country, with a full two-thirds of the population living within 100 km of the southern Canada-US border (representing 4 percent of total land area). Accordingly, transportation corridors and associated infrastructure are also very much non-randomly distributed. For example, much of the "main stem" Trans-Canada Highway is within 150 km of the US border from the east coast until the middle of Alberta. Generally, as one goes west and north, the number and density of major roads drops dramatically. This lack of transportation infrastructure, especially in northern Canada, has prompted the proposal to develop a Canadian Northern Corridor (CNC; Sulzenko and Fellows 2016, with Fellows et al. 2020 providing an updated discussion). The scale of the project is significant, estimated at 1 to 10 km wide and 7,000 km long, an area equivalent to the country of Georgia on the high end (Figure 1). As I discuss later, effects on biodiversity typically extend beyond the border of a road, power line, mine pit, etc. That is to say, it is difficult to predict the extent of impacts simply by looking at a map (see also Johnson et al. 2020). Because Canada is not shielded from the global biodiversity crisis (or the related climate change crisis), considerable research will be needed on the potential impacts of the CNC on species and protected areas in northern Canada.

Figure 1. CNC Notional Route

Source: Fellows et al. (2020)

This paper is part of a larger set of contributions related to the CNC, organized under nine research areas. Most relevant to this contribution are those categorized under (1) Environmental Impacts and (2) Geography and Engineering. I especially encourage reading Fawcett, Pearce and Ford (2020), Koch (2021) and Sidorova and Virla (2022), which address the relevant topics of climate change, Nordicity, and community-based environmental monitoring, respectively. The treatise on climate change especially influenced how I approached and framed this review, and we concur on many points, especially the need for meaningful engagement with Indigenous Peoples with regard to every kilometre and aspect of the CNC (see also Sidorova and Virla (2022), published subsequent to my review's completion).

This paper addresses four broad questions: (1) What is the current framework for operationalizing biodiversity conservation and preservation objectives in Canada, and what are the opportunities and challenges presented by this approach with regards to a pan-Canadian infrastructure corridor? (2) What are the specific biodiversity challenges in Canada's North (and near North) that will need to be considered within the context of the development and implementation of the CNC concept? (3) What are the key provisions relevant for the development and implementation of the CNC concept within various Canadian acts and regulations concerning species and areas under protection? (4) What are the opportunities presented by strategic and sustainable infrastructure investments for creating the resources required to monitor, conserve and manage the environment in Canada's North (and near North)? As successful and sustainable infrastructure development will require effective engagement and participation of Indigenous Peoples, the paper also addresses Indigenous stewardship of species, lands and waters.

2. METHODS

Given the breadth of the four questions, which focus on the intersection of topics as diverse as biodiversity, government policies and engagement with Indigenous knowledge systems, I did not attempt a systematic review of the literature in any area. With two research assistants (see acknowledgments), we used Web of Science, Google Scholar, University of Calgary Library's search function, and Google to search various combinations of terms. We did not record frequency of use, but common search terms include *Act*, *Arctic*, *assessment*, *biodiversity*, *development*, *ecological*, *ecology*, *ecosystems*, *impact*, *Indigenous*, *legislation*, *limitation*, *management*, *road(s*) and *wetlands*, with combinations such as: *"Indigenous + perspectives + biodiversity"*, *"biodiversity + roads"*, and *"ecological + impact + assessment*." Some sources were identified through following citations in sources identified by these searches. Regarding our third question, I am aware that additional relevant legislation exists e.g., the *Migratory Birds Convention Act* (Government of Canada 1994, last amended 2017; hereafter *MBCA 2017*) and the *Fisheries Act* (Government of Canada 1985, last amended 2019; hereafter *FA 2019*). Mindful of page limits, the focus on three Acts emerged from searches that focused on the passage referencing "regulations concerning species and areas under protection." Nevertheless, I expect that the CNC project will be impacted by provisions of *MBCA 2017* and *FA 2019* during the five-phase impact assessment phase of the *Impact Assessment Act*, and will likely require authorizations from Environment and Climate Change Canada and Fisheries and Oceans Canada, similar to the proposed Highway 413 Project that I discuss in greater detail in section 5.3.

3. OPERATIONALIZING BIODIVERSITY CONSERVATION

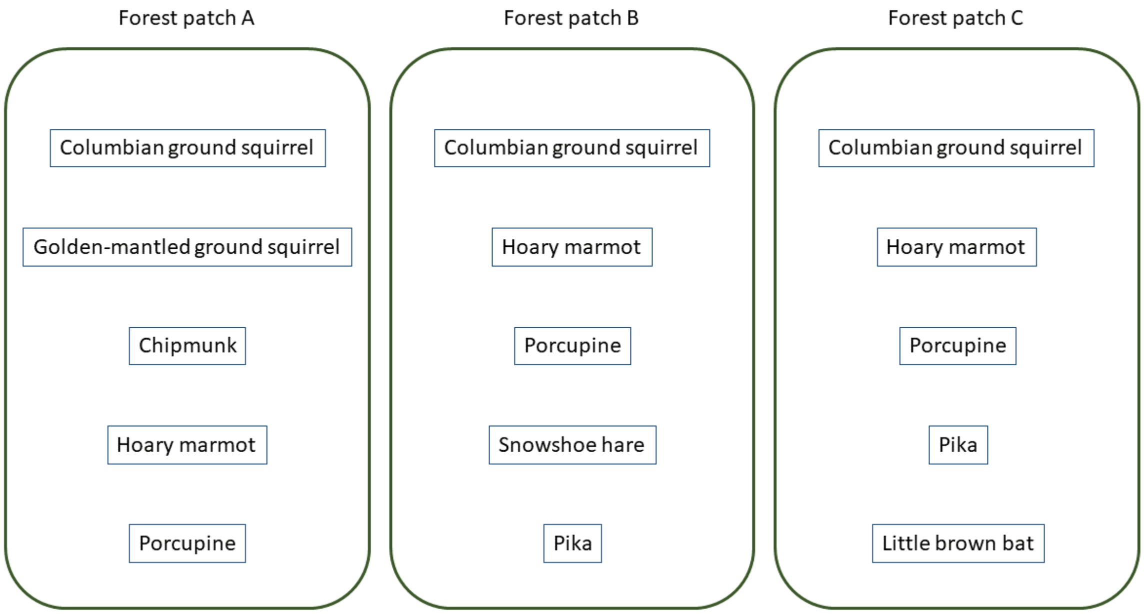
3.1 DEFINING BIODIVERSITY

Before I discuss frameworks for operationalizing biodiversity conservation and preservation objectives in Canada, a brief discussion of the concept of biodiversity is warranted. Biodiversity is a neologism and portmanteau, combining bio(logical) and diversity (see Sarkar (2002) for a discussion of the origins of the term). In its simplest formulation, it refers to the diversity of life, encompassing all units from molecules to ecosystems. The term can be applied at all hierarchical levels (alleles to individuals to populations to species, etc.) and also encompasses the diversity of interactions among them (e.g., predation, competition, etc.). This underlying complexity, compounded by disagreement regarding the validity of some of the hierarchical levels e.g., Hendry et al. (2000), can create issues for measurement and implementation of management and recovery plans. Additionally, there is a distinction between biodiversity (variability and complexity at every level of organization) and biological integrity (the functioning of ecosystems, which is maintained by maintaining biodiversity). While it is clear that maintaining biodiversity is important, operationalizing that goal requires targets. The standard way to deal with this is to approach the maintenance of biodiversity from three levels: genes, species and ecosystems. Complications arise when seeking to maintain hybrids or certain populations (e.g., migratory monarch butterflies), although these can be solved by approaching the maintenance of biodiversity as a function of place, which is actually maintaining features of a place that are relevant to the most biodiversity (Sarkar and Margules 2002).

3.2 EVOLUTIONARY HISTORY

A simple example illustrates how biodiversity conservation decisions might be made when phylogenetic diversity (in other words, evolutionary history) is incorporated (Figure 2). In this scenario, a development project has been proposed with the goal of identifying the patch with the lowest amount of biodiversity. Note that all three forest patches contain five species of small mammals, so species diversity alone is not helpful in this instance. In patch A, the five species are all members of the order Rodentia. Indeed, all species but the porcupine are in the Family Sciuridae (squirrels, including the chipmunk). In patch B, with the presence of snowshoe hare and pika, a new order (Lagomorpha) is represented. Finally, in patch C, there are now three orders represented, with three rodents, one lagomorph and one bat (Chiroptera). Even without considering that the little brown bat is Endangered, the order of prioritizing the three patches for protection from the development is: C > B > A. Of course, most real-world cases are more complicated, but the general principles of phylogenetic diversity (Barker 2002), which can be expanded to include within-species diversity (e.g., subspecies, herds, ecomorphs), and phylogenetic community structure (Vamosi et al. 2009) may be helpful in prioritizing otherwise comparably species-rich regions.

Figure 2. Three Hypothetical Forest Patches



Source: composed by author, with reference to a partial species list for small mammals in Kootenay National Park.

3.3 INDIGENOUS PERSPECTIVES ON BIODIVERSITY AND THE ENVIRONMENT

One caveat to the preceding discussion is that the whole concept of prioritizing species and areas to protect is rooted in Western ideals and science, which does not necessarily align neatly with Indigenous perspectives on biodiversity. Berkes and Davidson-Hunt (2006) illustrate this with reference to a workshop in which Shoal Lake Anishnaabe Elders were asked by the authors whether some plants (habitats) were more important than others. The context for this dialogue, comparable to the example described above, was a suggestion from the Ontario provincial government to manage productive forest lands for timber while designating others as protected (non-harvested) areas. Here I quote two passages from a narrative by Elder Dawn Green (see Box 2 of Berkes and Davidson-Hunt 2006):

> I take them out in the bush and show them where that plant is, because I won't be taking that with me. I like to leave it with the young people. That's what I do. I think that's how the teaching of our elders, a long time ago, that's how they did these things. It was passed on, passed on, generation to generation; whoever keeps it will take care of it and learn more about it. You never stop learning…right to the end. So, who are we to say what plants we need and those we don't. All of them should be kept for young people so they can go on learning.
>
> You asked me whether some bush is more important for plants we use than others. But you see, the Creator put everything on the earth for a reason, even if we don't know that reason. How can we decide which bush should stay and which should go?

Both perspectives will be important to hold while designing, building and maintaining the CNC. Incidentally, while the concept of "prioritizing" particular species or habitats represents one of many distinctions between Western science and traditional knowledge, this should not be taken as discouraging with regard to the CNC project. Many scholars, Indigenous and non-Indigenous, have talked and written about how the two may work together for mutual benefit in the areas of resource management, biodiversity conservation, and other such areas. Lertzman (2010), for example, makes a compelling case for the many benefits of bridging Western science and traditional knowledge for ecosystem-based management. The illustrated case is that of the Scientific Panel for Sustainable Forest Practices in Clayoquot Sound, which was convened in October 1993 in response to public reaction to the BC government's April 1993 decision about logging in Clayoquot Sound. The panel was co-chaired by Dr. Fred Bunnell (then Professor at the University of British Columbia) and Dr. Richard Alteo (Hereditary Chief, Ahousaht First Nation), with scientific panel members including three Nuu-Chah-Nulth Elders and a multidisciplinary team of (Western) scientists. Older readers will recall the escalating protests and blockades from 1984 to 1993, over ongoing and proposed logging (including clearcutting), with a series of prior negotiations having previously failed. By following a protocol informed by the Nuu-Chah-Nulth approach to group processes, the panel was able to collectively agree to a large number of general and guiding principles, which they believed would "make forest practices in the Clayoquot not only the best in the province, but the best in the world" (Clayoquot Sound Scientific Panel 1994). Because the spatial extent of the CNC is, of course, many times that of Clayoquot Sound, it is likely that multiple regional panels would be beneficial. Regardless, the success of the Scientific Panel for Sustainable Forest Practices in Clayoquot Sound provides a basis for optimism.

More recently, the calls are growing for incorporating Indigenous perspectives into biodiversity conservation/ecosystem-based management. Following from a series of dialogues, M'sɨt No'kmaq et al. (2021) introduce the concept of re-Indigenizing conservation, in Canada and beyond. Re-Indigenization provides a framework for transforming biodiversity conservation by respecting and amplifying Indigenous worldviews, languages, voices, stories, and insights, as well as natural laws (M'sɨt No'kmaq et al. 2021; for more on natural laws, see also Bastien 2004). Of relevance for the proponents of the CNC project, the authors introduce and elaborate on seven principles to guide a way forward for this work (see Table 1 of, and associated text in, M'sɨt No'kmaq et al. 2021). I do not list all those principles here, but note that many of them emphasize the importance of relationships, living on the land in a good way, respecting natural laws and treating Indigenous ways of knowing as equal to Western systems. The authors are conscientious about declaring that while the principles derived primarily from a Mi'kmaw worldview, they are common to diverse Indigenous worldviews. Certainly, the principles bring to mind the concept of ethical space (Ermine 2007) and teachings about natural laws that I have had the privilege to receive from Blackfoot Elder Dr. Reg Crowshoe.

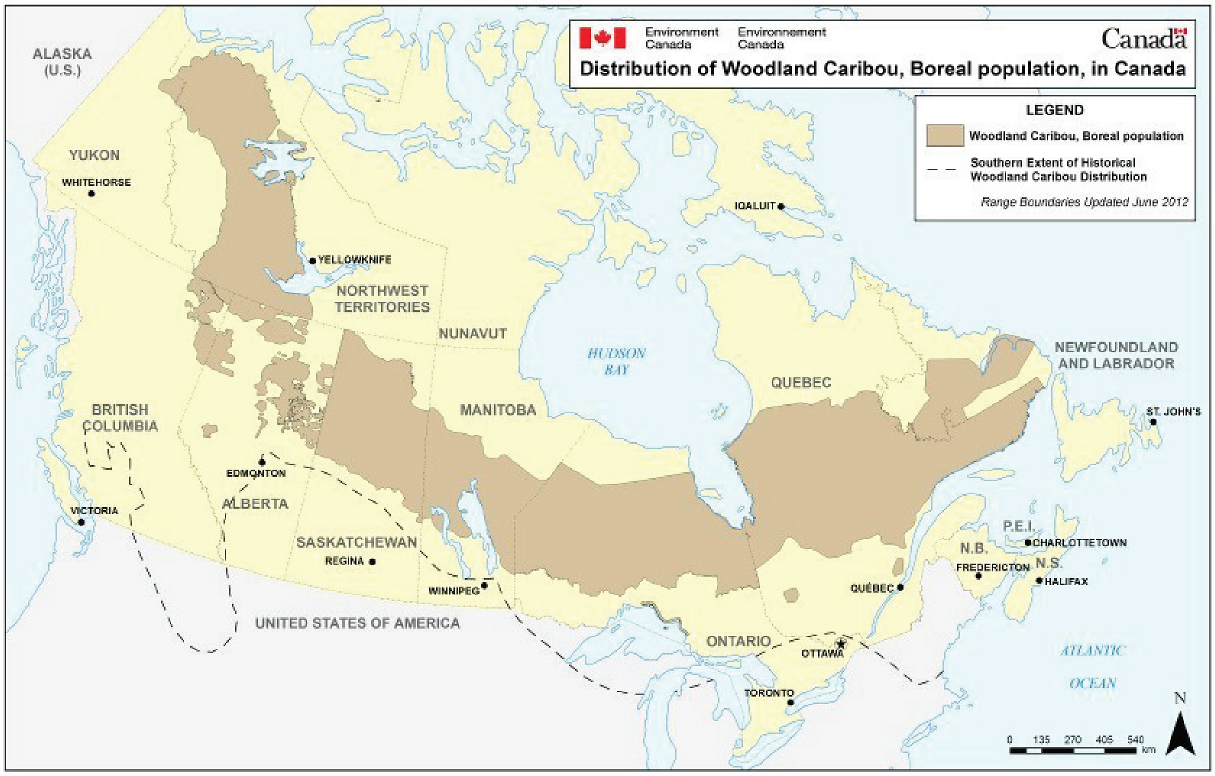
Indigenous knowledge not only provides insights into the land that go far beyond Western "scientific data" but also can help guide biodiversity conservation in our rapidly changing world. An illustration of this emerged from a landscape ethnoecology approach involving the Inuit of Nunatsiavut (Cuerrier et al. 2021). The paper discusses biodiversity in the region of Labrador between the tundra and boreal forest. Landscape ethnoecology was applied to preserve Inuit knowledge of important land features in the region, as native language and culture continue to deteriorate with colonization. It is a holistic approach meant to be used alongside contemporary Western scientific techniques to provide different interpretations of landscape and environmental patterns, resulting in better land and resource management. In common with similar studies (e.g., Berkes and Davidson-Hunt 2006), the authors met with Elders from the community to identify Inuit names and understandings of landscape features. I reference this study because 1) the concept and application of ethnoecology is relevant to the discussion of how we use and interpret biodiversity and 2) it is a good example of Inuit understandings of place that should be considered during the development of the CNC. Indeed, while Western approaches to resource extraction negatively impact natural ecosystems, Inuit harvesting practices have been found to have positive impacts on plant biodiversity at ecologically relevant scales (Oberndorfer et al. 2020).

3.4 UMBRELLA SPECIES

With regard to operationalizing biodiversity conservation and preservation objectives, one impediment to making decisions is a lack of knowledge about the distribution, requirements, and conservation status of all species in a region or ecosystem. This is especially true for certain taxa, such as fungi, mosses and lichens. Accordingly, we often look to the potential use of umbrella species (e.g., Bichet et al. 2016). Broadly construed, the idea is that conservation efforts focused on a focal species, generally through protection of its (critical) habitats, will also protect multiple species that co-occur with the focal species. The flip side to this is that, when we do not adequately protect the umbrella species, or increase negative effects on it through intensifying their threats, we may also be inadvertently increasing the threats to the co-occurring species.

A well-known umbrella species is caribou (*Rangifer tarandus*), which is represented by three subspecies in Canada: woodland (R. *tarandus caribou*, which includes boreal and southern mountain populations), Peary (*R. tarandus pearyi*), and barren-ground (*R. tarandus groenlandicus*) caribou. Of these, the woodland caribou, but especially the boreal caribou, have the greatest range and, subsequently, the greatest overlap with the proposed route of the CNC. Boreal caribou are considered Threatened by the *Species at Risk Act* (*SARA 2002*), and there are considerable federal protections in place for this subspecies, including the *Critical Habitat of the Woodland Caribou (Rangifer tarandus caribou) Boreal Population Order* (Government of Canada 2019b) and a recently amended *Recovery Strategy* (Government of Canada 2020b). Boreal caribou are key species in boreal forests and culturally and economically important for Indigenous Peoples throughout their range. A comparison of the map of its range (Figure 3) and that of the proposed CNC (Figure 1) reveals a great deal of overlap. This overlap is compounded by the nature of the predominant threats (Government of Canada 2020b), notably increased predation facilitated by anthropogenic habitat disturbance, including forestry, roads and other linear features. There is concern about illegal and unregulated hunting (Government of Canada 2020b), which again could be increased with the creation of the CNC through easier vehicle access to more of their range (Figure 1). Other threats include noise and light disturbance, vehicle collisions and pollution.

Figure 3. Range of Boreal Caribou in Canada



Source: (Government of Canada 2020b)

Will protecting boreal caribou reduce threats to co-occurring species? A study of the effect of different tree harvesting regimes on occupancy by boreal caribou and ninety-five common species from five species groups (birds, ground-dwelling beetles, flying beetles, ants and small mammals) in the Côte-Nord region of Québec suggests that this may be the case (Bichet et al. 2016). One of the study's main findings was that landscapes with cutting regimes intended to minimize impacts on caribou also resulted in the lowest rates of species loss among the other species groups. The CNC may mimic these regimes, given that 1 to 10 km of land will be cleared along the 7,000 km.

3.5 BEYOND UMBRELLA SPECIES

While umbrella species are undoubtedly important in informing conservation and preservation objectives, exclusive focus on them is likely detrimental. As mentioned earlier, one of the major threats to caribou is increased predation mediated via human-driven habitat disturbance. Wolves are known to be major predators of caribou, and most caribou recovery strategies focus on controlling wolf numbers (Mech 2017) with the hope that fewer wolves will allow caribou to recover. Biological systems are rarely that simple, and, indeed, there are several other important predators of caribou, including black bears, cougars, lynx and wolverines (Burgar, Burton and Fisher 2019). Additionally, the presence of white-tailed deer and moose in an area can support increased numbers of predators and, consequently, increased predation on caribou. This latter phenomenon has been termed "apparent competition" by evolutionary ecologists (Holt 1977). Another concept to introduce here is that of intraguild predation, which is predation among members occupying the same trophic level (e.g., coyotes feeding on foxes). Through the use of camera trap surveys and spatial count models, Burgar, Burton and Fisher (2019) demonstrated that low densities of caribou in northeastern Alberta were associated with high densities of black bears, coyote and moose, even though wolf densities were only intermediate. Focusing on controlling only a single predator could have a variety of consequences, including the potential to release other prey species (e.g., moose) or intraguild predators. Although they did not focus on the concept of umbrella species for guiding conservation, I echo Burgar, Burton and Fisher (2019) in advocating for the consideration of multiple interacting species when planning a large project, including the CNC.

4. BIODIVERSITY CHALLENGES

The vast extent of the proposed CNC project, the ongoing extinction crisis, and additional challenges associated with northern environments work together to highlight a number of biodiversity challenges. I do not attempt to be comprehensive in identifying all challenges or detailing all that is known about each challenge, focusing instead on some dominant themes and illustrative examples, respectively.

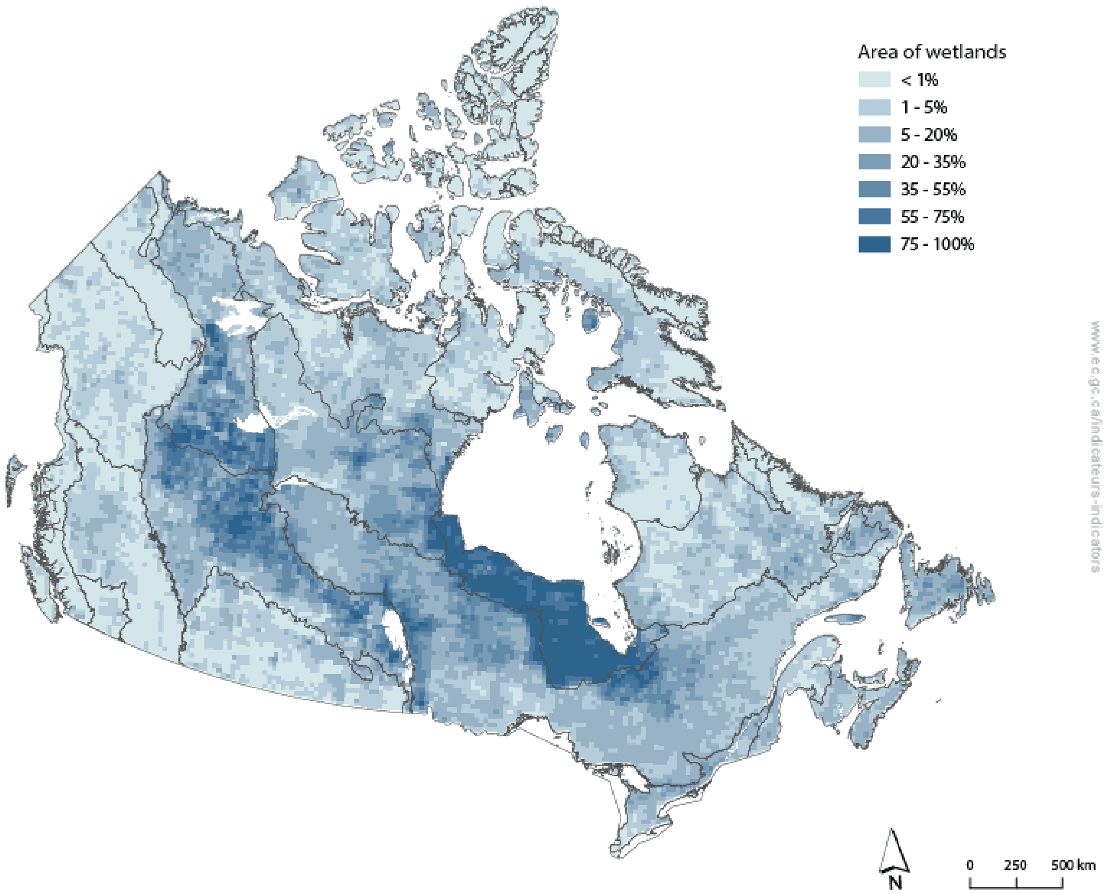
4.1 SPECIES LISTING BIASES

As part of my consideration of federal Acts, I discuss some biases and shortcomings of *SARA 2002* (see section 5.2). Here, I introduce an additional bias of relevance for the CNC. Mooers et al. (2007) examined biases in listings of imperiled species on the SARA registry for the period of 2003 through 2006. For background, COSEWIC uses a modified version of World Conservation Union quantitative criteria as a basis for species assessment, using information on population decline, abundance, and geographical range to rank and list species. They examined what proportion of species that had been recommended for listing by COSEWIC (186 in total) had been accepted or denied for listing. To assess listing biases, Mooers et al. (2007) used information on conservation rank, taxonomic categories and province/territories where species were listed. Taxonomic biases were found, with herpetofauna (amphibians and reptiles) and plants accepted onto the legal list at higher-than-expected proportions. Conversely, fewer marine fish and terrestrial mammals than expected were accepted. The underlying explanation for these results, which are possibly counterintuitive, becomes clear when focusing on trends in harvested vs. unharvested fish and mammals. Only 17 percent of harvested fish and mammals that had been recommended for listing had been accepted, compared to 93 percent of unharvested ones. Northern species (i.e., those occurring above 60° N) were significantly less likely to be listed than non-northern species. The magnitude of this effect was again striking (28 percent vs. 85 percent, respectively). These deficiencies in the process hamper the ability of *SARA 2002* to regulate our relationship to wildlife in the north and mammals and fish throughout Canada. Relevant to CNC, these impacts are likely greater for species in the North, but will be hard to outline and define due to the bias. The regulations in the *SARA 2002* may also minimally impact the development of the CNC because of its potential economic benefits. A prudent approach by CNC proponents would be to prioritize COSEWIC assessments over the legal (i.e., *SARA 2002*) list.

4.2 WETLANDS

Wetlands are incredibly important ecosystems, yet have been under assault throughout the globe, disappearing at a rate three times that of forests (Davidson 2014). Canada's boreal forest, the dominant habitat type that the proposed CNC route will traverse, is notable for several reasons. Altogether, it contains approximately 25 percent, and the single largest concentration, of the world's wetlands. Furthermore, over two thirds of Canada's boreal forest is composed of wetlands, which collectively constitute 85 percent of Canada's wetlands. With reference to the proposed CNC route, notable areas with high (more than 75 percent) wetland cover are northern Ontario and northern Manitoba, especially the route connecting to Hudson Bay (Figure 4; see also Amani et al. 2019). I encourage keeping these facts in mind while reading about roadless areas (section 4.7).

Figure 4. Extent of Canada's Wetlands (circa 2000)



Source: Canadian Wildlife Service, 2016

It will be vital to consider wetlands during the design and implementation of the CNC. The literature on the effects of anthropogenic impacts on wetlands suggests many areas of concern. Vehkaoja, Niemi and Väänänen (2020) is a recent study of the impact of road development and building density on naturally occurring wetlands in urban areas, using Helsinki as a case study. Admittedly, Helsinki (population more than 650,000, area approximately 214 square km) is a much larger city than any in northern Canada, but

I believe its latitude (60.17° N) warrants consideration of the study. Significant negative relationships were found between infrastructure and invertebrate diversity, but these were due mainly to the fragmentation effects of roads rather than directly to habitat loss. Invertebrate diversity was greatest in well-connected wetlands—as isolation increased, diversity decreased. They concluded that connectivity was the most important factor in maintaining wetland invertebrate biodiversity, with traffic intensity and speed have compounding negative effects. Their study highlighted a related factor for consideration. While forested areas near wetlands were beneficial for many of the invertebrate species, shoreline trees negatively affected their diversity as well as the density of aquatic vegetation. Closer to home, Findlay and Houlahan (1997) studied thirty wetlands in southeastern Ontario. They used a multiple regression approach to analyze the relationships between species richness of four wetland taxa (birds, mammals, herpetofauna and plants) and wetland area, road density and forest cover. One of their major findings was that the species richness of all taxa other than mammals was negatively correlated with road density up to 2 km from the wetland. Species richness of mammals and herpetofauna responded positively to proportion of forest cover with 2 km of wetlands. Together, these studies demonstrate the potential for effects within, and extending out from, wetlands in response to anthropogenic activities such as clearing forests for roads, power lines, pipelines, etc.

Wetlands are critical for migratory birds, both as rich sources of energy during stopovers during their long flights and for breeding habitats. It is estimated that up to 3 billion birds migrate north to breed in Canada's boreal forest (Boreal Songbird Initiative 2015). Accordingly, CNC sections that potentially impact wetlands may be subject to provisions under the *MBCA 2017*.

Interestingly, an experimental study focusing on impacts of road de-icers on food webs in forested wetlands also highlighted an interaction between factors—in this case, chloride ion levels and tree litter (Stoler et al. 2017). The highest chloride level was observed to reduce zooplankton densities and increase phytoplankton concentrations, but this effect was observed only in the presence of maple leaf litter. Possibly of more limited concern will be increased road dust—in the Bakken region of western North Dakota and Montana, Creuzer et al. (2016) documented a 355 percent increase in dust loading within 10 m of gravel roads in association with a large increase in oil wells over a two-year period (2012-2013). This dramatic increase in dust loading was not accompanied by consistent effects on water quality and soils of wetlands. However, the authors did caution that longer term responses to dust were possible. With reference to previous studies (Stoler et al. 2017; Vehkaoja, Niemi and Väänänen 2020), it will be important to monitor conditions in wetlands along the CNC, and in a way that allows the identification of interactive effects of road de-icers, leaf litter, dust, etc. that may not be apparent in isolation.

4.3 MARINE ENVIRONMENTS AND INVASIVE SPECIES

The volume of shipping traffic, especially trans-Pacific and trans-Arctic, has increased dramatically in the past decade or so (Miller and Ruiz 2014), and the creation of the CNC will only contribute to this, connecting to six ports (one Pacific, three Arctic, one Atlantic). Biodiversity concerns associated with cargo shipping include the spread of exotic species (primarily through ballast water release and hull fouling), noise pollution, vessel strikes and oil spills. There is a very real concern about increased invasions of the Arctic, which has historically not been a hotspot, from faraway Atlantic and Pacific bioregions (Miller and Ruiz 2014). Other studies suggest that domestic discharge events pose a significant risk for the spread of problematic invaders once they have colonized the Arctic (Goldsmit et al. 2019). More generally, the shipping sector is a massive contributor to global carbon dioxide emissions, with a cascading series of effects on biodiversity through climate change.

4.4 HERPETOFAUNA (ESPECIALLY AMPHIBIANS)

Amphibians and reptiles may warrant additional consideration from the perspective of biodiversity conservation in the North. Globally, both classes, but especially amphibians, are among the most threatened vertebrates. With reference to the IUCN Red List, 56.7 percent of amphibians and 38.6 percent of reptiles are listed as threatened (i.e., all classifications higher than Least Concern) or Data Deficient, compared to 44.2 percent for mammals and 23.9 percent for birds. In Canada, forty-four amphibian and fifty-five reptile species have been assessed by COSEWIC as of December 2021. Of these, twenty-eight (66 percent) amphibian species are considered at risk (Special Concern to Extirpated) or Data Deficient, while a staggering fifty (91 percent) reptile species are considered at risk. What is additionally concerning about these numbers is how they compare with those presented in a study highlighting the challenges of conserving herpetofauna in northern landscapes (Lesbarrères et al. 2014). Likely with reference to assessments up to December 2012, they indicated twenty amphibian and thirty-seven reptile species being listed as at-risk. The threats in northern landscapes that they mentioned included habitat loss and fragmentation, roads, pesticides and other contamination, infectious diseases and other invasive species, and climate change. Of these, the first three are clearly relevant to the CNC, with the possibility for indirect connections to climate change and infectious diseases/invasive species, mediated via increased inland and ocean traffic (section 4.3) and habitat alterations. It was also noted that the amphibians and reptiles present in Canada often reach their northernmost range limits in the northern portions of provinces and in the territories (Lesbarrères et al. 2014). Individuals living at the range margins are generally faced with multiple environmental challenges, which are intensified for species at risk (Bourn and Thomas 2002; Nadeau and Urban 2019). Together with the strong association of many amphibian species with wetlands, there is a case to be made for considering herpetofauna in the design and implementation of the CNC. At present, I found only two at-risk amphibians (western toad and northern leopard frog) that have ranges overlapping with the CNC. Comparison of historic and current range maps reveals that the distribution of the northern leopard frog has dramatically declined since the 1970s, especially in the west. Previously, the corridor would have overlapped with this species in Alberta and Saskatchewan. This reflects larger trends in amphibian range contractions (Lawler et al. 2009), and every effort should be taken to ensure that the CNC does not compound the issue.

4.5 ROAD HAZARDS

An area where multi-species impacts and interactions will be particularly germane for the CNC is road ecology, and the many direct and indirect impacts of roads on animals (Bennett 2017). Collectively, these impacts include direct mortality, curtailed movement either due to physical challenges to cross the road or behavioural changes such as avoidance, and habitat loss and degradation of quality (e.g., increased amounts of salt).

These impacts will tend to vary among different groups of species. As we have seen elsewhere, the review by Bennett (2017) suggests biases in our knowledge. Of the 215 studies considered, 170 focused on a single taxon, with the following distribution (percentage of 170 shown): mammals (50.5 percent), birds (21 percent), reptiles (13.5 percent), amphibians (10 percent), invertebrates (3 percent and fish (2 percent). Regardless, some trends strongly emerge from the data. For example, amphibians are often most represented in road kills, which is of particular concern because they already face so many threats (Green et al. 2020; Lesbarrères et al. 2014). There is also evidence for variation in road mortality rates among more closely related species, with three of eleven mammal carnivore species being most frequently documented. For impacts on movement, not only is there again evidence of species-specific responses, but also for within-species variation based on such factors as sex, age and life history stage (Bennett 2017). Although this phenomenon has been relatively understudied, there is growing evidence for roads impacting the abundance and distribution of individuals in adjacent habitats (the "road-effect zone"). I allude to this in the discussion (section 5.1) of Migratory Bird Sanctuaries and NWAs, including the Edéhzhíe Protected Area; consideration must be given to the potential impacts of the CNC on protected areas and critical habitats for listed species even if there is some physical separation between them. The road-effect zone interacts with the final major area, that of habitat degradation. Road-related pollution includes noise, light and contaminants (e.g., salt, dust and chemicals). Keeping the CNC clear during winter will be a significant challenge, and salt may be considered for help in melting snow and ice. Salt can present an indirect risk by attracting salt-limited individuals (e.g., birds) to road surfaces, and a direct risk, through increased salinity of aquatic habitats and potentially toxicity from ingestion (Mineau and Brownlee 2005).

Outdoor lighting may present an additional consideration during the development of the CNC. Obviously, there are safety considerations that will recommend their use along particular stretches. The benefits should be balanced against potential negative effects on plants and animals. For example, artificial light can cause deciduous trees to retain their leaves for longer, potentially exposing them to frost damage in colder environments (Bennie et al. 2016). These effects can also extend to the animals interacting with plants. Increased nocturnal lighting may negatively affect nocturnal pollination by reducing visits by nocturnal pollinators and causing overlap with diurnal pollinators (Knop et al. 2017). Related to the discussion of wetlands, emergence patterns and relative community composition of aquatic insects are affected when lights are increased along waterways (Davies, Bennie and Gaston 2012; Perkin, Hölker and Tockner 2014). Light can also impact bat commuting routes, as they avoid hunting and flying where light is significantly increased, making light another potential barrier to movement (Stone, Jones and Harris 2009).

4.6 OTHER PHYSICAL FEATURES

In addition to roads, other infrastructure and rights-of-way have demonstrated negative impacts on biodiversity. Powerlines and pipelines act as cutlines that foster highly different communities than surrounding forests, while presenting different risks (electrocution and oil spills, respectively). Although powerline cutlines often harbour greater diversity of plants, this is largely because invasive plants are typically considerably more abundant (Eyitayo 2020). They also act as linear features that enhance connectivity in problematic ways, such as increasing encounters between caribou and wolves (Ehlers, Johnson and Seip 2014), although scrub-shrub nesting birds may benefit (King et al. 2009). Furthermore, they can lead to direct mortality in birds, especially raptors, through collision and electrocution (Rubolini et al. 2005). The construction of pipelines carries with it the potential to increase heavy metals in the soil, although these effects may be restricted to small distances (about 50 metres; Shi et al. 2014). Plant communities again show predictable differences between pipeline clearing sites and surrounding forest, once again cascading to species that rely on these plants (MacDonald et al. 2020) or those that are impacted by the associated changes in moisture and light regimes (Silverman et al. 2008). Buried pipelines cause increased erosion and runoff, especially in their first year following construction, until some reestablishment of vegetation stabilizes sediments (Edwards et al. 2017). Conversely, aboveground pipelines contribute to habitat fragmentation, as they can impede animal crossings unless they are considerably raised off the ground (Dunne and Quinn 2009). Finally, I found fewer indications that culverts and bridges present significant concerns for biodiversity. Culverts, but not bridges, were found to increase sediment accumulation in streams, although the effect was not sufficient to negatively impact fish communities (Wellman, Combs and Cook 2000). Hanging culverts (where the outfall is elevated above the stream or river surface) are definitely a concern as barriers to fish movement (e.g., Park et al. 2008; personal observation). Because they can develop over time, not only will culvert placement need to be designed carefully, but it will be important to monitor culverts through time to ensure outfalls maintain connection with the water surface.

4.7 ROADLESS AREAS

Missing from the discussion of road hazards was a related phenomenon: the benefits of roadless areas for biodiversity and ecosystems in general. I note that, while I will focus on roadless areas, the principles discussed generally apply to areas devoid of railways, power transmission lines, pipelines, etc. One of the hallmarks of economic and population growth is the creation and expansion of road networks and associated infrastructure (Poley et al. 2022). This growth and expansion come at the cost of a reduction in the total extent of roadless areas, and there is a great deal of literature that supports the simple reality that intact areas are necessary for proper functioning of ecosystems. There is a general impression in more southerly locales (e.g., the densely populated band within 100 km of the Canada-US southern border) that the North is largely untouched, essentially a false "myth of the pristine." Of course, this is a problematic holdover from the myth of Terra Nullius. Some seven to eighteen million Indigenous Peoples were present on what we now call North America in 1491, and they played a significant role in shaping landscapes (Oberndorfer et al. 2020). This view also fails to acknowledge the long-term effects of colonialism. After all, Martin Frobisher made landfall in the Qikiqtaaluk region in 1576, the Hudson's Bay Company held a virtual monopoly of exploitative trapping in so-called "Rupert's Land" for two hundred years (1670-1870) and the Yukon was absolutely overrun by prospectors in the Klondike Gold Rush (1896-1899). In an extensive field sampling trip through the Yukon in fall 2021, I witnessed impacts wherever I went (Figure 5).

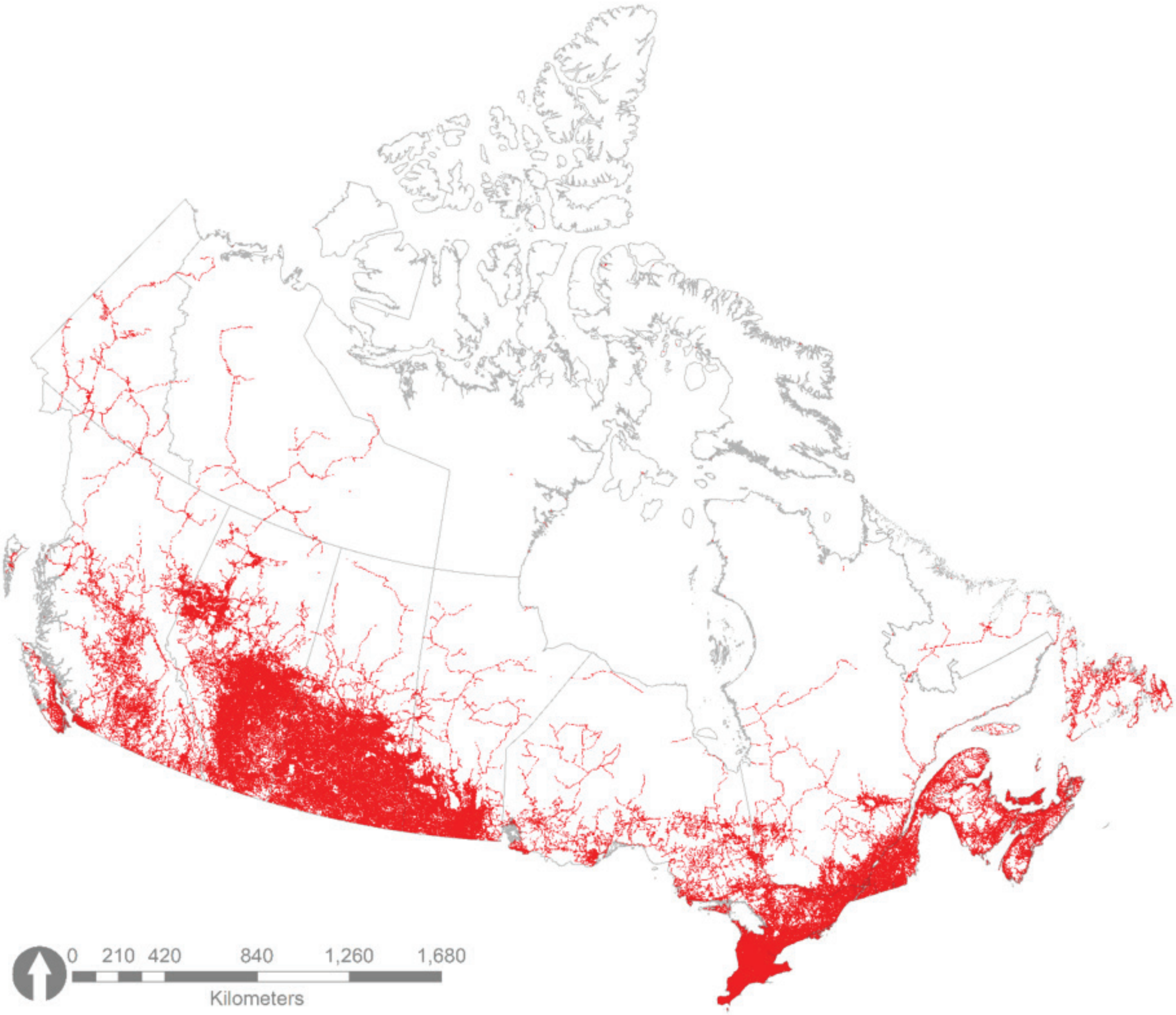
So, clearly the North is not without roads and impacts, but how important is it towards the global amount of roadless areas? This is a question that Poley et al. (2022) thoroughly investigated through the use of eleven global- to regional-scale databases. Generally, they found that the amount of roadless areas was overestimated in global-scale databases.

For the five provinces with good provincial-scale databases, the worst-performing global database (most often the Global Roads Open Access Data Set) captured less than 10 percent of the total road length in case. Furthermore, the mean roadless patch size calculated from all provincial datasets was less than 80 square km, and was much lower than the mean in some provinces (e.g., Nova Scotia) and generally along the southern border. With regard to our responsibilities, Poley et al. (2022) was clear: “Canada has a global responsibility for effective stewardship and maintenance of road-free areas within the context of biodiversity protection and climate change commitments.” Areas harbouring much of Canada’s roadless areas, which would be impacted by the CNC, include the Labrador region of Newfoundland and Labrador, central and northern Quebec, northern Ontario, central and northern Manitoba, northern Saskatchewan, Northwest Territories and northwest Nunavut (Figure 6).

Figure 5. Evidence of Human Activities in “Pristine” Yukon: **a) trash near a river crossing outside Watson Lake; b) abandoned vehicles dating back to the 1940s at South Canol Rest Area; c) a highly impacted stream and artificial streambed, and d) adjoining bulldozed roadside on the Klondike Highway (Hwy 2) approx. 100 km SE of Dawson City.**

Source: photos by author

Figure 6. Canadian Road Network



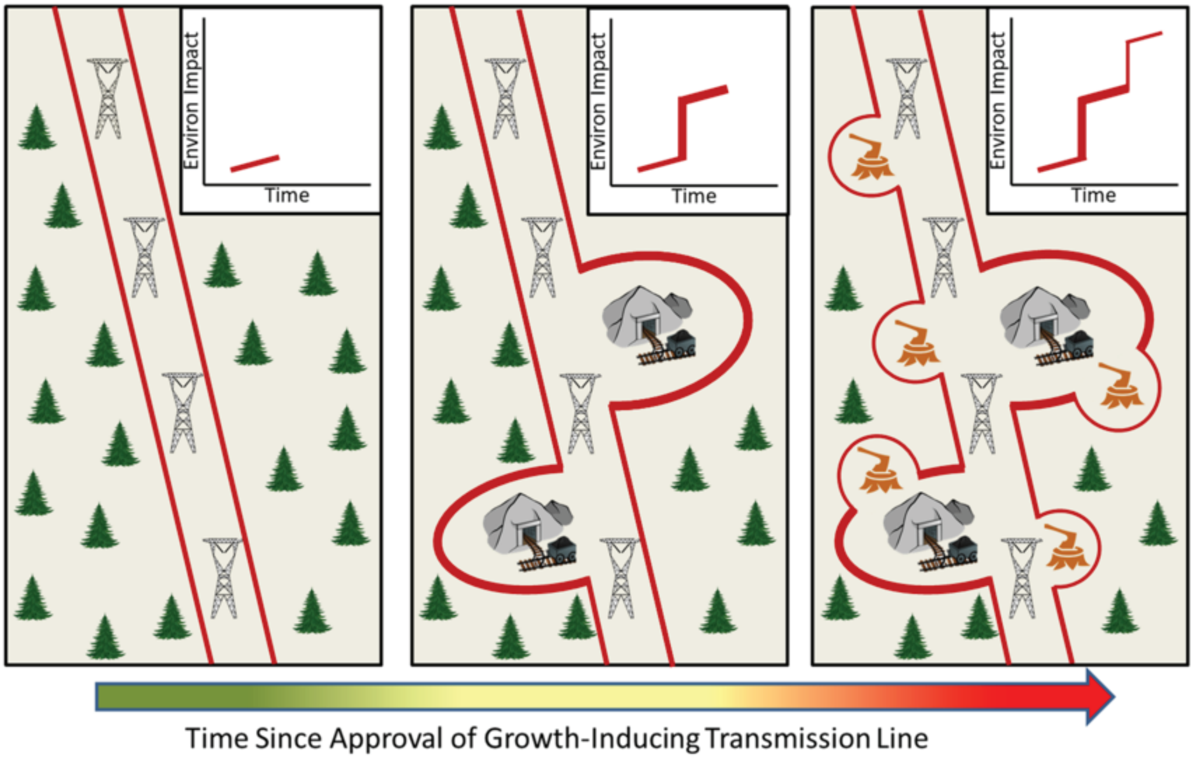
Source: Figure S1-D of Poley et al. (2022)

4.8 GROWTH-INDUCING INFRASTRUCTURE

An additional consideration for biodiversity conservation in the North, following from the previous discussion, is that of growth-inducing infrastructure (Johnson et al. 2020; Poley et al. 2022; Selva et al. 2015). In essence, it is an actualization of the "if you build it, they will come"[1] concept. This issue is described in detail by Johnson et al. (2020); project proponents are encouraged to read the paper in full. Here, I summarize some key points with reference to a graphic from their paper (Figure 7).

[1] The actual line from *Field of Dreams* (Universal Pictures, 1989) is: "If you build it, he will come", in reference to a baseball legend.

Figure 7. Timeline of Cumulative Effects Stemming From the "Keystone Decision" to Build an Electrical Transmission Line



Source: Figure 1 of Johnson et al. (2020)

In the first panel, we see the creation of an electrical transmission line, presumably approved based on a relatively small zone of influence (distance between red lines). This is what Johnson et al. (2020) call a "keystone decision," as it sets the stage for non-incremental and transformative changes to the environment. With the electrical transmission line in place, the availability of local and cheap energy facilitates the development of mines (second panel), which in turn provide road access for logging (third panel). With time, the zone of influence has grown, as has the magnitude of the impact (width of red line). Of course, the list of non-incremental and transformative changes is rather long. Once a road is in place, that opens up access (approved and illicit) for all manner of trails (single-track mountain bike trails to those created for off-highway vehicle use), hunting, fishing, trapping, etc. As noted by Poley et al. (2022), even the best provincial road network databases tend not to record these developments. Impacts that are hard to monitor are even harder to manage and remediate. Looking again at Figures 1 and 6, it is easy to visualize the "tendrils" present in (especially) central Quebec and northern Ontario and Manitoba lengthening to connect with the CNC, which would further reduce total amount of roadless areas and mean roadless patch size.

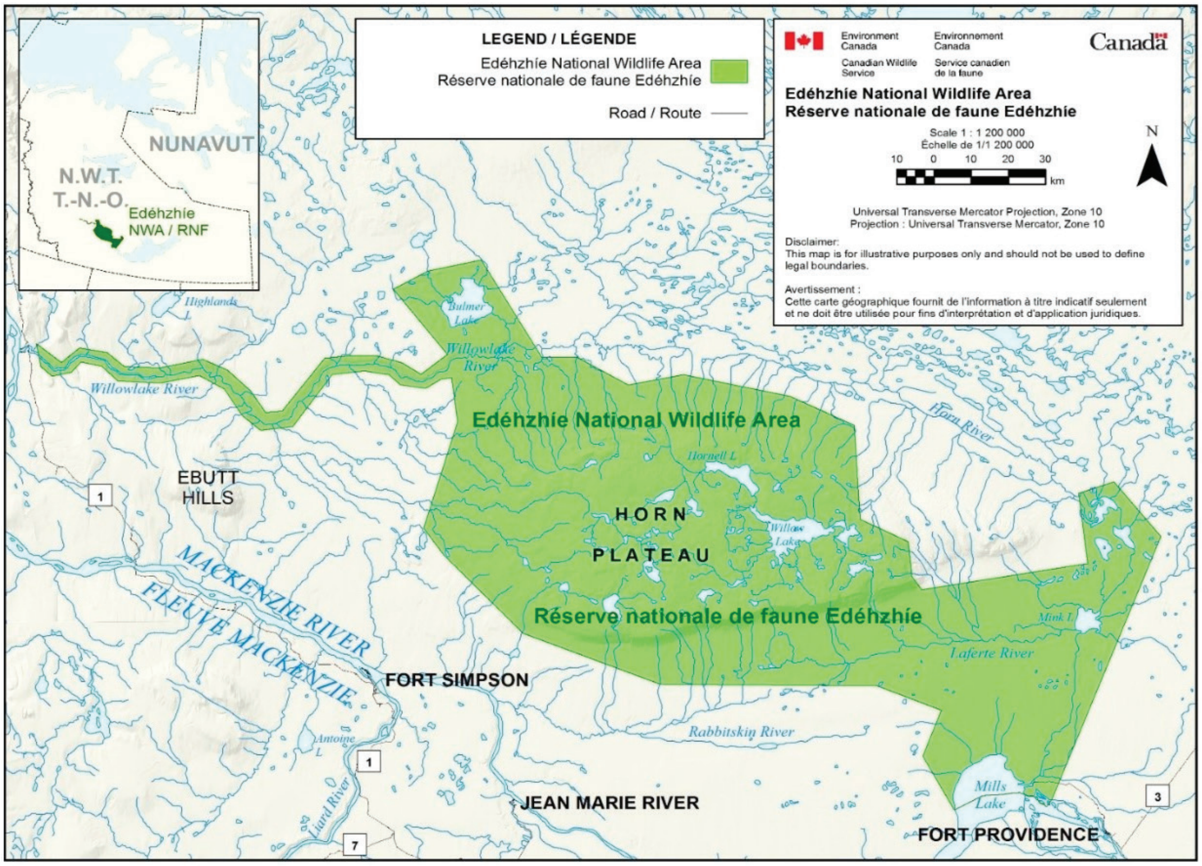
5. FEDERAL ACTS

I consider three federal acts that directly pertain to protecting species and designating and maintaining protected areas: the *Canada Wildlife Act* (1985, last amended 2017; hereafter *CWA 2017*), the *Species at Risk Act* (*SARA 2002*), and the *Impact Assessment Act* (2019; hereafter *IAA 2019*). Here, I summarize the purpose of these acts and provide an overview of their relevance to the CNC. While discussing *SARA 2002*, I also touch on provincial and territorial provisions for threatened species, because its provisions provide only protections for federally owned lands, which has significant implications for biodiversity conservation in Canada.

5.1 CANADA WILDLIFE ACT

CWA 2107 "allows for the creation, management and protection of wildlife areas for wildlife research activities, or for conservation or interpretation of wildlife" (Government of Canada 2008a). In synergy with *SARA 2002, CWA 2017* is designed to protect habitats that are critical for the long-term survival of wildlife species, especially those that are deemed to be at risk. Interestingly, *CWA 2017* distinguishes between migratory birds and other wildlife species, and there are currently ninety-two Migratory Bird Sanctuaries and fifty-five National Wildlife Areas across Canada. A comparison of the route of the proposed CNC with the locations of these protected areas suggests relatively little overlap of the two, with a rather notable exception possibly being the Edéhzhíe Protected Area in the Dehcho region of the Northwest Territories (Figure 8). This large (14,218 km^2) area was established in partnership between the Dehcho First Nations and the Government of Canada in 2018, and is noted for its great ecological, cultural and spiritual significance. With regard to biodiversity, it is home to many species, including several species at risk, such as boreal caribou, wood bison and peregrine falcon. Because it protects the headwaters of much of the watershed in the Dehcho region, it is likely that potential impacts of the CNC will need to be considered even if the actual route does not pass directly through.

Figure 8. Edéhzhíe Protected Area



Source: (Government of Canada 2020a)

Although it looks like relatively little of the notional route passes through existing Migratory Bird Sanctuaries and National Wildlife Areas, two points are worth mentioning. First, the notional route is exactly that: proposed. For many reasons, from negotiations with Indigenous communities to geological or hydrological features not yet accounted for, the exact route may deviate and consequently come closer to, or potentially pass through, more Migratory Bird Sanctuaries or National Wildlife Areas. Second, and I believe more interestingly, the increased access afforded by the CNC will lead to a better understanding of, and potentially greater potential impacts on, the flora and fauna of the lands surrounding the CNC. The result of these positive and negative consequences may be scientific and public support for the creation of additional protected areas. Although it is unlikely that the CNC would be substantively rerouted at that point, other retrofitting consequences are likely, such as the need to invest in highway wildlife crossings (Denneboom, Bar-Massada and Shwartz 2021). I discuss wildlife crossings in more detail in section 6.1.

5.2 SPECIES AT RISK ACT

The purposes of *SARA 2002* are multifold and fairly straightforward: to prevent the loss of wildlife species in Canada, to guide the recovery of species that are either extirpated (i.e., locally extinct) or at risk of extirpation because of human activities, and to manage species of concern before their status worsens (Government of Canada 2008b).

Compared to *CWA 2017*, much has been written about *SARA 2002* by ecologists and conservation biologists. Although a fulsome consideration of this literature is beyond the scope of this paper, it is important to highlight (1) the general approach to listing species, and (2) that there are deficiencies in *SARA 2002* itself and also in its application (Turcotte et al. 2021).

A strength of the listing process is that species reports are reviewed by—and often generated by—individuals with considerable experience with wildlife and biological science, who sit on various Species Specialist Subcommittees of the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). These subcommittees represent ten taxonomic groups (mammals, birds, reptiles, amphibians, fishes, arthropods, molluscs, vascular plants, mosses, lichens). While the distribution of species is biased, as (for example) reptiles are separated from amphibians whereas pines (a gymnosperm) and orchids (an angiosperm) are lumped together as vascular plants, the process generally serves well to produce rigorous assessments of species that are reviewed (for more on biases, see e.g., Creighton and Bennett 2019). I note that there is also an Aboriginal Traditional Knowledge Subcommittee, created to ensure that "Aboriginal Traditional Knowledge is incorporated into COSEWIC's assessment process." There are four "at risk" assessment statuses (Extirpated, Endangered, Threatened, Special Concern), an Extinct designation, and two other possibilities: Not at Risk and Data Deficient. Once they are internally approved, status recommendations are made by COSEWIC to the Minister of Environment and Climate Change Canada, who subsequently passes these recommendations to the Governor in Council, which acts on the advice of the cabinet and is responsible for making listing decisions (Turcotte et al. 2021). While this represents a logical flow of approvals, there are two main issues to highlight. First, not all species that are recommended by COSEWIC get listed for protection—indeed, Creighton and Bennett (2019) reported that the proportion that do not is exceedingly high (28.4 percent). Second, even when a species is listed, the responsibility for these federally listed species outside federally owned lands falls to provinces and territories, where recovery strategies considerably lag behind the standard set at the federal level (Wojciechowski et al. 2011). Because most land (approximately 59 percent) is not federally managed, this is not an insignificant challenge for protecting Canada's biodiversity (Mooers et al. 2007; Wojciechowski et al. 2011). The prudent approach would seem to be for CNC proponents to heed COSEWIC or *SARA 2002* recommendations, whichever are more stringent, regardless of the jurisdictional controls overseeing a particular stretch of the corridor.

Although Western science's knowledge of the biology of Northern species is generally less complete than for those living at more southerly latitudes, the number of *SARA 2002* listed species in the North is rather large. In Table 1, I list seventy-nine at-risk species (thirty-seven bird species; fourteen mammal species, not counting caribou and bison subspecies; sixteen fish species; ten invertebrate species and two amphibian species) with ranges that potentially overlap with the proposed CNC route. The list was assembled with reference to provincial and territorial records for listed species and the map from Fawcett, Pearce and Ford (2020).

Table 1: Listed animal species with ranges that overlap with the corridor. Abbreviations in parentheses indicate threat level: E = Endangered, SC = Special Concern, T = Threatened. Unless indicated with M, signifying migratory range overlap, included bird species have breeding ranges that intersect with the corridor. Because CNC effects might extend beyond ports, also listed are species occupying the Haida Gwaii (HG) and near-shore environments (NS).

Province/ Territory	Mammals	Birds	Fish, Invertebrates, Amphibians
NL	American marten (T), Polar bear (SC), Wolverine (E), Woodland caribou (T)	Barrow's goldeneye (SC), Chimney swift (T), Common nighthawk (T), Harlequin duck (SC), Ivory gull (E), Northern curlew (E), Olive-sided flycatcher (T), Peregrine falcon (SC), Red knot (E), Rusty blackbird (SC), Short-eared owl (SC)	• American Eel (T) • Gypsy cuckoo bumble bee (E), Transverse lady beetle (SC), Yellow-banded bumble bee (SC)
QC	Little brown myotis (E), Northern myotis (E), Wolverine (SC), Boreal caribou (T)	Bank swallow (T), Barn swallow (SC), Barrow's goldeneye (SC), Bicknell's thrush (T), Bobolink (T), Canada warbler (SC), Chimney swift (T), Common nighthawk (SC), Eastern meadowlark (T), Evening grosbeak (SC), Harlequin duck (SC), Olive-sided flycatcher (SC), Red-necked phalarope (SC), Rusty blackbird (SC), Short-eared owl (SC)	Gypsy cuckoo bumble bee (E), Maritime ringlet (E), Monarch butterfly (E), Nine-spotted lady beetle (E), Suckley's cuckoo bumble bee (T), Transverse lady beetle (SC), Yellow-banded bumble bee (SC)
ON	Boreal caribou (T), Little brown myotis (E), Polar bear (T), Wolverine (T)	Bank swallow (T), Barn swallow (T), Canada warbler (SC), Common nighthawk (SC), Eastern whip-poor-will (T), Eastern wood-pewee (SC), Evening grosbeak (SC), Golden eagle (E), Olive-sided flycatcher (SC), Red knot^{M} (E), Red-necked phalarope (SC), Rusty blackbird (SC), Yellow rail (SC)	• Shortjaw cisco (T), Lake sturgeon (LC in ON, but T or E in other parts of range) • Monarch butterfly (E), Suckley's cuckoo bumble bee (T), Transverse lady beetle (SC)
NU	Barren-ground caribou (SC), Polar bear (SC), Wolverine (SC)	Northern curlew (E), Peregrine falcon (SC), Short-eared owl (SC)	N/A
MB	Caribou (T/E), Little brown myotis (T), Wolverine (SC),	Buff-breasted sandpiper^{M} (SC), Canada warbler (T), Harris's sparrow (SC), Horned grebe (SC), Hudsonian godwit^{M} (T), Lesser yellow legs (T), Olive-sided flycatcher (T), Otoe skipper (E), Peregrine falcon^{M} (SC), Rusty blackbird (SC), Short-eared owl (SC), Streaked horned lark (E), Yellow rail (SC)	• Lake sturgeon (E), Northern brook lamprey (E) • Mussel (SC), Mottled duskywing (E), Gypsy cuckoo bumble bee (T), Yellow-banded bumble bee (SC) • Northern leopard frog (SC)
SK	Caribou (T), Little brown myotis (T), Northern myotis (E), Wolverine SC), Woods bison (T)	Barn swallow (SC), Buff-breasted sandpiper^{M} (SC), Canada warbler (T), Coastal vesper sparrow (E), Evening grosbeak (SC), Olive-sided flycatcher (T), Harris's sparrow (SC), Horned grebe (SC), Lesser yellow legs (T), Peregrine falcon^{M} (SC), Rusty blackbird (SC), Short-eared owl (SC), Streaked horned lark (E), Whooping crane^{M} (E), Yellow rail (SC)	• Northern brook lamprey (E) • Gypsy cuckoo bumblebee (E), Monarch butterfly (E), Cuckoo bumble bee (T), Yellow-banded bumble bee (SC)

Province/ Territory	Mammals	Birds	Fish, Invertebrates, Amphibians
AB	Caribou (T/E), Grizzly bear (SC), Little brown myotis (T), Northern myotis (E), Plains bison (T), Wolverine (SC), Wood bison (T)	Barn swallow (SC), Canada warbler (T), Coastal vesper sparrow (E), Evening grosbeak (SC), Harris's sparrow (SC), Horned grebe (SC), Lesser yellow legs (T), Olive-sided flycatcher (T), Peregrine falcon[M] (SC), Rusty blackbird (SC), Short-eared owl (SC), Streaked horned lark (E), Western grebe (SC), Whooping crane[M] (E), Yellow rail (SC),	• Bull trout (T), Rainbow trout (E) • Gypsy Cuckoo bumblebee (E), Monarch butterfly (E), Suckley's cuckoo bumble bee (T), Transverse lady beetle (SC), Yellow-banded bumble bee (SC) • Western toad (SC)
BC	Caribou (T/E), Haida ermine[HG] (T), Grey whale[NS] (SC), Grizzly bear (SC), Harbour porpoise[NS] (SC), Little brown myotis (T), Northern fur seal[NS] (T), Northern myotis (E), Plains Bison (T), Wolverine (SC), Woods bison (T)	Ancient murrelet (SC), Bank swallow (T), Barn swallow (SC), Coastal vesper sparrow (E), Evening grosbeak (SC), Horned grebe (SC), Hudsonian godwit[M] (T), Lesser yellow legs (T), Marbled murrelet (T), Olive-sided flycatcher (T), Peregrine falcon[M] (SC), Pink-footed shearwater[M] (E), Red knot[M] (T), Red-necked phalarope[M] (SC), Rusty blackbird (SC), Short-eared owl (SC), Short tailed albatross[NS] (SC), Streaked horned lark (E), Western screech owl (T)	• Bull trout (SC), Chinook salmon (E), Coastrange sculpin (E), Coho salmon (T), Green sturgeon [NS] (SC), Sockeye salmon (SC), Tope NS (SC), White sturgeon (E), Yellow eye rockfish [NS] (SC), • Gypsy cuckoo bumblebee (E), Suckley's cuckoo bumble bee (T), Transverse lady beetle (SC), Western bumblebee (SC), Yellow-banded bumble bee (SC) • Haida Gwaii slug [HG] (E), Western toad (SC)
NWT	Caribou (T), Collared pika (SC), Grizzly bear (SC), Little brown myotis (T), Ringed seal[NS] (SC), Wolverine (SC), Woods bison (T)	Barn swallow (SC), Buff-breasted sandpiper (SC), Northern curlew, Harris' sparrow (SC), Horned grebe (SC), Hudsonian godwit (T), Lesser yellowlegs (T), Olive-sided flycatcher (T), Peregrine falcon (SC), Red necked phalarope (SC), Rusty blackbird (SC), Short-eared owl (SC), Streaked horned lark (E), Whooping crane (E)	• Dolly Varden (SC) • Gypsy cuckoo bumblebee (E), Suckley's cuckoo bumble bee (T), Western bumblebee (SC), Yellow-banded bumble bee (SC) • Northern leopard frog (SC)

A point relevant to both *CWA 2017* and *SARA 2002* is the concept of critical habitats. Critical habitat is defined as the habitat "necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species" (SARA 2002). Critical habitats vary among species, but for animals they generally include habitats for reproduction (breeding grounds, spawning sites, etc.), habitats for rearing young (e.g., areas with particular resources and/or low predator abundances), and corridors that allow safe movement between feeding areas and breeding grounds, different feeding areas, etc. For vascular plants, mosses and lichens, critical habitats typically include those conducive to, or necessary for, growth (e.g., alkaline soils) and reproduction (e.g., meadows with particular pollinators for flowering plants). Interested readers can search the *SARA 2002* species at risk public registry (Government of Canada 2021b; link in citation) to learn more about the biology, range and critical habitats for species of interest.

The issue of critical habitats, in addition to range overlap, will likely be significant for the CNC. Earlier, I made reference to the Critical Habitat of the Woodland Caribou (*Rangifer tarandus caribou*) Boreal Population Order (Government of Canada 2019b). The purpose of the order is to support the persistence of boreal caribou through the explicit protection of critical habitat on federally managed lands. Despite the caveat that most land is not federally managed, there are several regions where critical habitat for boreal caribou may overlap with the notional corridor for the CNC, including central Newfoundland and Labrador, eastern Quebec, the north shore of Lake Superior in Ontario, and several regions throughout western Northwest Territories (Government of Canada 2019b). Closer examination of critical habitats for other species listed in Table 1, as well as for plant species, will likely reveal other species of concern. For example, the dataset "Critical habitat boundaries of species at risk in Quebec" (Government of Canada 2019a), which contains a sizable number of animal and plant species, includes a map of boundaries that overlaps with the proposed CNC route throughout the province. Similarly, the Government of Northwest Territories lists the species at risk in the NWT (Government of the Northwest Territories 2020). In addition to boreal caribou, various notable species, including little brown bats, wolverine, grizzly bear and northern curlew, may present challenges.

5.2.1 PROVINCIAL AND TERRITORIAL PROVISIONS FOR SPECIES AT RISK

As mentioned earlier, while *SARA 2002* provides provisions to prevent harm to listed species, these provisions hold only on federally owned lands. Unfortunately (from this perspective), the vast majority of lands, especially outside the territories, are not federally managed (Mooers et al. 2007; Wojciechowski et al. 2011). Recognizing the implications of these issues, Ecojustice commissioned a report of how well Canada's federal, provincial and territorial governments were upholding their obligations to protect species at risk (Nixon et al. 2021). They scored the different jurisdictions by asking four questions: Does a province or territory have laws 1) that require the government to identify and legally list species at risk?, 2) that prohibit species from being harmed in various ways?, 3) requiring the government to identify and protect the habitats that species need to survive and recover?, and 4) that require both the preparation of science-based recovery plans and actions to implement these plans, with timelines designed to achieve survival and recovery for the species? Overall, the federal government was given a score of C-, and no province or territory fared better. In the north and west, three provinces and one territory each obtained an F (Saskatchewan, Alberta, British Columbia, Yukon). For example, Manitoba (C-) had its own Endangered Species Act, requiring the creation of a committee to advise on species listings, and that prohibits harm to listed species and their habitats, but did not have provisions for recovery plans. Nunavut (C-) had a Wildlife Act that relied on "scientific information and traditional knowledge" to determine species listing, but at the time of the report no species had been listed in Nunavut beyond those listed by *SARA 2002*. Again, I believe existing provisions should be viewed as incomplete minimums, to be supplemented through engagement with local communities and Indigenous Peoples.

5.3 IMPACT ASSESSMENT ACT

IAA 2019 represents "a federal process for impact assessments and the prevention of significant adverse environmental effects" (Government of Canada 2019c), introduced by the Liberal federal government with the intention of increasing environmental protection over what was possible under the older Canadian Environmental Assessment Act, 2012. The goals of *IAA 2019* include the promotion of sustainability and protection of the environmental, health and social conditions, while deciding whether major projects should be completed on Crown lands. To do this, *IAA 2019* establishes a process for conducting impact assessments for these projects including both the positive and negative impacts and that promotes cooperation between Indigenous communities, the Canadian government, subject matter experts and other Canadians. *IAA 2019* introduced a five-phase process of impact assessment that all projects must go through: 1) Planning: a planning phase where there should be consultation with the public and Indigenous Peoples; 2) Impact statement: Western science and Indigenous knowledge are to inform an impact statement from the proponent, including studies and relevant info; 3) Impact Assessment: the Impact Assessment Agency of Canada (hereafter, IAAC) produces this report with reference to environmental, social, health, economic and treaty impacts; 4) Decision-making: if the negative impacts of the project are deemed in the public interest, the Minister of Environment and Climate Change must establish conditions for the proponent for the project to proceed; and 5) Post Decision: the IAAC will monitor compliance with the decision, and there are to be increased opportunities for Indigenous and community participation in these processes.

Given its scope and extent, the CNC project will almost certainly be considered a "designated activity;" i.e., subject to the *IAA 2019* process. Furthermore, given the mandates of *SARA 2002*, *MBCA 2017*, and *FA 2019*, the project will likely trigger the Minister to establish conditions for its proponent(s). Some elements of the anticipated process can be gleaned with reference to current projects being considered by the IAAC. At the time of writing, there were ninety-five projects with an in-progress assessment status; of those, fifty-nine had the tag "Highways and Roads." An illustrative project may be the Highway 413 Project (Government of Canada 2021c). In brief, the Ontario Ministry of Transportation (proponent) proposed to construct a new 59 km highway in the Greater Toronto Area, which would ostensibly serve as a bypass/ring road connecting Vaughn to Halton. The assessment was triggered by a letter requesting designation of the project, submitted by a representative of Ecojustice, on behalf of the environmental advocacy organization Environmental Defence. What is especially relevant to the current discussion is that the letter explicitly mentioned a number of specific environmental concerns, including potential destruction of seventy-five wetlands and almost 6 km of forest, as many as ninety-five stream crossings, and adverse effects to migratory birds, before making direct reference to *SARA 2002* and ten species designated federally and/or provincially as at risk, as well as thirty-five species of local concern, in the project area. They also raised concerns about impacts on First Nations harvesting, Treaty rights and cultural claims, as well as migratory birds and fish habitat destruction. A month later, the Minister received another designation request from the Mississaugas of the Credit First Nation. These requests for designation, together with submissions from several regions, cities and towns, comments from five First Nations and over 1,670 comments from the public, led to a formal analysis by the IAAC. Interested readers are encouraged to read the full analysis report (Government of Canada 2021a). In common with the initial designation request, it is striking how many of the Adverse Effects reference species and areas of concern, together with *SARA 2002* and other Acts. Indeed, the redside dace, silver shiner, western chorus frog, red-headed woodpecker, and rapids clubtail are explicitly mentioned, together with specific potential impacts and proposed mitigation measures. Based on the concerns and the analysis by the IAAC, the Minister of Environment and Climate Change declared that the Highway 413 Project warranted designation because it "may cause adverse direct or incidental effects on the critical habitat of federally listed species at risk that may not be mitigated through project design or the application of standard mitigation measures, or through existing legislative mechanisms" (Government of Canada 2021c).

Because *IAA 2019* was introduced only three years ago, with projects and assessments then impacted by the COVID-19 pandemic, it is too early to prognosticate its impact on biodiversity conservation. Certainly, *IAA 2019* provides the framework for necessary consultation with scientists, Indigenous communities and the public, all of whom have an interest in the protection of biodiversity. When the project begins moving forward, CNC leaders will have to consider how to effectively consult and include these groups in the design and planning phases to come to a plan that balances costs and benefits in terms of biodiversity and other realms of impact. Concerns have already been raised about implementation, citing a lack of transparency and public involvement in projects designated for assessment under *IAA 2019* to the end of 2020 (Johnston et al. 2021). I echo others (Johnston et al. 2021; Eckert et al. 2020; Sidorova and Virla 2022) in asserting that, regardless of *IAA 2019*, for the CNC project to be successful, it will need to engage with and respect Indigenous rights, laws and knowledge, and implement evidence-based approaches drawing on Western science and Indigenous knowledge systems.

6. OPPORTUNITIES

Throughout this paper, I highlight a suite of challenges that the CNC represents for the conservation and preservation of areas and species at risk in Canada's near North and North. While these challenges are significant and varied, the CNC does offer some opportunities. Here, I highlight some opportunities: mitigation of collisions and barriers to movement, reducing our uncertainty of the state of ecosystems and species in the North, and increased research, especially programs that incorporate Western science and Indigenous knowledge.

6.1 WILDLIFE CROSSINGS

One of the more significant challenges associated with the CNC—indirect effects of avoidance of, and inability to cross, corridors coupled with direct effects of wildlife-vehicle collisions—is also possibly one of its greatest opportunities. That is, if designed, built and maintained properly, the infrastructure associated with the CNC could set the standard for comparably significant corridor development projects.

Backing up a little, it is hard to overemphasize the magnitude of the costs (economic and otherwise) to both wildlife and humans of corridors in wilderness areas, which I have touched on at various points in this paper. For example, it is estimated that millions of vertebrate animals are killed by vehicles on roads every single day (Forman and Alexander 1998). Closer to home, the Wildlife Collision Prevention Program, overseen by the British Columbia Conservation Foundation, works to make British Columbia's highways safer for humans and wildlife. Some of the statistics report by the Wildlife Collision Prevention Program for the province are quite staggering. For example, approximately eleven thousand animal-related collisions are reported to the province's insurance corporation per year, with an average of 870 injured people and four human fatalities. With regard to wildlife, they estimate as many as twenty-three thousand animals killed per year. Additionally, the Wildlife Collision Prevention Program considers ripple effects, such as how much revenue these lost wildlife represent in terms of lost opportunities to sell a hunting license, arriving at a value of $700,000 for a given year. At the same time, the British Columbia Ministry of Transportation spends that much on highway cleanups.

The good news is that there are a variety of mitigation techniques for reducing wildlife-vehicle encounters. Unfortunately, many of these solutions are very expensive, especially for a corridor as long as the CNC. It is worth noting that the total cost is lower when these solutions are included in planning and implementation rather retrofitted down the road. Here, I will focus on exclusion fencing and wildlife crossings, especially their joint use. As with road ecology in general, a fulsome consideration of the vast literature on these topics is beyond the scope of this paper—reviews for interested readers include Denneboom, Bar-Massada and Shwartz (2021); Forman and Alexander (1998) and Hardy et al. (2003). Incidentally, railway ecology lags behind road ecology, although there is growing interest in mitigating its unique challenges for wildlife e.g., Barrientos et al. (2019). The simplest solution for reducing wildlife-vehicle collisions might be a tall, robust, impermeable, long-lasting, end-to-end (e.g., Baie-Comeau QC to Prince Rupert, BC) fence. Of course, not only is this impractical, but such a solution would disrupt animal movement, (further) fragment habitats, reduce gene flow and separate herds. Simply providing gaps between fence sections minimizes some of those challenges, but often leads to collision hotspots as wildlife concentrate their crossings near the edges of fenced areas. Therefore, these 'gaps' need to be intentional, typically in the form of crossing structures (Hardy et al. 2003), and designed to work with the adjacent fencing. Overpass and underpass are the two main categories (although some authors make a distinction between viaducts and underpasses (Denneboom, Bar-Massada and Shwartz 2021)), and within that, they may be relatively wide or narrow, and vegetated or open. Research suggests that there is no single best crossing structure. Viaducts may be most effective for ungulates and large and small carnivores, whereas underpasses are preferable to viaducts for small non-carnivores and herpetofauna (Denneboom, Bar-Massada and Shwartz 2021). But even this is an overly simplified categorization—elk and bears favour wide and open crossings, whereas cougars prefer narrow and vegetated ones. Some animals may benefit from specific crossing structures, which—counter to what I explain above about installing them as the corridor infrastructure is being built— would likely be placed strategically after gathering information about their movement patterns (see Box 1).

Box 1: Bat overpasses?

Although a discussion of corridor (especially road and railway) effects on animals tends to conjure up images of terrestrial animals such as deer, there is considerable evidence that flying animals are also impacted. Birds, bats and insects avoid and are attracted to openings such as roads, with varying consequences. SARA listed representatives of all three taxa have ranges overlapping with the proposed CNC (Supplementary Table 1), including the two bat species, little brown Myotis and northern Myotis. Bats are facing a suite of threats, including habitat loss, white-nose syndrome and many human-related concerns such as light pollution, wind turbines and roads. As discussed earlier, roads and light pollution can interact in their effects (Stone et al. 2019). With regard to the latter point, mortality of adults from attempting highway crossings is a significant concern, because bats are long-lived and slow to reach sexual maturity. In the EU, new projects must ensure that they do not negatively impact bat populations, and solutions arising from this directive include bat overpasses, underpasses, speed reduction, shrub-based diversion, improving habitat and adding artificial roosting sites. In a pair of studies, Claireau et al. (2019a, b) tested whether bats actually use bat overpasses and, if so, what factors may improve their effectiveness. One of their main findings was that it is vitally important that bat overpasses be placed along existing commuting routes (for the bats, not humans). Indeed, bat crossing proportions along commuting routes were comparable in the presence/absence of overpasses, but the risk of collisions is lowered for those individuals using overpasses. Another factor that contributed positively was the presence of trees on both sides of the overpass, which would need to be managed carefully with regard to the finding that roadside trees may impact macroinvertebrates in wetlands (see section 4.2). Tall vegetation has been found to be helpful in mitigating negative effects on bat foraging and movement (Bennett and Zurcher 2012). The placement of these bat overpasses relative to commuting routes appears critical, and ideally data would be collected on bat movement patterns prior to developing the corridor, so that the overpasses can be strategically placed to minimize habitat fragmentation and direct mortality (see also Frey-Ehrenbold et al. 2013). Although the magnitude of the effects may be smaller than observed for other animal taxa, bat crossing structures may still meaningfully contribute to minimizing impacts of the CNC on threatened bat species in the North. Bats also use underpasses (Abbott, Butler and Harrison 2012; Medinas, Marques and Mira 2013), which may be preferable at some sites, depending on topography.

One final complication to this discussion pertains to interchanges and intersections, which have been identified as hotspots for wildlife-vehicle collisions (Cserkész et al. 2013). Interchanges especially present various challenges with regard to fences, because of the area involved, changes in elevation along ramps, access roads, etc. Accordingly, these areas were often associated with interruptions in the continuity of the fence, with an overrepresentation of collision near these fence ends. It was observed that gaps also exist within interchanges at transitions between the fence running up the slope and the overpass railing. These gaps were sufficiently small that there were likely deemed by inspectors to “do the job,” but still allow access by small- and medium-sized mammals (e.g., foxes). Although I do not anticipate a large number of complex interchanges (e.g., cloverleafs) along the CNC, interchanges and intersections, especially in uneven terrain and near waterbodies, will require careful consideration with regard to placement and the extent of fences beyond them.

To conclude, a combination of robust fencing and a diversity of crossing structures (overpasses, underpasses, viaducts) with variable characteristics (e.g., differences in width) may minimize CNC impacts on biodiversity. Ideally, data on movement patterns collected along the entire route prior to development will inform the where and what of fences and crossing structures. The up-front costs will be significant, but they will pale in comparison to the economic, social and cultural costs of either not using them, placing a few stock overpasses haphazardly during the creation of the CNC, or retrofitting them (with the possible exception of flyover overpasses such as those in Europe (Claireau et al. 2019b) after the CNC is in place. If designed and implemented using a data-informed approach, their benefits will be great.

6.2 DATA-DEFICIENT AREAS AND SPECIES

A potential benefit of having the CNC in place, from a Western science perspective, will be that it will facilitate increased access to ecosystems and species in the North. While it can be hard to estimate just how data deficient we are with regard to overall biodiversity, there are hints that at least Western science knowledge of the North is limited. For example, World Wildlife Fund Canada recently commissioned a reassessment of the state of Canada's freshwater health (WWF Canada 2020). They assessed four indicators of health: hydrology, water quality, benthic invertebrates and fish. A very striking outcome of their report is that approximately 60 percent (100 of 167) of sub-watersheds were data deficient overall. I do not reproduce the map here, but its correspondence to Figure 6 is not coincidental – from personal experience, sites requiring helicopter access or extended travel over very rough terrain are generally not well monitored. While data-deficient watersheds are not limited to north of 60° latitude, sub-watersheds in the North are well represented in the data-deficient list. Given the great interest in clean water and in fish, it may be that the degree of data deficiency is even greater for terrestrial ecosystems and species.

6.3 INCREASED RESEARCH IN THE NORTH

As I indicated in the previous section, many regions that the CNC would eventually intersect and connect are relatively understudied for a variety of reasons, including financial costs and logistic challenges associated with conducting research in sites far from roads, railways and airports. Various programs are in place to offset these hurdles, including the Polar Continental Shelf Program and NSERC's Northern Research Supplement Program, which could work in tandem with increased ease of accessing the region. In addition to its effect on access, it is easy to imagine that studying the effects of the CNC on biodiversity will be a rich area of research. For example, with reference to wildlife crossings and fencing, not only will existing literature help guide decision-making, but ongoing research will further contribute to our knowledge of the relative efficacy of different structures in a variety of habitat types in the North. I expect the greatest gains for new knowledge will be obtained from programs that include local Indigenous knowledge, which has been largely lacking in older literature on road ecology. Earlier, I discussed the case of boreal caribou and the potential pitfalls of relying too much on umbrella species when planning projects and making management decisions. Because of the large extent over which the range of the boreal caribou overlaps with that of the CNC, there will be many "natural experiments" that will help us better understand where umbrella species are helpful and where more nuanced considerations of additional community members are needed for effective biodiversity conservation.

6.4 WORKING IN A GOOD WAY

Before discussing the final potential opportunity, I will reiterate that, from a strict evidence-based perspective, biodiversity in Canada's North and near North will be better off without developing seven thousand km of roads, railways and powerlines, and thereby losing, degrading and fragmenting habitats and ecosystems, etc. I would also be remiss in not reiterating and expanding on the approaches, some of which I have touched on at various points, with the best chance for success within the context of undertaking such a massive development project. At a high level, I see this organized into two overlapping themes/steps. First, we need the most comprehensive possible understanding of the current distribution, abundance and state (which might be body condition of individuals or levels of within- and among-population genetic variation) of threatened species along the proposed CNC route. I will add, mindful of biases in which species are accepted by the Minister for official protection by *SARA 2002*, that this should be expanded to include all species recommended for listing by COSEWIC. Additionally, as mentioned earlier, no level of government has scored higher than a C- for their record of protecting species at risk (Nixon et al. 2021). I see the CNC project contributing significantly to improving the application of acts and regulations related to biodiversity protection. Along with an understanding of species, I advocate for better monitoring of forests, waterbodies, etc. before the CNC project begins, as it is (at best) much harder to make inferences about impacts without a good understanding of initial conditions. Of course, much of this knowledge should be gained in partnership with local communities and Indigenous Peoples, incorporating cultural monitoring processes alongside typical Western science approaches. Second, insights gained from early stages of the CNC should be used to systematically improve the design, implementation and maintenance of later stages. For example, if the project starts on the east coast and develops westward and northward (which is likely, given the relative human population from the Maritimes to Ontario), boreal caribou will interact with the CNC from its very beginning. While some potential impacts may take time to detect (e.g., population genetic structure changes as a consequence of behavioural avoidance), others will likely emerge rather quickly (e.g., behavioural avoidance revealed by movement patterns of collared individuals). Such information could be incorporated by, and update existing insights and knowledge held within, the scientific panel. Although more difficult to implement, successes and failures from later stretches of the CNC may also guide retrofitting measures to the earlier stretches. Here, I again see the opportunity for the CNC to guide possible revisions to various federal, provincial and territorial acts and regulations, but especially *IAA 2019* (Government of Canada 2019c), which is in its relative infancy at the time of writing.

7. CONCLUSIONS

This paper reviews scientific evidence and Indigenous knowledge about species and areas of concern, especially as they pertain to the development of the CNC, a proposed multi-modal transportation corridor and associated infrastructure. Although they all have their limitations, proponents will have to be especially mindful of various acts and regulations as they plan, build and maintain the CNC, including the *CWA 2017*, *FA 2019*, *IAA 2019*, *MBCA 2017* and *SARA 2002*. Proponents will also have to engage with and navigate the complexities of provincial and territorial legislature pertaining to protected areas, listed species and environmental impacts. Throughout the process, proponents will also want to interweave Western science and Indigenous knowledge, which will not always produce aligned goals or perspectives without considerable work, especially around "prioritizing" species and areas. In some cases, conservation planning that seeks to minimize impacts on important umbrella species (e.g., boreal caribou) will do a great deal of good, but it will always be important to think beyond single-species approaches. Habitat fragmentation, herd separation, (genetic) isolation of sub-populations, species northern range margins, wildlife-vehicle collisions, wetlands, herpetofauna (but especially amphibians), a global premium on maintaining roadless areas and the tendency of infrastructure in new areas to beget additional infrastructure are some of the main issues, habitat types and species groups that bear specifically on the CNC and more generally on biodiversity conservation in the North. Collectively, this is a very large set of concerns to manage and mitigate, especially as they relate to the livelihood of Indigenous Peoples, who will be well represented on the lands relevant to the CNC. In all cases, there is a moral obligation for the CNC proponents to go beyond the minimum required by any specific federal Act, and I encourage referencing standards and lessons learned internationally. For example, I would look to European Union standards for minimizing road and train impacts on wildlife. I also encourage this because many of the topics discussed are simultaneously local and global issues, such as the rapidly shrinking inventory of roadless areas, threats to herpetofauna and the imperative to work closely with local communities, and especially Indigenous Peoples, all along the proposed corridor route (see also closing remarks by Fawcett, Pearce and Ford (2020)). To increase the odds of successful partnerships and minimize impacts on biodiversity, it will be vital to have a good sense of local community needs and solid data on abundance, distribution and connectivity/movement patterns of flora and fauna before breaking ground. A long-term commitment also needs to be in place with regard to biodiversity conservation, as increased traffic, hunting, OHV use, noise, light, fragmentation, infrastructure, etc. will require monitoring and potential mitigation well past the development of the CNC.

REFERENCES

Abbott, Isobel M., Fidelma Butler, and Simon Harrison. 2012. "When Flyways Meet Highways – the Relative Permeability of Different Motorway Crossing Sites to Functionally Diverse Bat Species." *Landscape and Urban Planning* 106 (4): 293–302. https://doi.org/10.1016/j.landurbplan.2012.03.015.

Amani, Meisam, Sahel Mahdavi, Majid Afshar, Brian Brisco, Weimin Huang, Sayyed Mohammad Javad Mirzadeh, Lori White, Sarah Banks, Joshua Montgomery, and Christopher Hopkinson. 2019. "Canadian Wetland Inventory Using Google Earth Engine: The First Map and Preliminary Results." *Remote Sensing* 11 (7): 842. https://doi.org/10.3390/rs11070842.

Barker, Gary M. 2002. "Phylogenetic Diversity: A Quantitative Framework for Measurement of Priority and Achievement in Biodiversity Conservation." *Biological Journal of the Linnean Society* 76 (2): 165–94. https://doi.org/10.1111/j.1095-8312.2002.tb02081.x.

Barrientos, Rafael, Fernando Ascensão, Pedro Beja, Henrique M. Pereira, and Luís Borda-de-Água. 2019. "Railway Ecology vs. Road Ecology: Similarities and Differences." *European Journal of Wildlife Research* 65 (1): 12. https://doi.org/10.1007/s10344-018-1248-0.

Bastien, Betty. 2004. *Blackfoot Ways of Knowing: The Worldview of the Siksikaitsitapi.* http://www.doabooks.org/doab?func=fulltext&uiLanguage=en&rid=15532.

Bennett, Victoria J. 2017. "Effects of Road Density and Pattern on the Conservation of Species and Biodiversity." *Current Landscape Ecology Reports* 2 (1): 1–11. https://doi.org/10.1007/s40823-017-0020-6.

Bennett, Victoria J., and Arthur A. Zurcher. 2013. "When Corridors Collide: Road-Related Disturbance in Commuting Bats." *The Journal of Wildlife Management* 77 (1): 93–101. https://doi.org/10.1002/jwmg.467.

Bennie, Jonathan, Thomas W. Davies, David Cruse, and Kevin J. Gaston. 2016. "Ecological Effects of Artificial Light at Night on Wild Plants." *Journal of Ecology* 104 (3): 611–20. https://doi.org/10.1111/1365-2745.12551.

Berkes, Fikret, and Iain J. Davidson-Hunt. 2006. "Biodiversity, Traditional Management Systems, and Cultural Landscapes: Examples from the Boreal Forest of Canada." *International Social Science Journal* 58 (187): 35–47. https://doi.org/10.1111/j.1468-2451.2006.00605.x.

Bichet, Orphé, Angélique Dupuch, Christian Hébert, Hélène Le Le Borgne, and Daniel Fortin. 2016. "Maintaining Animal Assemblages through Single-Species Management: The Case of Threatened Caribou in Boreal Forest." *Ecological Applications: A Publication of the Ecological Society of America* 26 (2): 612–23. https://doi.org/10.1890/15-0525.

Bourn, Nigel A. D, and J. A Thomas. 2002. "The Challenge of Conserving Grassland Insects at the Margins of Their Range in Europe." *Biological Conservation* 104 (3): 285–92. https://doi.org/10.1016/S0006-3207(01)00193-8.

Boreal Songbird Initiative. 2015. "North American's Bird Nursery." https://www.borealbirds.org/boreal-birds.

Burgar, Joanna M., A. Cole Burton, and Jason T. Fisher. 2019. "The Importance of Considering Multiple Interacting Species for Conservation of Species at Risk." *Conservation Biology* 33 (3): 709–15. https://doi.org/10.1111/cobi.13233.

Claireau, Fabien, Yves Bas, Jean-François Julien, Nathalie Machon, Benjamin Allegrini, Sébastien J. Puechmaille, and Christian Kerbiriou. 2019a. "Bat Overpasses as an Alternative Solution to Restore Habitat Connectivity in the Context of Road Requalification." *Ecological Engineering* 131 (June): 34–38. https://doi.org/10.1016/j.ecoleng.2019.02.011.

Claireau, Fabien, Yves Bas, Sébastien J. Puechmaille, Jean-François Julien, Benjamin Allegrini, and Christian Kerbiriou. 2019b. "Bat Overpasses: An Insufficient Solution to Restore Habitat Connectivity across Roads." *Journal of Applied Ecology* 56 (3): 573–84. https://doi.org/10.1111/1365-2664.13288.

Clayoquot Sound Scientific Panel. 1994. "Report of the Scientific Panel for Sustainable Forest Practices in Clayoquot Sound." http://www.llbc.leg.bc.ca/public/PubDocs/bcdocs/158782/clay1.pdf

Creighton, Maria J.A., and Joseph R. Bennett. 2019. "Taxonomic Biases Persist from Listing to Management for Canadian Species at Risk." *Écoscience* 26 (4): 315–21. https://doi.org/10.1080/11956860.2019.1613752.

Creuzer, Jessica, Christina L. M. Hargiss, Jack E. Norland, Thomas DeSutter, Francis X. Casey, Edward S. DeKeyser, and Mike Ell. 2016. "Does Increased Road Dust Due to Energy Development Impact Wetlands in the Bakken Region?" *Water, Air, & Soil Pollution* 227 (1): 39. https://doi.org/10.1007/s11270-015-2739-1.

Cserkész, Tamás, Barnabás Ottlecz, Ágnes Cserkész-Nagy, and János Farkas. 2013. "Interchange as the Main Factor Determining Wildlife–Vehicle Collision Hotspots on the Fenced Highways: Spatial Analysis and Applications." *European Journal of Wildlife Research* 59 (4): 587–97. https://doi.org/10.1007/s10344-013-0710-2.

Cuerrier, Alain, Courtenay Clark, Frédéric Dwyer-Samuel, and Michel Rapinski. 2021. "Nunatsiavut, 'Our Beautiful Land': Inuit Landscape Ethnoecology in Labrador, Canada." *Botany*, December. https://doi.org/10.1139/cjb-2021-0112.

Davidson, Nick C. 2014. "How Much Wetland Has the World Lost? Long-Term and Recent Trends in Global Wetland Area." *Marine and Freshwater Research* 65 (10): 934. https://doi.org/10.1071/MF14173.

Davies, Thomas W., Jonathan Bennie, and Kevin J. Gaston. 2012. "Street Lighting Changes the Composition of Invertebrate Communities." *Biology Letters* 8 (5): 764–67. https://doi.org/10.1098/rsbl.2012.0216.

Denneboom, Dror, Avi Bar-Massada, and Assaf Shwartz. 2021. "Factors Affecting Usage of Crossing Structures by Wildlife – a Systematic Review and Meta-Analysis." *Science of The Total Environment* 777 (July): 146061. https://doi.org/10.1016/j.scitotenv.2021.146061.

Dunne, Bridget M., and Michael S. Quinn. 2009. "Effectiveness of Above-Ground Pipeline Mitigation for Moose (Alces Alces) and Other Large Mammals." *Biological Conservation* 142 (2): 332–43. https://doi.org/10.1016/j.biocon.2008.10.029.

Eckert, Lauren E., Nick XEMŦOLTW_ Claxton, Cameron Owens, Anna Johnston, Natalie C. Ban, Faisal Moola, and Chris T. Darimont. 2020. "Indigenous Knowledge and Federal Environmental Assessments in Canada: Applying Past Lessons to the 2019 Impact Assessment Act." *FACETS*, February. https://doi.org/10.1139/facets-2019-0039.

Edwards, Pamela J., Bridget M. Harrison, Karl W.J. Williard, and Jon E. Schoonover. 2017. "Erosion from a Cross-Country Natural Gas Pipeline Corridor: The Critical First Year." *Water, Air, & Soil Pollution* 228 (7): 232. https://doi.org/10.1007/s11270-017-3374-9.

Ehlers, Libby P. W., Chris J. Johnson, and Dale R. Seip. 2014. "Movement Ecology of Wolves across an Industrial Landscape Supporting Threatened Populations of Woodland Caribou." *Landscape Ecology* 29 (3): 451–65. https://doi.org/10.1007/s10980-013-9976-8.

Ermine, Willie. 2007. "The Ethical Space of Engagement." *Indigenous Law Journal* 6 (1). https://jps.library.utoronto.ca/index.php/ilj/article/view/27669.

Eyitayo, Damilola L. 2020. "Ecological Consequences of Human-Modified Landscapes: Features of Powerline Corridors." Ph.D., United States -- Ohio: Ohio University. https://www.proquest.com/docview/2461608869/abstract/5B86ABEFBB0A4CB6PQ/1.

Fawcett, David, Tristan Pearce, and James Ford. 2020. "Climate Change and the Proposed Canadian Northern Corridor." *The School of Public Policy Publications* 13 (26). https://doi.org/10.11575/SPPP.V13I0.69570.

Fellows, G. Kent, Katharina Koch, Alaz Munzur, Robert Mansell, and Pierre-Gerlier Forest. 2020. "The Canadian Northern Corridor: Planning for National Prosperity." *The School of Public Policy Publications*, December, Vol. 13 (2020). https://doi.org/10.11575/SPPP.V13I0.71388.

Findlay, C. Scott and Jeff Houlahan. 1997. "Anthropogenic Correlates of Species Richness in Southeastern Ontario Wetlands." *Conservation Biology* 11 (4): 1000–1009. https://doi.org/10.1046/j.1523-1739.1997.96144.x.

Forman, Richard T. T., and Lauren E. Alexander. 1998. "Roads and Their Major Ecological Effects." *Annual Review of Ecology and Systematics* 29 (1): 207–31. https://doi.org/10.1146/annurev.ecolsys.29.1.207.

Frey-Ehrenbold, Annie, Fabio Bontadina, Raphaël Arlettaz, and Martin K. Obrist. 2013. "Landscape Connectivity, Habitat Structure and Activity of Bat Guilds in Farmland-Dominated Matrices." *Journal of Applied Ecology* 50 (1): 252–61. https://doi.org/10.1111/1365-2664.12034.

Goldsmit, Jesica, Christopher McKindsey, Philippe Archambault, and Kimberly L. Howland. 2019. "Ecological Risk Assessment of Predicted Marine Invasions in the Canadian Arctic." *PLOS ONE* 14 (2): e0211815. https://doi.org/10.1371/journal.pone.0211815.

Government of Canada. 1985. "Consolidated Federal Laws of Canada, Fisheries Act." https://laws-lois.justice.gc.ca/eng/acts/f-14/.

———. 1994. "Consolidated Federal Laws of Canada, Migratory Birds Convention Act." https://laws-lois.justice.gc.ca/eng/acts/m-7.01/.

———. 2008a. "About the Canada Wildlife Act." https://www.canada.ca/en/environment-climate-change/services/environmental-enforcement/acts-regulations/about-wildlife-act.html.

———. 2008b. "About the Species at Risk Act." https://www.canada.ca/en/environment-climate-change/services/environmental-enforcement/acts-regulations/about-species-at-risk-act.html.

———. 2019a. "Critical Habitat Boundaries of Species at Risk in Quebec - Open Government Portal." https://open.canada.ca/data/en/dataset/e0ffaf05-1db5-4422-abe3-c159bd186306.

———. 2019b. "Canada Gazette, Part 2, Volume 153, Number 13: Critical Habitat of the Woodland Caribou (Rangifer Tarandus Caribou) Boreal Population Order." Government of Canada, Public Works and Government Services Canada, Integrated Services Branch, Canada Gazette. https://canadagazette.gc.ca/rp-pr/p2/2019/2019-06-26/html/sor-dors188-eng.html.

———. 2019c. "Consolidated Federal Laws of Canada, Impact Assessment Act." https://laws.justice.gc.ca/eng/acts/I-2.75/page-1.html.

———. 2020a. "Edéhzhíe Protected Area." https://www.canada.ca/en/environment-climate-change/services/national-wildlife-areas/locations/edehzhie.html.

———. 2020b. "Woodland Caribou, Boreal Population (Rangifer Tarandus Caribou): Amended Recovery Strategy 2020." https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/recovery-strategies/woodland-caribou-boreal-2020.html.

———. 2021a. “Analysis Report: Whether to Designate the GTA West Project in Ontario Pursuant to the Impact Assessment Act.” https://iaac-aeic.gc.ca/050/documents/p81381/138551E.pdf.

———. 2021b. “Species Search - Species at Risk Registry.” https://species-registry.canada.ca/index-en.html#/species?sortBy=commonNameSort&sortDirection=asc&pageSize=10.

———. 2021c. “Highway 413 Project.” https://iaac-aeic.gc.ca/050/evaluations/proj/81381.

Government of the Northwest Territories. 2020. “Species at Risk in the Northwest Territories, 2020.” Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, NT. https://www.nwtspeciesatrisk.ca/sites/enr-species-at-risk/files/species_at_risk_in_the_nwt_2020.pdf

Green, David M., Michael J. Lannoo, David Lesbarrères, and Erin Muths. 2020. “Amphibian Population Declines: 30 Years of Progress in Confronting a Complex Problem.” *Herpetologica* 76 (2): 97–100. https://doi.org/10.1655/0018-0831-76.2.97.

Hardy, Amanda, Anthony P. Clevenger, Marcel Huijser, and Graham Neale. 2003. “An Overview of Methods and Approaches for Evaluating the Effectiveness of Wildlife Crossing Structures: Emphasizing the Science in Applied Science.” UC Davis: Road Ecology Center. https://escholarship.org/uc/item/8gj3x1dc.

Hendry, Andrew P., Steven M. Vamosi, Stephen J. Latham, Jana C. Heilbuth, and Troy Day. 2000. “Questioning Species Realities.” *Conservation Genetics* 1 (1): 67–76. https://doi.org/10.1023/A:1010133721121.

Holt, Robert D. 1977. “Predation, Apparent Competition, and the Structure of Prey Communities.” *Theoretical Population Biology* 12 (2): 197–229. https://doi.org/10.1016/0040-5809(77)90042-9.

Johnson, Chris J., Oscar Venter, Justina C. Ray, and James E. M. Watson. 2020. “Growth-Inducing Infrastructure Represents Transformative yet Ignored Keystone Environmental Decisions.” *Conservation Letters* 13 (2): e12696. https://doi.org/10.1111/conl.12696.

Johnston, Anna, Stephen Hazell, Hugh Benevides, Justina Ray, Mike Kofahl, Julia Levin, Geneviève Paul, and Anne-Sophie Doré. 2021. “Is Canada’s Impact Assessment Act Working?” West Coast Environmental Law, Nature Canada, WCS Canada, East Coast Environmental Law, Environmental Defence, Centre Quebecois du Droit de l’Environnement. https://www.wcel.org/sites/default/files/publications/2021-impact-assessment-act-report-en-web.pdf.

King, David I., Richard B. Chandler, Jeffrey M. Collins, Wayne R. Petersen, and Thomas E. Lautzenheiser. 2009. “Effects of Width, Edge and Habitat on the Abundance and Nesting Success of Scrub–Shrub Birds in Powerline Corridors.” *Biological Conservation* 142 (11): 2672–80. https://doi.org/10.1016/j.biocon.2009.06.016.

Knop, Eva, Leana Zoller, Remo Ryser, Christopher Gerpe, Maurin Hörler, and Colin Fontaine. 2017. "Artificial Light at Night as a New Threat to Pollination." *Nature* 548 (7666): 206–9. https://doi.org/10.1038/nature23288.

Koch, Katharina. 2021. "Nordicity and Its Relevance for Northern Canadian Infrastructure Development." *Polar Geography* 44 (4): 255–81. https://doi.org/10.1080/1088937X.2021.1995066.

Lawler, Joshua J., Sarah L. Shafer, Denis White, Peter Kareiva, Edwin P. Maurer, Andrew R. Blaustein, and Patrick J. Bartlein. 2009. "Projected Climate-Induced Faunal Change in the Western Hemisphere." *Ecology (Durham)* 90 (3): 588–97. https://doi.org/10.1890/08-0823.1.

Lertzman, David Adam. 2010. "Best of Two Worlds: Traditional Ecological Knowledge and Western Science in Ecosystem-Based Management." *Journal of Ecosystems and Management* 10 (3). https://jem-online.org/index.php/jem/article/view/40.

Lesbarrères, David, Sara L. Ashpole, Christine A. Bishop, Gabriel Blouin-Demers, Ronald J. Brooks, Pierre Echaubard, Purnima Govindarajulu, et al. 2014. "Conservation of Herpetofauna in Northern Landscapes: Threats and Challenges from a Canadian Perspective." *Biological Conservation* 170 (February): 48–55. https://doi.org/10.1016/j.biocon.2013.12.030.

MacDonald, Amanda, Samuel F. Bartels, S. Ellen Macdonald, Karine E. Pigeon, Doug MacNearney, and Laura Finnegan. 2020. "Wildlife Forage Cover and Composition on Pipeline Corridors in Alberta: Implications for Wildlife Conservation." *Forest Ecology and Management* 468 (July): 118189. https://doi.org/10.1016/j.foreco.2020.118189.

Mech, L. David. 2017. "Where Can Wolves Live and How Can We Live with Them?" *Biological Conservation* 210 (June): 310–17. https://doi.org/10.1016/j.biocon.2017.04.029.

Medinas, Denis, J. Tiago Marques, and António Mira. 2013. "Assessing Road Effects on Bats: The Role of Landscape, Road Features, and Bat Activity on Road-Kills." *Ecological Research* 28 (2): 227–37. https://doi.org/10.1007/s11284-012-1009-6.

Miller, A. Whitman and Gregory M. Ruiz. 2014. "Arctic Shipping and Marine Invaders." *Nature Climate Change* 4 (6): 413–16. https://doi.org/10.1038/nclimate2244.

Mineau, Pierre and Lorna J. Brownlee. 2005. "Road Salts and Birds: An Assessment of the Risk with Particular Emphasis on Winter Finch Mortality." *Wildlife Society Bulletin (1973-2006)* 33 (3): 835–41. https://doi.org/10.2193/0091-7648(2005)33[835:RSABAA]2.0.CO;2.

Mooers, A. Ö., L. R. Prugh, M. Festa-Bianchet, and J. A. Hutchings. 2007. "Biases in Legal Listing under Canadian Endangered Species Legislation." *Conservation Biology* 21 (3): 572–75.

M"sɨt No"kmaq, Albert Marshall, Karen F. Beazley, Jessica Hum, shalan joudry, Anastasia Papadopoulous, Sherry Pictou, Janet Rabesca, Lisa Young, and Melanie Zurba. 2021. ""Awakening the Sleeping Giant": Re-Indigenization Principles for Transforming Biodiversity Conservation in Canada and Beyond." *FACETS* 6 (1): 839–69. https://doi.org/doi.org/10.1139/facets-2020-0083.

Nadeau, Christopher P. and Mark C. Urban. 2019. "Eco-Evolution on the Edge during Climate Change." *Ecography* 42 (7): 1280–97. https://doi.org/10.1111/ecog.04404.

Nixon, Sean, Devon Page, Susan Pinkus, Liat Podolsky, and Sasha Russell. 2021. "Failure to Protect: Grading Canada's Species at Risk Laws." Vancouver, British Columbia: ecojustice. https://ecojustice.ca/wp-content/uploads/2014/08/Failure-to-protect_Grading-Canadas-Species-at-Risk-Laws.pdf.

Oberndorfer, Erica, Todd Broomfield, Jeremy Lundholm, and Gita Ljubicic. 2020. "Inuit Cultural Practices Increase Local-Scale Biodiversity and Create Novel Vegetation Communities in Nunatsiavut (Labrador, Canada)." *Biodiversity and Conservation* 29 (4): 1205–40. https://doi.org/10.1007/s10531-020-01931-9.

Park, David, Michael Sullivan, Erin Bayne, and Garry Scrimgeour. 2008. "Landscape-Level Stream Fragmentation Caused by Hanging Culverts along Roads in Alberta's Boreal Forest." *Canadian Journal of Forest Research* 38 (3): 566–75. https://doi.org/10.1139/X07-179.

Perkin, Elizabeth K., Franz Hölker, and Klement Tockner. 2014. "The Effects of Artificial Lighting on Adult Aquatic and Terrestrial Insects." *Freshwater Biology* 59 (2): 368–77. https://doi.org/10.1111/fwb.12270.

Poley, Lucy G., Richard Schuster, Wynet Smith, and Justina C. Ray. 2022. "Identifying Differences in Roadless Areas in Canada Based on Global, National, and Regional Road Datasets." *Conservation Science and Practice* n/a (n/a): e12656. https://doi.org/10.1111/csp2.12656.

Rubolini, Diego, Marco Gustin, Giuseppe Bogliani, and Roberto Garavaglia. 2005. "Birds and Powerlines in Italy: An Assessment." *Bird Conservation International* 15 (2): 131–45. https://doi.org/10.1017/S0959270905000109.

SARA. 2002. "Consolidated Federal Laws of Canada, Species at Risk Act." https://laws-lois.justice.gc.ca/eng/acts/s-15.3/FullText.html.

Sarkar, Sahotra. 2002. "Defining 'Biodiversity'; Assessing Biodiversity." *The Monist* 85 (1): 131–55. https://doi.org/10.5840/monist20028515.

Sarkar, Sahotra and Chris Margules. 2002. "Operationalizing Biodiversity for Conservation Planning." *Journal of Biosciences* 27 (4): 299–308. https://doi.org/10.1007/BF02704961.

Selva, Nuria, Adam Switalski, Stefan Kreft, and Pierre L. Ibisch. 2015. “Why Keep Areas Road-Free? The Importance of Roadless Areas.” In *Handbook of Road Ecology*, 16–26. John Wiley & Sons, Ltd. https://doi.org/10.1002/9781118568170.ch3.

Shi, Peng, Jun Xiao, Yafeng Wang, and Liding Chen. 2014. “Assessment of Ecological and Human Health Risks of Heavy Metal Contamination in Agriculture Soils Disturbed by Pipeline Construction.” *International Journal of Environmental Research and Public Health* 11 (3): 2504–20. https://doi.org/10.3390/ijerph110302504.

Sidorova, Evgeniia and Luis D Virla. 2022. “Community-Based Environmental Monitoring (CBEM) for Meaningful Incorporation of Indigenous and Local Knowledge within the Context of the Canadian Northern Corridor Program.” *The School of Public Policy Publications* 15: 54.

Silverman, Bareena, David J. Horn, Foster F. Purrington, and Kamal J. K. Gandhi. 2008. “Oil Pipeline Corridor through an Intact Forest Alters Ground Beetle (Coleoptera: Carabidae) Assemblages in Southeastern Ohio.” *Environmental Entomology* 37 (3): 725–33. https://doi.org/10.1603/0046-225X(2008)37[725:OPCTAI]2.0.CO;2.

Stoler, Aaron B., William D. Hintz, Devin K. Jones, Lovisa Lind, Brian M. Mattes, Matthew S. Schuler, and Rick A. Relyea. 2017. “Leaf Litter Mediates the Negative Effect of Road Salt on Forested Wetland Communities.” *Freshwater Science* 36 (2): 415–26. https://doi.org/10.1086/692139.

Stone, Emma Louise, Gareth Jones, and Stephen Harris. 2009. “Street Lighting Disturbs Commuting Bats.” *Current Biology: CB* 19 (13): 1123–27. https://doi.org/10.1016/j.cub.2009.05.058.

Sulzenko, Andrei, and G. Kent Fellows. 2016. “Planning for Infrastructure to Realize Canada”s Potential: The Corridor Concept.” *The School of Public Policy Publications*, May, Vol 9 (2016). https://doi.org/10.11575/SPPP.V9I0.42591.

Turcotte, Audrey, Natalie Kermany, Sharla Foster, Caitlyn A. Proctor, Sydney M. Gilmour, Maria Doria, James Sebes, Jeannette Whitton, Steven J. Cooke, and Joseph R. Bennett. 2021. “Fixing the Canadian Species at Risk Act: Identifying Major Issues and Recommendations for Increasing Accountability and Efficiency.” *FACETS* 6 (January): 1474–94. https://doi.org/10.1139/facets-2020-0064.

Vamosi, S. M., S. B. Heard, J. C. Vamosi, and C. O. Webb. 2009. “Emerging Patterns in the Comparative Analysis of Phylogenetic Community Structure.” *Molecular Ecology* 18 (4): 572–92. https://doi.org/10.1111/j.1365-294X.2008.04001.x.

Vehkaoja, Mia, Milla Niemi, and Veli-Matti Väänänen. 2020. “Effects of Urban Infrastructure on Aquatic Invertebrate Diversity.” *Urban Ecosystems* 23 (4): 831–40. https://doi.org/10.1007/s11252-020-00947-x.

Wellman, Jennifer C., Daniel L. Combs, and S. Bradford Cook. 2000. "Long-Term Impacts of Bridge and Culvert Construction or Replacement on Fish Communities and Sediment Characteristics of Streams." *Journal of Freshwater Ecology* 15 (3): 317–28. https://doi.org/10.1080/02705060.2000.9663750.

Wojciechowski, Stéphane, Sue McKee, Christopher Brassard, C. Scott Findlay, and Stewart Elgie. 2011. "SARA"s Safety Net Provisions and the Effectiveness of Species at Risk Protection on Non-Federal Lands." *Journal of Environmental Law and Practice* 22 (3): 203–22. https://www.proquest.com/docview/917763084.

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