Transportation Association of Canada

Managing and Enhancing Terrestrial Road Ecology

July 2021

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ABSTRACT

The location, design and operation of roads can be highly influential to the character, function and livability of adjacent communities and land uses. Both urban and rural roadways have strong linkages with the natural environment. Fish, wildlife, birds, waterbodies, vegetation communities and local air and water quality are affected by roads and vehicular traffic. Roads can alter habitats, increase wildlife mortality and facilitate the spread of invasive weeds. The concept of "road ecology" is relatively new, and its primary focus is on the potential effects of roadways on natural landscapes and processes as an element of sustainable transportation systems.

This document provides decision-making criteria to assist in various aspects of roadway design and operation for management of sustainable road systems, including:

- The influence of road type and context
- Roadside vegetation management
- Pollinator habitat enhancement opportunities along roadways
- Interactions of wildlife with roadways
- Regulatory compliance obligations
- Road safety requirements and considerations
- Public perception of visual aesthetics
- Feasibility and operational considerations
- Cost considerations

KEYWORDS

Environment

Planning of transport infrastructure

- Cost benefit analysis
- Environment protection
- Highway
- Layout
- Nature protection
- Operations (transp network)
- Planning
- Safety
- Sustainability

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RÉSUMÉ

L'emplacement, la conception et l'exploitation des routes peuvent avoir une grande influence sur le caractère, la fonction et la qualité de vie des communautés adjacentes et sur l'utilisation des terres. En milieu urbain et rural, les routes ont des liens étroits avec l'environnement naturel. Les poissons, la faune, les oiseaux, les plans d'eau, les communautés végétales et la qualité de l'air et de l'eau de la région sont affectés par les routes et la circulation des véhicules. Les routes peuvent modifier les habitats, augmenter la mortalité de la faune et faciliter la propagation de mauvaises herbes envahissantes. Le concept d'« écologie routière » est relativement nouveau et son objectif principal concerne les effets potentiels des routes sur les paysages et processus naturels en tant qu'éléments des réseaux de transport durables.

Ce document fournit des critères de décision pouvant être appliqués à divers aspects de la conception et de l'exploitation des routes pour la gestion des réseaux de transport routier durables, notamment :

- l'influence du type de route et du contexte;
- la gestion de la végétation en bordure de route;
- les améliorations potentielles de l'habitat des pollinisateurs près des routes;
- les interactions de la faune et de la flore avec la route;
- les obligations de conformité réglementaire;
- les exigences et considérations en matière de sécurité routière;
- la perception de l'esthétique visuelle par le public;
- la faisabilité et les considérations opérationnelles;
- les considérations en matière de coût.

MOTS-CLÉS
Environnement

Planification des infrastructures de transport

- Analyse coûts-avantages
- Protection de l'environnement
- Autoroute
- Aménagement
- Protection de la nature
- Exploitation
- (réseau de transport)
- Planification
- Sécurité
- Durabilité

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Executive summary

Canadian roadways provide an essential link connecting people, goods and services through both urban and rural spaces. However, they often lie within natural or naturalized landscapes, and their design and operation can influence the ecological function of adjacent lands as well as the species that live within those habitats. Road ecology has developed into an established research and applied science discipline that offers mitigative practices and management approaches to address impacts to natural ecosystems, as well as to public safety and adjacent land use. This synthesis identifies Beneficial Management Practices (BMPs) to help avoid, minimize or compensate for the direct and indirect effects of roads, across Canada's diverse geographic environments and road systems.

Beginning with an explanation of road ecology as a scientific discipline, broad principles for management over the course of the full road life cycle are provided. These principles include use of planning tools, such as environmental impact assessment, mitigation planning and multi-criteria decision frameworks, which can help to identify impacts and evaluate relevant and practical mitigation options. Planning is a key principle, since careful evaluation of alternatives and costs associated with road development and operation can help to avoid future concerns, and management costs. Throughout the life cycle of a road, from design, through construction, operation, maintenance to decommissioning, planning is one of the most important tools for managing potential road ecology concerns.

Within Canada, road networks cross urban, rural and natural or less developed areas, each with different types of plant and animal species, including species at risk, and natural communities and ecosystems, generating regionally specific road ecology concerns. Northern and southern Canadian landscapes also differ in terms of climatic conditions, level of development and specific to the North, Indigenous co-management requirements. Despite this range of diversity, mitigation can be categorized relative to the type of road ecology concern. Canadian mitigation falls into the following categories:

- Mitigation of wildlife vehicle collisions (WVCs)
  - Planning for avoidance
  - Collision warning systems
  - Wildlife guidance fencing
  - Crossing structures
- Vegetation management
  - Conventional right-of-way (ROW) management (mowing, weed management, revegetation)
  - Invasive and weed species control
  - ROW naturalization
  - Pollinator habitat management
  - Wetland management
- Emerging concerns
  - Northern road management
  - Caribou management, as a species at risk
  - Bat use of bridges, including species at risk
  - Mitigation of night lighting impacts on nocturnal species
  - Restoration of habitats and landscape connectivity

- Mitigation of climate change and spread of invasive species

For each type of mitigation within these categories, an overview of the road ecology concern, approaches to mitigation, and application to relevant stage of the road life cycle are presented. That discussion helps identify general principles and BMPs that practitioners can use to avoid, minimize, or where appropriate, compensate for road ecology effects. Each chapter on a mitigation category is supported with case studies that explore the application of these mitigation measures relative to ecological goals, but also costs, design, construction and operational, implications and other factors contributing to successful implementation. Lastly, key resources are summarized to offer easy reference to additional information.

This synthesis provides a general overview of the range of practices used to manage terrestrial road ecology issues across Canada. Further, it identifies 'state of the art' mitigation options, relative to their application across Canada. The information provided here offers solutions, and considerations for appropriate use in a given ecological setting, and relative to the stages of the road life cycle. The resulting recommendations of Beneficial Management Practices, or BMPs, builds on scientific research and practitioner experience, illustrated with applied project examples and case studies.

The process of compiling this synthesis also generated insights on the state of practice of road ecology in Canada, relative to challenges, data gaps and future directions. Globally, road ecology has become a recognized discipline, with extensive expertise at the research and practitioner level. In examining the practice within Canada, gaps were discovered in the available mitigation measures, as well as in standardized practice. These broader observations include:

- The **need for context specific solutions**, customized to geographic ecological conditions, broader land use planning objectives, stakeholder interests and available funding. Universal, one-size-fits all solutions are not realistic, particularly in a county as geographically diverse as Canada.
- The **need for collaboration and partnerships**, to generate the public and political support to sustain mitigation projects and programs. Often mitigation measures aim to create change, sometime over several years. Building realistic expectations for outcomes, benefits and timelines among stakeholders can foster the broader support needed throughout implementation.
- **Building a business case** for a preferred solution is as important as ecological justification. Multi-criteria decision-making frameworks can present a comparison of monetary and non-monetary elements relevant to selecting mitigation options.
- Funding discussions should also **include sufficient resources for monitoring**, for both scientific assessment and adaptive management. Some types of road ecology mitigation can be expensive, and without robust scientific evidence of cost-effectiveness and information to refine techniques, current and future business cases are less compelling.
- **Monitoring should also evaluate other factors** relevant to a business case, such as engineering design, construction, social and economic outcomes of specific mitigation approaches. Ecological benefits have been far more often examined in scientific studies of road ecology mitigation, leaving gaps the information needed for robust decisions.

- **In terms of future directions,** Canadian transportation agencies must deal with emerging social and environmental changes, including climate change, and develop tools for urban, and more natural landscapes, including Northern Canadian road systems. Collaborative, interdisciplinary approaches will be essential to innovative, appropriate solutions.

Résumé

Les routes canadiennes constituent un lien essentiel qui relie les personnes, les biens et les services dans les espaces urbains et ruraux. Cependant, elles se situent souvent dans des paysages naturels ou naturalisés, et leur conception et leur exploitation peuvent influencer la fonction écologique des terres adjacentes ainsi que les espèces qui vivent dans ces habitats. L'écologie routière est devenue une discipline de recherche et d'application établie qui propose des pratiques d'atténuation et des approches de gestion pouvant être utilisées pour faire face aux impacts sur les écosystèmes naturels, ainsi que sur la sécurité publique et l'utilisation des terres adjacentes. La présente synthèse définit les pratiques de gestion bénéfiques (PGB) qui permettent d'éviter, de minimiser ou de compenser les effets directs et indirects des routes, dans différents environnements géographiques et réseaux routiers du Canada.

La synthèse explique d’abord l'écologie routière en tant que discipline scientifique et présente ensuite les principes généraux de gestion tout au long du cycle de vie des routes. Ces principes comprennent l'utilisation d'outils de planification comme l'évaluation de l'impact environnemental, la planification de l'atténuation et les cadres décisionnels multicritères qui peuvent être utilisés pour définir les impacts et évaluer les options d'atténuation pertinentes et pratiques. La planification est un principe clé, car une évaluation minutieuse des options de remplacement et des coûts associés à l’aménagement et à l'exploitation des routes peut éliminer certaines préoccupations et certains coûts de gestion futurs. Tout au long du cycle de vie d'une route, de la conception à la mise hors service en passant par la construction, l'exploitation et l'entretien, la planification est l'un des outils les plus importants pour la gestion des problèmes potentiels d'écologie routière.

Au Canada, les réseaux routiers traversent des zones urbaines, rurales et naturelles ou sauvages, chacune abritant différents types d'espèces, y compris des espèces en péril, ainsi que des communautés et des écosystèmes naturels, ce qui suscite des préoccupations en matière d'écologie routière au niveau régional. Les paysages du nord et du sud du Canada diffèrent également en termes de conditions climatiques, de niveau de développement et, en ce qui concerne le nord, d'exigences de cogestion autochtone. Malgré cette diversité, les mesures d'atténuation peuvent être classées en fonction du type de préoccupation lié à l'écologie routière. Les mesures d'atténuation canadiennes se classent dans les catégories suivantes :

- Atténuation des collisions entre véhicules et animaux sauvages
  - Planifier pour éviter
  - Systèmes anticollision
  - Clôtures de guidage de la faune
  - Structures croisées
- Gestion de la végétation

    - Gestion conventionnelle des emprises (fauchage, gestion des mauvaises herbes, revégétalisation)
    - Lutte contre les espèces envahissantes et les mauvaises herbes
    - Naturalisation des emprises
    - Gestion de l'habitat des pollinisateurs
    - Gestion des zones humides
- Enjeux émergents
    - Gestion des routes du Nord
    - Gestion du caribou en tant qu'espèce en péril
    - Utilisation des ponts par les chauves-souris, y compris les espèces en péril
    - Atténuation des impacts de l'éclairage nocturne sur les espèces nocturnes
    - Restauration de la connectivité des habitats
    - Atténuation des changements climatiques et de la propagation des espèces envahissantes

Pour chaque type d'atténuation dans ces catégories, la synthèse présente une vue d'ensemble des préoccupations en matière d'écologie routière, des approches d'atténuation et de l'application à l'étape pertinente du cycle de vie de la route. Ces renseignements servent à définir les principes généraux et les bonnes pratiques de gestion que les spécialistes peuvent utiliser pour éviter, minimiser ou, le cas échéant, compenser les effets de l'écologie routière. Chaque chapitre portant sur une catégorie d'atténuation est étayé par des études de cas qui explorent l'application de ces mesures d'atténuation en ce qui concerne les objectifs écologiques, mais aussi les coûts, la conception, la construction et l'exploitation, les incidences et les autres facteurs contribuant à une mise en œuvre réussie. Enfin, on y présente un résumé des principales ressources afin de faciliter la consultation d'informations supplémentaires.

Cette synthèse donne un aperçu général de l'éventail des pratiques utilisées pour gérer les questions d'écologie routière terrestre au Canada. En outre, elle définit les options d'atténuation « de pointe » par rapport à leur application dans les différentes régions du Canada. Les informations fournies proposent des solutions et les facteurs devant être pris en compte pour une utilisation appropriée dans un cadre écologique donné et par rapport aux étapes du cycle de vie de la route. Les pratiques de gestion bénéfiques (PGB) recommandées qui en résultent s'appuient sur la recherche scientifique et l'expérience des spécialistes, illustrées par des exemples de projets appliqués et des études de cas.

Le processus de compilation de cette synthèse a également permis d'obtenir des informations sur l'état de la pratique de l'écologie routière au Canada en ce qui concerne les défis, les lacunes des données et les orientations futures. À l'échelle mondiale, l'écologie routière est devenue une discipline reconnue, une grande expertise ayant été acquise au niveau de la recherche et des spécialistes. En examinant la pratique au Canada, des lacunes ont été découvertes en ce qui concerne les mesures d'atténuation offertes, ainsi que dans la pratique normalisée. Ces observations plus générales sont les suivantes :

- Il est **nécessaire d'établir des solutions adaptées au contexte,** aux conditions écologiques géographiques, aux objectifs plus larges de l'aménagement du territoire, aux intérêts des parties prenantes et aux fonds disponibles. Les solutions universelles et uniformes ne sont pas réalistes, en particulier dans un pays aussi diversifié sur le plan géographique que le Canada.

- Il est **nécessaire d'établir de la collaboration et des partenariats** afin de générer le soutien public et politique nécessaire pour soutenir les projets et programmes d'atténuation. Souvent, les mesures d'atténuation visent à créer un changement, parfois sur plusieurs années. L'établissement d'attentes réalistes en matière de résultats, d'avantages et d'échéanciers parmi les parties prenantes peut favoriser le soutien plus large nécessaire tout au long de la mise en œuvre.
- L'**analyse de rentabilité** de la solution privilégiée est aussi importante que la justification écologique. Les cadres décisionnels multicritères peuvent présenter une comparaison des éléments monétaires et non monétaires pertinents entre les options d'atténuation offertes.
- Les discussions portant sur le financement doivent également **prévoir des ressources suffisantes pour la surveillance**, tant pour l'évaluation scientifique que pour la gestion adaptative. Certains types de mesures d'atténuation en écologie routière peuvent être coûteux, et sans preuves scientifiques solides de la rentabilité et sans informations permettant d'affiner les techniques, les analyses de rentabilité actuelles et futures sont moins convaincantes.
- **Le suivi devrait également évaluer d'autres facteurs** pertinents à l'analyse de rentabilité, notamment la conception technique, la construction, les résultats sociaux et économiques de certaines approches d'atténuation. Les avantages écologiques ont été beaucoup plus souvent examinés dans les études scientifiques sur l'atténuation des effets de l'écologie routière, ce qui laisse des lacunes dans les informations nécessaires pour la prise de décisions solides.
- **En termes d'orientations futures**, les organismes de transport canadiens doivent faire face aux nouveaux changements sociaux et environnementaux, notamment les changements climatiques, et mettre au point des outils pour les paysages urbains et plus naturels, y compris les réseaux routiers du nord du Canada. Des approches collaboratives et interdisciplinaires seront essentielles pour trouver des solutions innovantes et appropriées.

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1. Introduction

Canadian roadways provide an essential link connecting people, goods and services through both urban and rural spaces. However, they often lie within natural or naturalized landscapes, and their design and operation can influence the ecological function of adjacent lands, as well as the species that live within those habitats. In the 1980s, concerns such as wildlife-vehicle collision (WVC) and spread of invasive (weed) species began to emerge as road networks expanded and traffic volumes increased, but management of 'road ecology' focused mainly on public safety or adjacent human land use. Today, concern has shifted to the direct and indirect ecological effects of roads, including the sustainability of the adjacent ecological systems, and emerging issues such as climate change and the need to conserve pollinator habitat. The concept of 'road ecology' has developed into a broad discipline that examines the ecological effects and human safety aspects of roadways in natural and urban landscapes, and the effectiveness of mitigation measures and management for sustainable transportation systems.

Purpose of this Synthesis:

Road ecology has developed into a scientific discipline that studies the effects of road development and operation on the environment, and how effects can be avoided or minimized.

Drawing on research and experience from across Canada and internationally, this synthesis describes the current 'state of the art' for management of ecological concerns, in the design, construction, operation, maintenance and decommissioning of road systems.

In recent years, the Environmental Issues Committee (EIC) of the Transportation Association of Canada (TAC) has initiated various guidance documents to increase awareness of environmental concerns relative to road design and operations. Where practices have become well-established within the transportation industry, those measures have been compiled as guideline documents. Generally, these guideline documents provide high-level recommendations to ensure road design and operation will meet regulatory compliance requirements. Examples addressed in past guidance documents include aquatic elements of roadway design such as fish passage and beaver management[1]. Various operational concerns related to the *Migratory Birds Convention Act* have also been addressed recently[2]. Typically, these guidelines have focused on compliance with federal and provincial environmental legislation, rather than beneficial management practices for sustainability, which can often span a range of options.

Where practices are not yet standardized, or where a range of mitigation options are available, such measures have been compiled in TAC synthesis documents. These documents are intended to provide

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[1] *Examples include the National Guide to Erosion and Sediment Control on Roadways Projects (2005) and Sustainability Considerations for Bridges Guide (2015)*

[2] *Migratory Birds Practices and Operational Guidance Documents Package: Beneficial Practices for Compliance with the Migratory Birds Convention Act and Regulations (2019), Operational Guidance for Migratory Birds and Vegetation Management for Existing Transportation Facilities and Infrastructure (2019), Operational Guidance for Migratory Bird Nests under Bridges and Culverts (2019)*

an overview of the types of mitigation applied globally, or across the country, and considerations for their use in other locations[3].

The EIC recognized a gap in its guidance documents relative to the development and operation of sustainable roadway systems and terrestrial road ecology. Understanding the factors contributing to successful mitigation of road ecology impacts, and an awareness of the associated costs and unforeseen challenges in application across Canada, can provide critical insights for future road planning and operations. This document fills this gap by reviewing the practices used across Canada, to assess their success in addressing road ecology issues and, ultimately, in supporting conservation of native plant and animal biodiversity.

Road ecology itself is a broad topic, and measures for certain concerns vary in their depth, from the wide variety of mitigations for WVCs, to emerging concerns such as ice road management. The sections below summarize the current 'state of the art' of managing and enhancing road ecology for current and emerging road impacts across Canada, beginning with an introduction to the discipline, and then the specific types of mitigation that have been applied across Canada. While standard practices are not yet established for many of these measures, the aim of this synthesis was to capture general learnings – beneficial management practices, or BMPs – that could be applied to other locations.

Information was drawn from academic and 'grey' literature to identify not only practices, but also the factors leading to effective implementation, such as ecological and administrative context, budgets, other resource requirements and timelines. EIC members also provided important context on transportation agency standards and management practices at the federal, provincial, territorial, national parks and municipal level, through a questionnaire circulated among committee members (Appendix A). Each section on specific road ecology issues provides:

- A general overview of the current understanding of the specific concern, and any applicable regulatory requirements influencing management decisions
- The 'state of the art' on available mitigation options, how they have been applied in Canada as part of road planning, design, and operation, and what factors should be considered for application in other contexts
- A summary of BMPs emerging from application of road ecology management approaches across Canada, or where applicable, internationally
- Select case studies illustrating application of management approaches in locations across Canada, or other relevant international examples
- Additional resources that provide more detailed guidance or information related to the management approach

The resulting synthesis of BMPs provides insight to the applicability of identified BMPs to a given situation, and the associated effort and cost required to achieve desired outcomes. Case studies that highlight cost, feasibility and operational considerations influencing planning decisions relative to BMPs are also provided. For emerging, but not yet standardized, practices, current applications and gaps have been described.

[3] *Recent examples include the Synthesis of Environmental Management Practices for Road Construction, Operations, and Maintenance Roadways (2014) and the Canadian Guide to Greener Roads (2015).*

This synthesis provides broad, high level principles for addressing road ecology practice through proven management approaches applied globally, before reviewing the types of mitigation and specific practices within them. Section 1 introduces the objectives of this synthesis and provides an overview of road ecology as a scientific discipline. It also describes how the information presented in this synthesis can be used in managing road ecology concerns in Canada. Section 2 introduces the practice of road ecology, in terms of the higher-level management approaches and tools used by practitioners to identify appropriate solutions, at the right stage of project development. Subsequent sections present the types of road ecology problems currently addressed by practitioners across Canada, and the BMPs that can be used to avoid, minimize or mitigate those concerns. Section 3 discusses the various mitigation measures used to prevent WVCs and maintain habitat connectivity, one of the first and more diverse areas of road ecology management. Section 4 discusses vegetation management in road rights-of-way (ROWs), and the range of conventional and emerging practices used by urban, provincial and territorial agencies to manage ROWs for multiple management objectives. Section 5 includes a range of emerging concerns, including night-lighting, climate change adaptation and management of Endangered species like bats and caribou. Lastly, conclusions drawn from the synthesis are summarized.

1.1 Road ecology – A growing discipline

Roadways have undeniable impact on natural habitat and ecological function, which until recently, was recognized mainly in terms of the direct footprint of habitat disturbance [1,2]. Growing awareness of the broader and lasting effects of roadways, from traffic impacts to the altered habitat in managed ROWs, highlighted the need to view roadways as an integrated ecological system. Today, road ecology recognizes the functional disturbance, as well as the physical impact of road development and operation. Wildlife crossings and associated mortality were initially addressed, and mitigation focused mainly on reducing vehicle collisions with large animals and improving human safety. Increasing road densities, traffic volumes, speeds and types of vehicles and rates of collisions spurred this initial interest, from both a human and property cost perspective [3,1].

The discipline has since evolved to consider ecological processes that contribute to sustainable road systems, such as habitat connectivity for plants and animals of all sizes, and ecological health of terrestrial to aquatic habitats. Road ROW management now considers the habitat value of these lands, by creating pollinator habitat, controlling the spread of invasive plant species, and restoring connection to adjacent habitats. The discipline of road ecology has expanded beyond the road footprint, in physical and conceptual focus.

Globally, road length and traffic volumes continue to grow and vehicles have shifted in size and variety. As an example, 83% of the continental United States (US) is now within one km of the nearest road, of any type [4]. Although Canada's road network is less dense than the US, the growth in diversity in road and vehicle types are similar to global trends. In addition, Canada's population is increasingly urban. Urban road networks have grown considerably in recent years.

Given these changes, and an increasing focus on sustainability, road ecology research has turned to creating sustainable transportation *systems*. These efforts consider ecological, social and economic perspectives, and address the design, operation and maintenance of roadway networks. Practitioners have considered how to retain ecological function in the surrounding landscape through better understanding of how plants, wildlife and other living organisms react to roads. But practitioners have also found that the social, economic and aesthetic aspects of sustainable management options can provide convincing arguments in management decisions, in addition to the ecological benefits.

Climate change will impose other economic and operational influences on roadway design and operation, and a need to design for future changing conditions. Some jurisdictions are already beginning to consider these factors in bridge and culvert design, to accommodate more frequent extreme events and future predicted changes. Adapting to these changes, road ecology has shifted to consider policy, economic and ecological implications of sustainable roadway operation as an integrated system, rather than an isolated disturbance.

Over these past several decades, 'road ecology' has also matured as a scientific discipline to become an established area of academic and practitioner research on road design and operation. University research centers, like the National Center for Sustainable Transportation at the University of California Davis campus and the Western Transportation Institute at Montana State University, have become recognized as thought leaders. Environmental Non-Government Organizations (ENGO), like the Yellowstone to Yukon (Y2Y) Network, and practitioner conferences, such as the International Conference on Ecology and Transportation (ICOET) and Infrastructure and Ecology Network Europe (IENE), actively promote innovative management. Textbooks, such as Forman et al. [5] and van der Ree et al. [4], have begun to consolidate the practical aspects of road ecology management, and provide useful resources to practitioners. With such diverse resources on road ecology and management approaches, it is timely to compile a document that evaluates and recommends BMPs applicable to Canadian road systems.

Modern management of the ecological effects of roads considers both the type and extent of impact relative to noise, light and chemical pollution, disturbance effects and habitat loss and degradation [4,5,10]. Roads and managed ROWs can be a source of mortality, an attractant, a barrier, or filter for movement of wildlife, or potentially a corridor to facilitate movement or spread of species (e.g. invasive plants). The size of the zone where these effects extend also depends on road, landscape and species characteristics, such as:

- Road type (width, surface type, elevation above adjacent lands)
- Traffic (volume, speed, vehicle size, and timing)
- Adjacent landscape (topography, hydrography, vegetation, habitat quality)
- Prevailing wind speed and direction
- Species traits and sensitivity to impact [4]

Canada's road network

Canada has over one million kilometers of two-lane equivalent roads, including 38,000 km of the National Highway System [6]. The most recent estimate in 2009 found vehicles ranged from:

- *light vehicles (20 million)*
- *medium and heavy trucks (0.75 million)*
- *public transit buses, motor coaches, and motorcycles (15,000) (Transport Canada, 2020)*

Road density has also increased, and now averages 14.1 km/100km^2 (2009 statistics [7]). Much of this growth, and density, is urban. About 81% of Canadians live in urban centres, based on the 2016 census [8], and growth is highest in large urban centers, particularly in Ontario [9].

Species-specific responses to roads have received considerable study, and findings have influenced design of both roads and crossing structures [11,12]. The capacity of animals to learn and adapt introduces another dynamic aspect to road management that has been incorporated into design of mitigation and operating procedures for transportation systems [13]. In practice, these situational factors interact: impacts do not occur in isolation, and management action requires careful evaluation of unintended outcomes. For example, many agencies use mowing to reduce wildlife attraction to roadsides and potential collisions, but mowing will also reduce availability of flowering plants for pollinators. Understanding the potential interactions of management action is essential.

1.2 Applying road ecology principles In Canada

Drawing on this understanding of road ecology, this review evaluates the current suite of measures used to address specific road ecology concerns, to derive BMPs recommended for sustainable road systems. That synthesis step was based on the following guiding questions:

- Where have practices become standardized, and where are they still emerging?
- What are the general management goals relative to this road ecology concern?
- What are some of the constraints applicable to a given road ecology concern?
- How are multi/interdisciplinary approaches being applied to the design of BMPs?

Three additional considerations were explored that are applicable to a Canadian context:

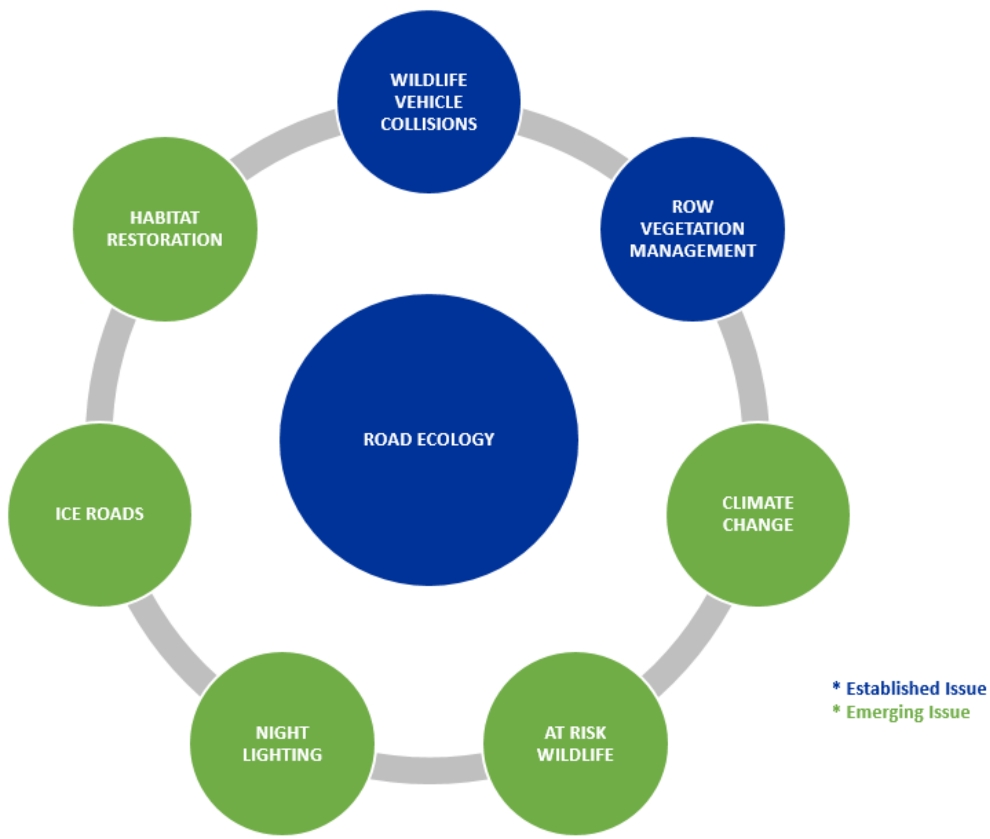
- Does geographic region (east/west/north) influence the BMPs being used?
- Do BMPs differ for specific species?
- Do road type and location (e.g. urban/rural, freeway/collector road) influence BMPs?

The resulting types of road ecology problems currently addressed in Canada include well-developed and emerging issues, as shown in Figure 1 below. For each type of ***mitigation category*** (e.g. WVCs, ROW vegetation management), this document describes the set of ***mitigation practices*** used to address it, before summarizing ***beneficial management practices (BMPs)*** that could inform management in other places in Canada.

Ecological problems are challenging to manage because they are context specific. The environmental setting and the type of human activities associated with a new or operational project create a unique management problem that must be solved. As a result, the first step in identifying appropriate solutions is to properly define the problem. Often, as the problem becomes clearer, the options for management are also. For example, a new four-lane highway in a mountain wilderness park context, with terrain and water constraints to movement, and a range of large to small mammals, will require measures to prevent animal crossings for human and wildlife safety, in combination with means to maintain connectivity to key habitats. In an urban, developed context, the same solutions may be required, but the distance between crossing structures and the types of structures may be quite different, since fewer large animals may be present and habitat corridors, less frequent. In addition, management mandates may weight ecological sustainability and human safety objectives differently, and thus influence mitigation budgets. Environmental, social and economic context may all play a role in defining the problem and feasible solutions, and thus management often demands customized solutions.

The descriptions of the mitigation practices provided in this document attempted to provide examples from various locations across the county, to help identify where flexibility exists, as well as describing aspects as BMPs.

Figure 1. Categories of current Canadian road ecology mitigation



In a country as ecologically diverse as Canada, identifying road ecology management approaches that will apply universally is an additional challenge. Climate, plant and wildlife communities and human influences add to the complexity of identifying specific measures applicable in any given location. As a result, some past project examples may not be directly applicable to other regions. However, many of the past road ecology studies conducted in Canada, and internationally, do identify planning and design considerations that can be used to provide general planning considerations to mitigate road ecology issues. To help users of this synthesis apply the specific road ecology management practices identified here, the following contextual considerations are provided, where available:

- The influence of road type and context (e.g. rural wildland, urban settings, highways, parkways, arterial roads, ice and winter roads)
- Roadside vegetation management
- Habitat enhancement opportunities along roadways
- Interactions of wildlife (mammals, reptiles, amphibians) with roadways (i.e. foraging along and movement across roadways), and potential means of conflict avoidance and mitigation

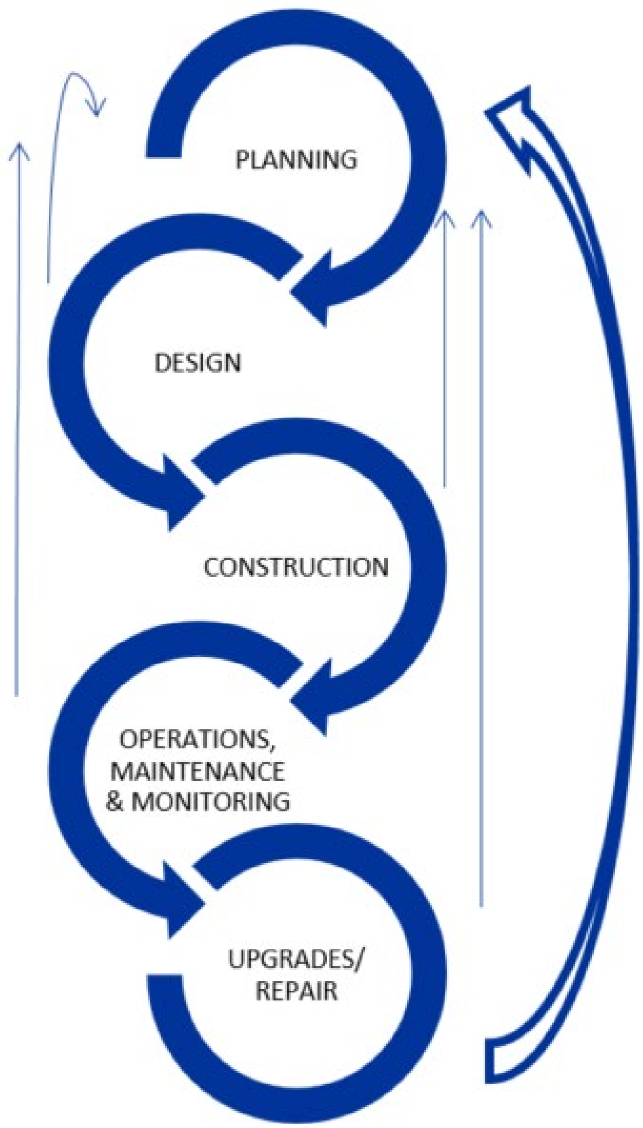
- Regulatory compliance obligations (e.g. species at risk, migratory birds4, weed control)
- Road safety requirements and considerations
- Public perception of visual aesthetics
- Feasibility and operational considerations
- Cost considerations

Lastly, the description of mitigation practices is organized around the **road management 'life cycle'**, the sequence in which Canadian roads are planned, built, operated and upgraded. This sequence provided a logical organization for presenting mitigation practices in a manner that would be useful to transportation managers, environmental specialists and engineers in identifying practices relevant to their projects. In each section on specific mitigation practices within a given mitigation category, the steps in Figure 2 have been used to identify, at a glance, the relevant road management stages to which the practice applies.

Together these planning considerations helped to identify and describe the BMPs for common and emerging road ecology management concerns, and gaps in current practice, from a holistic and practitioner perspective. The next section describes management approaches for road ecology problems, and provides examples of 'rapid assessment' decision frameworks to assist in selecting the appropriate practices for a site-specific concern. Practitioners can use these tools, and the BMPs presented here, to assess the ecological, economic and social considerations that may influence mitigation decisions.

[4] *Note that migratory birds were addressed in a previous TAC guideline (Migratory Birds Practices and Operational Guidance Documents (2019)). Where certain additional design mitigations might apply to birds, including migratory birds, these were included in this synthesis document. For a more complete guidance, please see the Migratory Birds guidelines package.*

Figure 2. Road management life cycle



Arrows indicate feedback loops to the planning stage, recognizing the essential role of planning in mitigating impacts of each life cycle stage.

2. Road ecology in management practice

Road ecology was practiced in Canada long before it was established as a distinct scientific discipline. Vegetation management of road ROWs is an excellent example: mowing 'standards' have evolved to include a mixture of aesthetic, human safety, wildlife management and weed management objectives, based on understandings from research and historical practice. Transportation agencies have generally kept pace with the new understandings of ecological impacts of road systems arising from the emerging science of road ecology, by creating new management approaches to incorporate findings into road planning, design and operation. Road ecologists have also adapted to provide frameworks to help transportation planners and managers evaluate specific options for managing road ecology impacts based on competing economic, engineering, safety, social and environmental considerations. The sections below introduce some of those higher-level management approaches and tools, which can be used to help support decision-making processes faced by transportation practitioners.

2.1 Environmental assessment approaches

Government transportation agencies usually conduct road development and operational management through a series of standardized procedural reviews over the road management life cycle introduced in Section 1.2. Each of those procedural stages offers opportunities to integrate management considerations drawn from road ecology research, as well as other social, economic and environmental concerns, and, increasingly, society expects such review from road agencies [14]. For example, most new roads and road enhancements require a phase of engineering design to evaluate design options relative to economic, engineering, health[5], safety, environmental, and aesthetic standards. In practice, environmental assessments for road projects are completed under legislative, or more commonly policy, requirements across Canada.

While most new and upgraded road projects are not required to undergo formal environmental impact assessment (EIA) under federal, provincial or territorial legislated processes (see relevant legislation, Table 1), many Canadian transportation agencies now require some form of internal environmental, or biophysical, assessment. The form of assessment varies by jurisdiction, as does linkage to legislated EIA and other regulatory processes. For example, all new roads proposed in Canada's northern territories undergo a preliminary environmental screening, and larger or more contentious roads may be directed to pursue a full environmental assessment under the legislated territorial EIA process. An EIA is also mandated in National Parks and Wilderness Areas under Canada's *Impact Assessment Act* and the *Canada National Parks Act*. In contrast, Alberta Transportation has adopted an non-legislative environmental evaluation process for all of its road design projects. The environmental evaluation assesses baseline environmental conditions and identifies mitigations to offset project related impacts and to ensure the project complies with all relevant legislation. Unless the road is in a particularly sensitive area such as a provincial park, no other jurisdictional review is involved. Municipalities, on the other hand, typically require environmental assessments on a discretionary basis, directed by their own

[5] For example, TAC (2019) Integrating Health and Transportation in Canada provides planning considerations from a human health perspective.

transportation department, or in rare cases where an EIA process is mandated under by-law (e.g. the City of Edmonton's North Saskatchewan River Valley Redevelopment Bylaw 7188).

Table 1. Canadian environmental assessment and management legislation

Regulator	Legislation	Description
Federal		
Canada Impact Assessment Agency	Canadian Impact Assessment Act	Process for assessing the impacts of major projects and projects carried out on federal lands or outside of Canada.
Environment & Climate Change Canada	Canadian Environmental Protection Act	Protect the environment and human health and to contribute to sustainable development through pollution prevention, relating to fuels and vehicle and engine emissions.
Environment & Climate Change Canada	Canada Wildlife Act	Regulates the management and protection of wildlife areas and habitats in Canada.
Environment & Climate Change Canada	Migratory Birds Convention Act and its regulations (MBCA)	Provides limitations on impacts to wildlife, specifically birds regulated as migratory birds.
Environment & Climate Change Canada	Species at Risk Act (SARA)	Provides limitations on impacts to wildlife (species of management concern) and vegetation (rare plants).
Environment & Climate Change Canada	Fisheries Act	Regulates the protections for fish and fish habitat.
Parks Canada	Canada National Parks Act	Regulates parks, historical sites and wilderness areas set aside to protect habitats and species representative of Canadian biodiversity.
British Columbia		
Environmental Assessment Office	Environmental Assessment Act	Provides mechanism for the review of major projects and to assess their potential impacts on the environment.
Alberta		
Alberta Environment and Parks	Environmental Protection and Enhancement Act	Regulates the protection, enhancement and wise use of Alberta's environment. Projects reviewed under the Act are evaluated for potential impacts and if safe development can occur.
Saskatchewan		
Ministry of Environment	Environmental Assessment Act	Requires developments to undergo an Environmental Impact Assessment to evaluate the potential environmental impacts before any irreversible decisions are made that may lead to negative impacts on the environment, natural resources or public health and safety.
Manitoba		
Manitoba Conservation and Climate	Environment Act	Promotes environmental protection for public and private developments with the goal of maintain resources for future generations.

Regulator	Legislation	Description
Ontario		
Ministry of Environment, Conservation and Parks	Environmental Assessment Act	Regulates provincial and municipal planning and decision-making processes that considers potential environmental impacts of a development prior to project initiation.
Quebec		
Ministière de l'Environnement et de la Lutte contre les changements climatiques	Environment Quality Act	Regulates developments and the decision-making process for those developments within the Province.
Newfoundland and Labrador		
Environment, Climate Change and Municipalities	Environmental Protection Act	Regulates developments to protect the environment and facilitate the management of natural resources in the Province.
New Brunswick		
Department of the Environment and Local Government	Clean Environment Act	Regulates the environmental impact assessment process for large scale projects (falling under Schedule A of the Act), which evaluates existing environmental conditions and potential impacts associated with the proposed development.
Nova Scotia		
Nova Scotia Environment	Environment Act	Promotes the protection of Nova Scotia's environment through environmental assessment regulations for new activities.
Prince Edward Island		
Department of Environment, Water and Climate Change	Environmental Protection Act	Promotes the protection of the environment through an environmental assessment process to evaluate potential impacts associated with new developments.
Yukon		
Environmental and Socio-economic Assessment Board	Environmental and Socio-economic Assessment Act	Promotes the protection and maintenance of environmental quality and heritage resources through an environmental and socio-economic assessment process.
Northwest Territories		
Mackenzie Valley Land and Water Board	Mackenzie Valley Resource Management Act (MVRMA) – western NWT	Regulates development applications for projects within the Mackenzie Valley and areas in the region where land claims have not been settled to protect and manage the environment for current and future use.

Regulator	Legislation	Description
Environmental Impact Screening Committee (EISC) and Environmental Impact Review Board (EIRB)	Inuvialuit Land Claim Agreement – NWT (Inuvik Area)	The Land Claim Agreement established Inuvialuit participation on co-management boards for Environmental Impact Screening and Environmental Review. These boards establish whether an impact assessment is required and the review those assessments. The federal Impact Assessment Act also applies, and assessments are conducted with both Inuvialuit boards and federal agency involvement.
Nunavut		
Nunavut Impact Review Board	Nunavut Land Claims Agreement	Establishes the co-management of development and processes for examining land use and development projects within the Territory. EIAs for projects managed through Nunavut Impact Review Board, and through the federal Impact Assessment Act process.

Most of these assessment processes focus on legislative requirements for environmental protection and mitigation of impacts. Other than northern EIA processes, none have formalized a life-cycle approach to evaluate and mitigate the social, economic and environmental implications of a project. Best Management Practices created by Ontario Parks [15] require an environmental assessment for new road or major maintenance projects that considers all ecological costs and benefits, and opportunities to maintain or enhance the ecological integrity of the road. This policy also suggests that project managers should plan to retain at least 10% of the project's budget and staff time for environmental protection. In practice, such a generalized budgeting approach may be challenging to implement. Sensitive habitats, or sites with species at risk, may require more complex and costly mitigation measures, while other projects may require only standard mitigation, such as reclamation and weed management. Regardless, the principle is quite relevant: planning for the cost of mitigation and follow-up monitoring will help ensure implementation.

The benefits of these comprehensive assessments include compliance with environmental legislation, and careful consideration of future operational impacts that might impose longer-term environmental impacts. Such reviews also allow transparent evaluation of the management trade-offs that may be required to manage impacts, which can help to satisfy public concerns regarding a given project. Section 2.4 outlines more specific evaluation methods that could be used to consider the trade-offs and benefits of a particular mitigation approach for a road ecology concern, as another alternative to a comprehensive assessment process.

The road engineering design process life cycle across Canada generally incorporates other forms of environmental assessment within functional design, detailed design and construction implementation. During these design stages, advice from an appropriate environmental professional (e.g. wildlife ecologist, vegetation ecologist) can help to identify and mitigate concerns, such as known wildlife travel routes or areas supporting rare plant communities. Since most road ecology problems are project and site specific, identification and scoping of potential problems is a critical step in evaluating road development and management options to ensure solutions are practical and specific to the concern. For example, early design may recommend wildlife crossing structures be incorporated into a project, but not where. Environmental professionals can help identify potential problems that could be alleviated through design changes, or flag sites where mitigation may be required, early enough in the process to incorporate into project budgets.

For operations and maintenance, the opportunities for constructive review of environmental concerns are less structured, and review tends to be done on an 'ad hoc' basis, as standards change or issues emerge. Regardless, defining the problem to be solved is essential to avoid mitigating symptomatic issues, rather than the root cause (e.g. use of warning signage at a site with high WVCs, where a crossing structure might be a better long-term solution).

From a practical standpoint, these procedural design processes can aid or detract from management goals, and additional cautions are worth consideration. For example, while the design process may consider a variety of perspectives, including ecological concerns, the construction stage of a road project is where the practicality of road mitigations are first tested. Plans may be adjusted for constructability, safety, or cost considerations, diluting their potential effectiveness [16]. While interdisciplinary reviews may be applied during design, the design team is not always retained through the construction phase, when additional adjustments may be applied. Pre-construction planning and inclusion of dedicated environmental personnel during construction are essential to ensure that planned measures are implemented as intended, or enhanced if circumstances allow [16].

Project-specific assessments and periodic updates to specific operational procedures do not necessarily consider broader landscapes at which ecological processes, such as habitat connectivity, play out. Often such assessments are outside the mandate of transportation ministries. Municipal and regional land use planners will often consider such environmental concerns in long-range planning, but as Laurance [17] notes, the absence of comparable federal zoning system means that the ecological, social and economic benefits of new and improved road systems may not be consistently assessed. While recommendations for national-level land use planning are well beyond the scope of this synthesis, examples of regional coordination and co-management do exist (e.g. caribou management), and illustrate how broader, regional planning might be implemented within a collaborative or strategic project planning process.

This synthesis identifies mitigation options for the current ecological concerns associated with Canadian roadway systems, applicable to the design review and the operational revisions periodically done by transportation agencies. The management considerations described above can be applied as guiding principles for anyone involved in road design, construction, operation and maintenance. Key recommendations include the following:

- Engage environmental professionals to assist in the review of a project early in design, and ideally, maintain involvement through to construction for continuity.
- Work collaboratively to ensure that engineering, social, health, economic and environmental concerns are considered in evaluating mitigation options.
- Identify the root problem to be solved before moving toward mitigations.
- Where possible, apply the mitigation hierarchy: avoid, minimize and then, lastly, mitigate.

Additional planning steps should also consider mitigation options closely, to provide clear justification for the selected mitigation option, particularly for more costly or innovative solutions. As outlined below, such steps include identifying the goals and objectives of mitigation planning, applying the mitigation hierarchy, and evaluating mitigation options.

2.2 Goals and objectives of mitigation planning

Planning and implementation stages of management both require careful consideration of the goals and objectives for the management problem, once defined. Developing consensus around the expected outcomes of mitigation used to address road impacts builds realistic expectations regarding 'effectiveness', as well as setting targets against which actual performance can be assessed. This is particularly true when significant investment is involved, whether in terms of time, funding, or other resources. Envisioning and defining effectiveness will provide means of evaluation to demonstrate return on investment and/or information to improve the mitigation measures. Such goal setting is foundational to a robust, defensible experimental design that can help confirm effectiveness of management. Goals that are SMART (specific, measurable, achievable, realistic and time-framed) require project managers to specify the road impact that is to be managed (i.e. the problem), quantify the desired reduction in impact(s), determine objectives through consensus (preferably), match available resources and specify the timeframe over which reduction is to be achieved [18].

The multi-criteria decision process developed by Rees et al. [19], discussed below, provides a good framework for developing consensus on feasible and realistic mitigation goals, and desired outcomes. Through that process, many of the SMART aspects of sound goal setting can be established. Van der Grift et al. [18] provide additional guidelines that can be used to evaluate the effectiveness of road mitigation measures. Although these lessons were gained mainly from wildlife crossing structure projects, they offer sound advice applicable to the design, and future evaluation of most types of mitigation that might be used to address road ecology issues:

- Identify and describe the target species and goals of mitigation.
- Monitor target species that are most likely to exhibit statistically significant effects, with relatively low sampling effort.
- Select monitoring parameters that will reflect the anticipated outcome (i.e. the factors that will demonstrate 'successful' management), and ideally reflect explanatory variables describing how or why mitigation was effective.
- Develop a defensible study design that will lead to rigorous conclusions.
- Use model simulations to determine appropriate sampling regimes (and note that models may also be useful in the previous step, to demonstrate anticipated ecological benefits and feasibility).
- Select monitoring and control sites based on the objectives of the evaluation (e.g. selecting sites where collisions are anticipated to be reduced, and unmitigated areas for controls).
- Use survey methods that can monitor several species simultaneously, to maximize survey results.

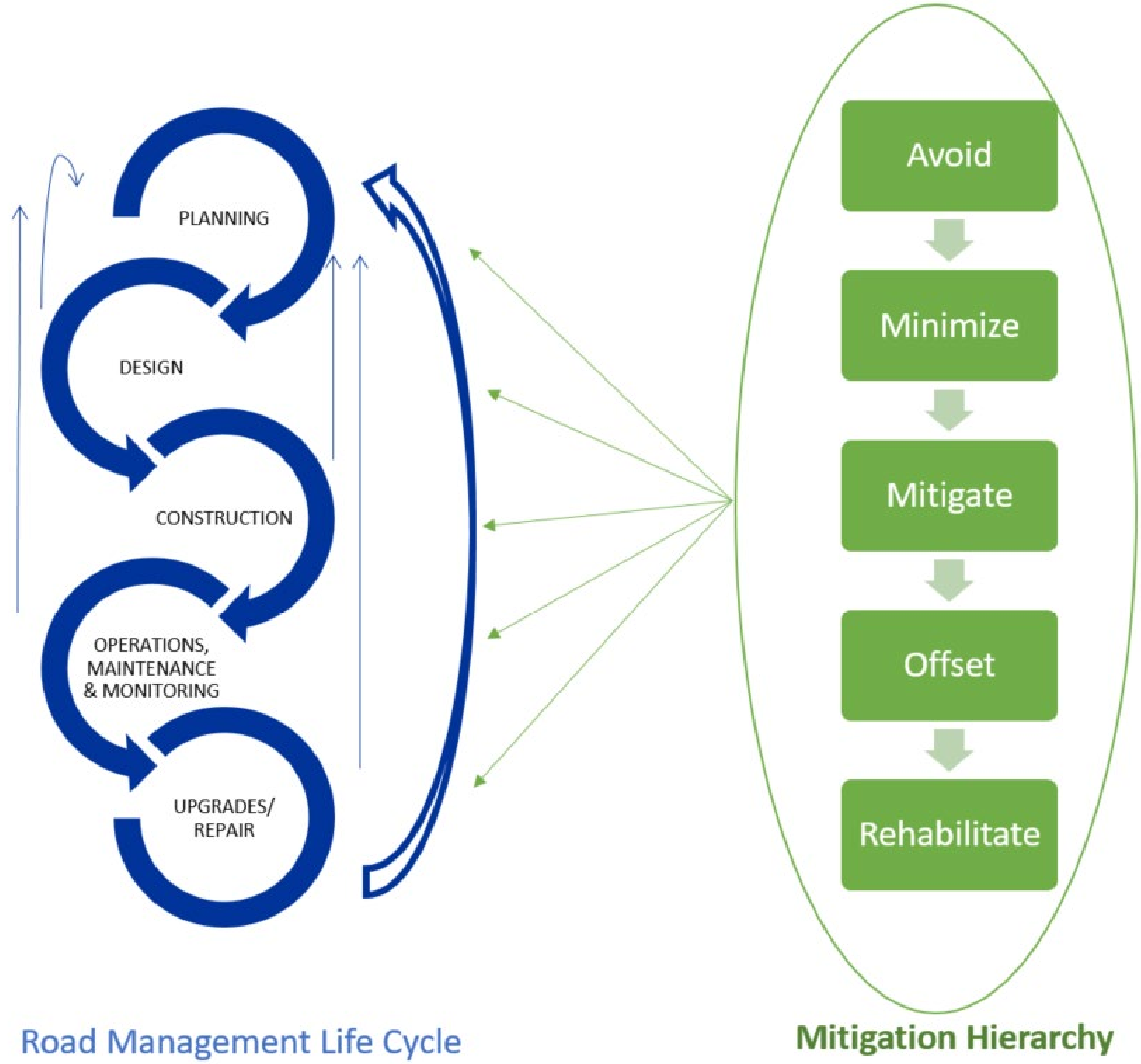
Together the multi-criteria decision process, and identification of best measures of effectiveness of mitigation, can help project managers build the support necessary for a mitigation approach, particularly if it is innovative. Developing and articulating SMART goals and objectives through consensus with key stakeholders helps to build context specific justifications for the selected option, while also building necessary understanding and support.

2.3 The mitigation hierarchy

Environmental impact assessment aims to avoid, minimize or mitigate impacts through a structured review of a project. In the context of a road project, this review can occur at any point in road management. As shown in Figure 3 below, the mitigation hierarchy is typically applied at each stage of the road management life cycle. Mitigation can start by redesign of project aspects, to avoid impacts or minimize them (e.g. through re-routing). Such an approach can sometimes generate cost-savings in the long-term, by reducing future maintenance of mitigation measures installed to manage a predicted impact, or on-going maintenance created by conditions at the road alignment (e.g. roads crossing caribou migration routes). In most environmental assessment processes today, this mitigation hierarchy is considered a standard planning approach, although in practice decisions about mitigation choices are often evaluated relative to social, economic and environmental concerns [20]. Avoidance may not always be possible, given other project constraints, but, increasingly, government transportation agencies are being required to demonstrate that avoidance and minimization were considered.

Where impacts are addressed by legislation, consideration of the mitigation hierarchy is a required step in project planning. For example, permitting processes for wetland impacts in Alberta and Manitoba must describe the efforts used in avoidance and minimization, before compensation will be approved. Such regulatory requirements affect schedule and project cost, which must be incorporated into the overall project timeline. Legislated processes will often also differentiate between mitigation and off-setting, habitat compensation provided in another location, and require specific rehabilitation or reclamation (e.g. through specific landscaping seed mixes). This synthesis included all of these aspects of 'mitigation' in describing the practices applied to address road ecology concerns.

Figure 3. Integration of road management life cycle and mitigation hierarchy



The roadway management life cycle introduced in Section 1.2 typically triggers a return to the planning stage when change is required. The upwards feedback loops on the road management life cycle (Figure 3) represent the need, as part of due diligence, to return to the planning step when conditions change or significant potential impacts are likely. Planning reviews are also required when mitigation options are identified, and so there is opportunity to apply the mitigation hierarchy, as shown in Figure 3. The detail and depth of assessment at each stage in the road management life cycle depends on the scale of the project, the potential ecological impacts and regulatory approval pathways. In many cases, such as for routine maintenance or small repairs, the planning and design stages may be quite small. For larger projects, the planning and design stages may take a few years, and, where required, follow an environmental impact assessment process. Regardless, the need for a planning review also allows for the opportunity to consider mitigation options.

The mitigation hierarchy should be applied at each and every stage to ensure that ecological impacts are avoided wherever possible, but particularly at the early stages. The opportunity for avoidance and minimization declines as the life cycle progresses, since those stages address established infrastructure. For example, avoidance can best be achieved during planning, by selecting roadway corridors that avoid important habitats, while micro-siting of the road within the selected corridor occurs during detailed design. At the subsequent stages of construction, operation / maintenance and upgrading stages, little additional avoidance can occur.

2.4 Mitigation rapid assessment decision tools

As noted above, transportation agencies are faced with balancing ecological, financial and social aspects of road management, and must consider all of these factors in selecting an appropriate solution for road ecology concerns. For many agencies, benefit-cost analysis is used to justify the expense related to potential conservation solutions, yet these methods do not always consider co-benefits that may apply. For example, some conservation measures can reduce future maintenance requirements relative to invasive species, reduce WVCs or enhance pollinator habitat. Multi-criteria decision analysis approaches can assist in the decision-making process, by considering benefits, costs and co-benefits of proposed solutions. For Canadian road systems, such frameworks can be helpful in bringing together site-specific considerations, such as winter and summer operational challenges, which may not apply in all geographic locations.

Frameworks that would facilitate such multi-criteria decision analyses have been developed for specific road ecology mitigation measures and projects [21,22,23]. While a useful approach, often they have used a cost accounting model that considered input costs and benefits that may vary in different jurisdictions (e.g. insurance and property costs for wildlife collisions, relative to material and maintenance costs of fencing or crossing structures). Such frameworks can be adapted to other jurisdictions, but would require additional research to make them relevant to local context. In contrast, Rees, et al. [19] developed a framework for analysis of conservation strategies that simplifies the analytical process into a rapid assessment of co-benefits of proposed options. Their approach offers the advantages of transparency, flexibility, speed, and ability to bridge into the project implementation phase by prioritizing a series of options according to their costs, feasibility and benefits to key stakeholder interests. Since these considerations are typically also the factors of most interest to transportation managers and the public, such a framework offers means to evaluate and identify potential mitigation options for a given site.

The approach was designed as a semi-quantitative process that determines a cost-effectiveness score (CE) for each proposed option ([potential ecological benefit x feasibility]/ overall strategy cost). While their initial use of this method evaluated options for invasive species impacts in agricultural areas, relative to biodiversity and agricultural interests, their approach is also easily applied to management practices related to road ecology. The advantage of this approach lies in a flexible approach to determining the ‘ecological benefits’ and ‘feasibility’, which considers site-specific conditions and conservation/transportation interests. These two parameters can be developed based on qualitative methods, then translated to a relative scale. Further, these values can be determined through evaluation of the design, planning and operational considerations identified in this synthesis document, and/or consultation with various local experts.

This approach is particularly useful in the context of this synthesis, which identified both well-used mitigation practices with regional evaluations (e.g. regional wildlife collision mitigation reviews [24,10]), and newer practices, lacking widespread application. The information provided in this synthesis is organized to present design and planning, operational and maintenance considerations that could be used in using multi-criteria analysis to evaluate mitigation options at the project level.

3. Wildlife collision mitigation

Wildlife collisions are challenging to mitigate due to the varied circumstances influencing animal use of roadside habitats, and their behaviour near roads. For example, animals may attempt to cross roadways to access other habitat, an event that may occur seasonally or daily. Some wildlife species are attracted to road ROWs (e.g. for new vegetation in spring, or salt in winter), and may cross the roadway to escape vehicles, or to access other parts of the road ROW. Some of these crossing events may be seasonal and species specific (e.g. during deer or moose mating seasons, or bear foraging along roadsides during early spring green-up). Other crossing events may involve a range of species that cross at a given location due to favourable terrain conditions, or proximity to important core habitats. A large part of avoiding potential collisions requires an understanding of the behavioural factors that draw wildlife to be active near roadways, to design mitigation that can eliminate or reduce collisions, yet still allow wildlife to access the habitats, mates and resources they require. Human behaviour must also be considered, to ensure road users remain vigilant for potential crossing activity where absolute avoidance is not possible.

Road collision mitigation is one of the most advanced techniques used in road ecology, and measures are now being applied around the globe, with projects in Europe, South Africa, China, India, and Australia [4]. Yet, the earliest application of many of those techniques has been in North America, and in Canada with road crossing structures in particular. The sections below describe various types of management practices developed to prevent WVCs, and their application across Canada. Many of these techniques have been used for decades, and BMPs can be recommended based on research on their effectiveness. For some practices, like collision warning signage, mitigation approaches have been adopted as traditional practice, with limited assessment of their effectiveness. Such practices are only now being assessed, and new evidence-based BMPs are emerging. Where gaps in knowledge exist, those are noted in summarizing relevant BMPs.

Case studies provided at the end of this section give examples of wildlife collision mitigation in practice, with a summary of the challenges and lessons learned. Lastly, any additional resources applicable to wildlife collision mitigation in Canada are listed.

3.1 Planning for avoidance

3.1.1 General overview

The extensive research and development of road crossing mitigation measures has obscured one of the most important, and effective, means of avoiding collision impacts: identification of corridor locations, and avoidance through design. A growing range of tools and information are available to planners that are affordable and site specific, including wildlife cameras and digital data. As such tools become more universally incorporated into road management, planners can work collaboratively with transportation engineers and managers, as well as the public and other stakeholders throughout the road management life cycle, to identify potential WVC sites and consider options for avoiding or managing potential concerns through the mitigation hierarchy.

The availability of geographic information systems (GIS) data and analysis techniques can help identify wildlife movements at the landscape level, and plan new roadways to avoid key movement corridors. Road crossing observations, both successful or resulting in collisions, can also be used to identify areas with high probability of crossing activity, where mitigation could reduce human and wildlife risk [25]. Such tools can also help identify sites where crossing structures might be best placed for early adoption by wildlife known to use a project area. The resulting information can be readily incorporated into the design phase of new roadway design, or in the retrofit of existing roadways, to upgrade or widen lanes, in urban or rural locations [24,10,26]. Lastly, such information can inform agency policies, mitigation, future research, and public and stakeholder engagement, as has been done by the British Columbia Ministry of Transportation and Infrastructure (BC MoTI) (see Text Box on BC MoTI Wildlife Program).

BC Ministry of Transportation and Infrastructure Wildlife Program

2020 Finalist, TAC Environmental Achievement Award

The BC MoTI has developed a Wildlife Program over the past decade to protect wildlife and prevent WVCs through all stages of the road management life cycle [39]. The program includes five components that aim to inform all aspects of WVC avoidance and mitigation:

- Monitoring, analysis and evaluation
- Policy and design standards development
- Mitigation
- Research and innovation
- Communications, public outreach and stakeholder engagement

The program's modest annual budget is maximized by leveraging stakeholder relationships with First Nations, ENGOs, external professionals and academics, as well as public support. Collaboration and outreach, through programs such as the Wild Kidz Camp offered with the BC Wildlife Federation, allows BC MoTI to build support for large, high-profile and many smaller projects. Research, pre-project and ongoing monitoring of wildlife activity and use of crossing structures supports evidence-based planning by demonstrating mitigation effectiveness.

Photo credit: Leonard E. Sielecki, BC Ministry of Transportation and Infrastructure

Globally, crossing mitigation has been informed by available, context specific data, including wildlife surveys of various forms and, to a lesser degree, landscape level analysis. Well designed scientific analysis of road impacts, in general, is lacking, which has limited the improvement of mitigation and 'best practice' [27,28]. Further, there are a variety of field assessment methods that can be used, but without a sound research design, and clear objectives, the data may not inform mitigation as intended. Further, data gaps exist for some ecosystems and species responses to road development and use [27], and base research may be an important first step of mitigation design. Crossing mitigations in many jurisdictions has focused on larger animals, and particularly species at risk (e.g. jaguars in Central America, elephants in Kenya [29,30]). North America has had a similar focus on large animals, including carnivores (e.g. bears), and herbivores (e.g. deer, moose and elk [31,21,25]). Road mitigation and behaviour of small mammals, amphibians and reptiles are only beginning to be considered [32,33].

Various jurisdictions across Canada have established some form of tracking collision data and often such datasets have been used in planning collision mitigation efforts. For example, Alberta Transportation has developed an application for use by government staff and other highways workers, to record observations of both live animals and road mortality [34]. The data collected is used by Alberta Transportation planners to identify high risk collision areas, by way of statistical analysis. Such statistical analysis tools are discussed in further detail in Section 3.4.1 below. Yet wildlife crossing mitigation in Canada is mainly informed by the extensive study in specific locations, such as Banff and adjacent mountain National Parks, British Columbia's mountain highway systems, and Quebec's highways, in boreal forest conditions. Other ecosystems in northern Canada, the Prairies and the Maritimes have had far less study.

Analysis that extends beyond the road itself, to consider the influence of the surrounding landscape, can be even more critical to planning mitigation and avoidance strategies [27]. Animals move for various reasons, but are typically driven by a need to reach suitable habitats, ideally through habitat that offers hiding or security cover. For example, seasonal movements such as migration involve long-range travel to habitats for breeding, calving or overwintering. More frequent movements at a given location may be linked to use of a large home range by individual animals, or by terrain constraints on movement that direct movement to a specific location. Knowing what drives animals to cross roadways, and the potential use of adjacent habitats, can be critical to avoiding fragmentation of critical habitat or to facilitating design of effective mitigation. In an urban context, an understanding of existing and future land use in lands adjacent to a roadway can help identify where wildlife movements are or will be constrained to narrow zones that funnel movement to a specific location (e.g. river valleys and riparian areas [24]).

Consideration of local context information has other benefits for design and construction of crossing mitigation [36]. Local-scale connectivity will be best protected by ensuring lands on both sides of the structure are managed for wildlife movements in the long-term. An integrated design approach that considers regional level mapping tools and ecological information (e.g. terrain, natural areas mapping, or ideally, wildlife movement or connectivity mapping), early in the design process, can help to avoid future conflicts. Early identification of crossing locations allows for economies of scale during construction; contracts for crossing structures, fencing and other measures can be grouped to benefit from lower unit prices and other cost benefits. Similarly, staying informed of other highway improvement projects, or future plans, allows for measures to build on other mitigation measures to achieve synergies. This can include anticipated changes to highway standards that may influence design or location of planned crossing structures and other mitigation.

Such landscape level factors are often examined during environmental impact assessments in Canada and in other jurisdictions, and can draw on various information sources, such as research data on specific wildlife populations in an area (e.g. caribou herd movements, bear home ranges), or GIS landscape analysis to identify potential habitat corridors and core habitats. Other relevant information that should be considered in the road planning stage is the scale of potential impacts on wildlife movement and corridors (i.e. affecting local movements, or broader, regional travel corridors connecting key habitats [24]). Data on past WVCs can be helpful in identifying high risk zones on existing roadways, prior to planned improvements [24]. Similarly, winter tracking data or wildlife camera data can be used to confirm road crossing activity by wildlife at specific locations. Such data can also help to design species-specific mitigation strategies (e.g. wildlife crossing or passage structures) suitable for the species known to be active in the area. BC MoTI's Wildlife Program has adopted wildlife camera monitoring as a preliminary design step to identify species-specific modifications, as part of ongoing maintenance of its existing crossing structures [35].

While site selection is often considered in environmental assessments, options for engineering design are not always done in an interdisciplinary, collaborative approach. Evaluation of design lifespan should fit the expected contextual setting and other functional goals of the mitigation measures. Exploring design options for crossing structures can create alternative solutions to meet design standards, and achieve ecological goals [36]. For example, buried bridge designs can be cost-effective solutions, from a construction, operational and ecological perspective. Seeking locations that can minimize the need for structural fill by taking advantage of adjacent grades may also facilitate wildlife use by reducing graded transitions. McGuire et al. [36] offer a variety of design alternatives, including reuse of materials, combined use of structures, and experimentation of new materials and methods.

Lastly, characterizing existing road infrastructure that could be retrofitted to improve or provide wildlife passage under roads can provide a cost-effective road crossing solution [37,38]. Bridges and large culverts can provide passage under roads, with additional vegetation or other hiding cover. Similarly, small culverts to be replaced during road rehabilitation projects can be sized to support movement by smaller animals (e.g. amphibians, small mammals), and made safe with relatively simple enhancements, like wing fencing or vegetation screens. An understanding of opportunities to add value to existing or required road infrastructure can offer options not immediately evident to project designers.

3.1.2 Mitigation implementation in road management

Identifying wildlife movement corridors is most effective during planning stages for new roadways or improvements to existing ones, when alternative routing could be used to avoid impact. This information can also be useful during design of upgrading or widening of existing roadways. Understanding the location of potential corridors, and species and timing for use of such areas provides important context for decisions regarding options to avoid, minimize or mitigate impacts to wildlife movements. For example, wildlife road crossing areas used seasonally might be appropriate sites for temporary warning signage [40], while more frequent use might require a combination of fencing and wildlife crossing structures to avoid collisions, yet still facilitate habitat connectivity [41]. Various techniques have been used across Canada to identify and monitor potential crossing locations.

GIS landscape analysis

Various GIS analysis tools are available to assist in identifying the landscape features that may contribute to animal movements across a proposed or existing roadway (e.g. CircuitScape, least-cost path analysis). Most of these tools are desktop analyses based on terrain and aerial imagery. Results can be enhanced by combining with data on known crossing sites, and ideally would include both successful crossings and collision sites [26,3]. An understanding of core habitats (larger habitats that can support high biodiversity and abundance), and larger movement corridors like major river valleys and stepping stones (habitat patches enhancing connectivity), can help to identify movement patterns that can be incorporated into project design. This information can help identify critical pathways that, if maintained, can sustain regional or local biodiversity. Various options may be available to avoid intersections with existing corridors or to maintain connection, and involving a road ecologist early in the design phase of a project may help identify such possibilities.

Where collision or live crossing data is not available, expert opinion, literature based models [42] and other spatial movement models have been used to identify movement corridors that intersect roadways (e.g. CircuitScape analysis [43], or multivariate analysis of landscape variables [44]). This method has the potential advantage of identifying likely corridors used by a broad variety of species, but being a model, it is limited by the depth of understanding of those parameters predictive of ‘good’ movement corridors, for all target species. Few examples of such modelling approaches to mitigation planning have been published, in part because model validation often relies on site-specific WVC or live crossing data, such that the models are not generalizable and may reflect only unsuccessful crossing sites, rather than all crossing locations [3]. Species-specific habitat requirements may also be applied, but the corresponding behavioural reaction to roadways are not always available, or incorporated. Use of such models can be improved through consultation with transportation planners, engineers and ecologists familiar with the project context, to incorporate known behavioural responses. Models that incorporate management scenarios are also feasible, if confounding and interacting variables can be adequately controlled. For example, clearing a wide ROW improves driver and animal sightlines, but may also attract more use of road ROW for grazing, a factor that would need to be included in model parameters.

Identifying large mammal crossing sites

Based on past studies that have noted correlations between road contextual factors, a first step in developing mitigation for large WVCs often involves identifying crossing hot spots, and the species involved. Most transportation agencies in Canada now collect information on WVCs, which at a minimum typically includes the species involved, a specific road location (e.g. kilometer post) and the date. In some cases, these datasets extend over decades, and allow analysis to identify areas where animals have consistently crossed roadways, and the patterns of use (e.g. seasonality). Alberta Transportation has developed a statistical framework to use its extensive highway collision data to identify cluster locations where mitigation might be applied. WVC data reflects unsuccessful crossings, and does not necessarily capture all potential crossing activity. BC Ministry of Transportation and Infrastructure (BC MoTI) has begun monitoring live crossings at suspected corridor locations, in advance of mitigation design, which provides species-specific data, plus, frequency of use, temperature, time of day, and traffic levels. Both live crossing and collision clusters can inform decisions regarding new crossing structures, and associated cost-benefit discussions.

As an example, cluster analysis was used to develop a comprehensive strategy for WMC mitigation along the Yellowhead Highway and the Canadian National (CN) Railway through Jasper National Park and Mount Robson Provincial Park, as part of an effort to improve habitat connectivity [26]. Data was compiled from records held by Parks Canada, British Columbia Ministry of Environment, BC MoTI and CN, and analyzed to identify species and collision locations, and clustering of WVCs. In this instance, they were also able to combine WVC data with live wildlife observations from the park agencies, which generally showed a correlation between sightings and collisions. The analysis allowed the authors to recommend crossing structures (large overspan bridges and large mammal underpasses plus wildlife overpasses), supported by cost-benefit economic comparisons. As Rytwinski et al. [45] caution though, collisions do not always indicate all crossing attempts, and live crossing observations may also highlight future potential areas of concern. This consideration may be particularly relevant if road or traffic conditions change in the future (e.g. wider roads, more traffic volume).

Such studies highlight the need for ongoing, spatially accurate data collection for road WVCs (and rail, since they often share a transportation corridor), not only to quantify impacts, but to ensure that crossing structures and associated fencing are installed where crossing movements are occurring. Crossing sites can vary in length, depending on the species and the adjacent habitat characteristics. Gunson and Zimmermann Teixera [3] cite examples of moose crossings along a 1 to 2 km section of road, and others involving species with specialized habitat requirements and low mobility (e.g. turtles), with several grouped crossing sites of 100 m each. Understanding where crossings are likely, ideally from both WVCs and successful (live) crossing data will help ensure design of successful mitigation.

Many provincial and territorial transportation agencies began WVCs data collection informally, through individual branch offices and using paper formats. More recently, agencies have identified the need to ‘go digital’, and improve both the quality and timeliness of the WVC data collection system by developing a web-based data management system for data input and management, and a standardized data collection and management system. Examples include the Yukon Territorial Government [46], BC MoTI [47] and Alberta Transportation’s Alberta Wildlife Watch program, in partnership with Red Deer College [34]. The Alberta system is an app-based solution that incorporates smartphone GPS for accurate spatial and temporal reporting, and standardized data fields for both live and dead animal sightings.

GPS locations provide critical support for mitigation planning, since locations are more precise. Past reporting often had significant spatial error (e.g. 800 to 6,500 m [3]). Apps that collect both live and dead (WVC) data can be used to monitor crossings by species at risk, and known wildlife corridors for patterns of activity. Applications can be easily shared with other jurisdictions too, facilitating coordinated management. Expansion to include police, citizen scientists, truckers and other frequent road travelers is possible, and would greatly enhance data collection efforts, particularly for live sightings [34]. Potential for observation bias by interest groups can arise, but this effect can be reduced through the study of design controls used in citizen science studies. Effective community engagement outlining the purpose of data collection can also help reduce bias, by activating a broad range of observers (e.g. the Highway 3 “Road Watch in the Pass” program by the Miistakis Institute).

Analysis techniques have also evolved over time, particularly as spatial accuracy of reporting has increased. Various statistical approaches have been developed to help identify collision clusters from WVC data, as well as the temporal peaks of collision timing:

- Ripley’s K technique for differentiation of clusters [48]
- Kernel density analysis of WVC aggregations [49]
- HotSpot Identification analysis [50]
- ‘Hot moment’ (peak timing) identification analysis [51]

Where live crossing data exists, this information would provide additional context, but as noted above, such data has historically been limited. Wildlife collision and observation recording applications, such as the systems noted above, may add both live observations and collision data to future analyses, and enhance understandings of landscape and other factors influencing collision risk.

Such collision analyses have also been combined with landscape and vegetation features to identify habitat features associated with WVCs in a particular context [32,52,53]. Siriema is a free software package that analyzes spatial distribution of WVCs along roads (www.ufrgs.br/siriema), using Ripley's K function and HotSpot Identification analysis [3].

Identifying small animal crossings

As with larger wildlife species, it is important to understand when, where and why small and medium WVCs occur along roads, to ensure appropriate collision mitigation is installed. WVCs with small to medium size mammals, amphibians and reptiles tend to increase around open water and WVCs may occur within several hotspots of relatively short length (e.g. 100 m) for species with low mobility or specialised habitat requirements [3]. As a result, localised mitigation is required at each hotspot, which in turn can increase mitigation cost. Gaining clear understanding of where crossings are located, and the number of crossings involved, can help justify mitigation expense, but often such data is lacking. WVC data collection frequently focuses on larger animal collisions [34], because of public safety implications. Regardless, methods for habitat analysis, and past research on crossings have been used to design smaller animal crossings, and can be helpful in creating mitigation strategies.

Clevenger et al. [42] found species-specific use of drainage culverts relative to traffic volume, noise levels and road width, for a range of small to medium-sized mammal species [42]. Culvert use increased for American martens, snowshoe hares and red squirrels with traffic volume, which was a critical variable for these species. In contrast, culvert use by coyotes was negatively correlated with traffic volume. Increasing noise and road width were negative influences on culvert use by coyotes, snowshoe hares and red squirrels. Based on these results, they recommended frequently spaced culverts (e.g. 150–300 m), with abundant vegetative cover near culvert entrances. Mixed size classes were also recommended, particularly if large animal crossing structures were not also available.

Gunson et al. [26] developed a GIS modeling tool to predict high-risk road mortality locations for selected wetland-forest amphibian and reptile species that are representative of the landscape. Validation of the model with on-road presence (alive and dead) data showed animals were more at risk of road mortality when roads bisected large areas of wetland-forest habitat. Municipal and provincial level agencies used modeling output to develop small mammal mitigation along a 50-km extension of a four-lane freeway in Ontario. Although there has been some success with these mitigation measures, future research requires specific modeling for each target species on a road-by-road basis, and measuring the predictive power of model results within similar landscapes [26].

Monitoring

As discussed in Section 2, a key aspect of mitigation planning should involve monitoring. Since most wildlife crossing management solutions are necessarily customized to site-specific conditions, monitoring is essential, both as part of the initial planning stage, and during operation. Monitoring of suspected crossing sites, or those where retrofitting is considered, prior to developing mitigation plans can ensure species-specific mitigation design. Monitoring data can also provide evidence of effectiveness for constructed measures, to help justify not only the initial investment at one site, but other future applications within a given jurisdiction. Such programs have become central to on-going support of crossing mitigation, British Columbia's wildlife management system, as an example [47]. Project managers should be sure to include sufficient budget to monitor mitigation measures once implemented. Since wildlife may require some time to become accustomed to mitigation (e.g. wildlife crossing structures and fencing), monitoring should be scheduled over several years during the operational phase of a project.

3.1.3 Beneficial management practices

Key management practices identified in the literature include the following activities, applicable during road project planning, design, operation or maintenance:

- Consider habitat connectivity from a landscape level early in project planning phase, when potential impacts to movement could be avoided or minimized in route selection. Corridors that lead into private lands are subject to changes in land use and may not be sustainable as crossings, unless long-term agreements that establish conservation guidelines are established with landowners (e.g. conservation easements).
- Enlist a road ecologist familiar with landscape level analysis, and relevant data sources, to identify potential connective habitat features and help design mitigation options to avoid, minimize or mitigate impacts on animal movement to prevent potential WVC.
- Consider data on live crossings and WVCs in identifying sites in need of crossing mitigation to avoid collisions. If possible, use wildlife cameras at suspected sites to confirm crossing frequencies, species involved and other contextual variables, to ensure mitigation design is tailored to fit actual activity.
- Ensure sufficient resources are available to continue monitoring after implementing mitigation measures, using a scientific design that can confirm mitigation effectiveness against project goals and objectives.

3.2 Collision warning systems

3.2.1 General overview

Traditionally, warning signage was the main mitigation applied at known WVC sites. Inexpensive to install and maintain, signage relies on driver awareness to avoid collisions with wildlife. Collision warning systems have since evolved, and various options have been developed and applied in various jurisdictions, based on a better understanding of both wildlife and human risk perception. Signage is commonly used in many parts of the world; animal detection systems are a newer mitigation, applied in fewer locations [35,54].

Collision warning systems, whether through signage or electronic means, will not, however, eliminate all collisions [35,54]. Where the goal is to reduce collisions more effectively, exclusion fencing is a better solution [54]. New techniques continue to be developed and tested, alone and in combination with other forms of WVC mitigation, to improve reliability and cost-effectiveness. Few 'tried and true' solutions have yet emerged, due to a variety of factors that affect consistent performance, and thus perceived cost-effectiveness.

Generally, warning systems aim to reduce collision risk by altering human and/or animal behaviour [54]. Ideally, the warnings are tailored to communicate risk in ways specific to humans or the animals of concern. Key considerations include the following factors:

- A one-size-fits-all solution does not apply: the most effective warnings may not necessarily be perceptible to both people and animals, or even to a broad range of wildlife, and a combination of mitigation measures may be needed.
- Animals and humans are both more responsive to actual than unrealized risk. Warning systems that are misplaced or only relevant at specific times tend to be ignored, since the threat is not perceived to be real or probable.
- In the Canadian context, systems must operate in varied weather conditions, from deep snow to fog. Costs of some options (e.g. electronic sensor systems) may be prohibitive in terms of installation, maintenance and operational budgets, given these demands.

Such limitations have not always been understood by practitioners, leading to unrealistic expectations of performance, disappointment and misperceptions of mitigation value. Such experiences may also have justified reliance on less effective, but inexpensive, traditional solutions (e.g. static wildlife crossing signage). As new approaches are tried and evaluated, additional design considerations may emerge that would promote change in practice. Current warning systems in use for reducing WVC, and considerations for their use, are summarized below.

3.2.2 Mitigation implementation in road management

Humans and wildlife can become habituated to permanent warning systems, particularly if the location and information conveyed do not accurately describe the risk of collision. Huijser et al. [55] completed a thorough evaluation of these systems, and their effectiveness, in terms of human and wildlife safety. Their review highlights the application of the four most common forms of warning systems (discussed below), all of which mainly target warnings toward drivers rather than wildlife:

- Permanent (static) wildlife warning signage
- Enhanced wildlife warning signage
- Temporary warning signage
- Animal detection and warning systems

Permanent signage

Permanent wildlife warning signage is intended to reduce WVC by notifying drivers of wildlife activity on or near a road [40]. TAC's *Manual of Uniform Traffic Control Devices for Canada* (MUTCDC) provides recommendations for use of signage for various large animals (moose, deer, etc.) and for crossing areas longer than 1 km, as well as specifications on sign placement. Such guidance imply an accepted level of effectiveness, but recent research has challenged such assumptions.

Although initially, the primary goal of signage was to improve human safety; it has not always proven effective in terms of human safety or wildlife mortality. Yet warning signage is still being used in this manner across Canada on urban and rural roads and highways, in part due to cost of more technical solutions, but also the well-established, historical reliance on the practice. As a simple and relatively inexpensive mitigation, signage has been used for decades to reduce WVCs, but when used in isolation of other mitigation measures, the signs appear to be ineffective in reducing collisions [40].

The intention of the signs is to notify drivers of potential for a vehicle collision with a particular wildlife species or group of wildlife species on a section of a road. The selection of these sites is typically based on previous vehicle wildlife collisions and the signs are a static mitigation technique that do not usually communicate risk associated with a specific crossing location, season or time of day [40]. For example, risk may be higher in breeding or migratory seasons, or over a short (tens of metres) to long (kilometers) distance, but this information is not always specified on the sign. Some agencies use signs that can be changed to show seasonally relevant messages about crossing activity, which may be more successful in communicating risk to the motorists.

Once the sign has been established, the relevance of the sign location is rarely reassessed, even after environmental and infrastructure conditions in the area have changed. As a result, drivers tend to disregard the warnings, since the assessed risk seems inaccurate.

Figure 4. Permanent wildlife warning signage

(credit: Karen Truman)

Enhanced warning signs

An advancement of the permanent wildlife sign is an enhanced wildlife warning sign, which involves additional features such as flashing lights, bright flags or even a screen with customized text [40]. The enhanced signs have been designed to attract driver attention and even provide information about the safety and conservation nature of the crossing warning. For example, trailered electronic screens (portable variable or changeable message sign) can be positioned in key crossing sites, and updated to describe the animals of concern, their probable locations (e.g. “bear near road over next 5 km”), and the recommended driver precautions (e.g. “no stopping, lowered speed limit”). The advantages of such systems are the ability to adapt to changing conditions, alert road users to new concerns and provide a more dynamic warning (flashing lights) designed to capture driver attention. They do involve more expense to maintain and update than traditional static signage.

Monitoring of effectiveness of such signage would be helpful and is lacking. Anecdotal evidence suggests such signage has helped reduce WVCs, but little evidence-based evaluation is currently available for applications across Canada.

Temporary warning signs

The temporary wildlife warning sign is even more specific to a time and place [40]. These signs can communicate risk to drivers for a particular season or time of day (e.g. evening). Seasonal warning signs can be temporarily placed where roads intersect migration corridors, for species ranging from amphibians to bighorn sheep. If time of day plays an important role in the elevated risk of WVC, signs can be permanently mounted, but the message can be enhanced during a particular time such as dawn or dusk (e.g. through flashing lights). Alternatively, enhanced warning signage, such as portable variable message signage, may be used so that the message can be changed to update to current concerns (e.g. during peak migration or feeding times). Such signage has been used in recent years on Highway 93 in Radium National Park to warn road users of bear activity near roads in spring. As noted above, however, its effectiveness in terms of reduced WVCs has not been assessed.

Animal detection systems

The most recent advancement in wildlife warning signs involves animal detection systems [40]. These systems detect large animals (i.e. deer or larger) as they approach or attempt to cross the road. When triggered, the system sets off a warning to drivers. Past applications relied on passive warnings to wildlife, such as wildlife reflectors or mirrors mounted on roadside posts, which use reflections from car headlights to create a flash intended to mimic eye-shine of a possible predator [45]. This system had limitations for some wildlife species (e.g. predators) and led to development of systems that use electronic sensors to detect wildlife activity near a road, then trigger warnings for drivers.

Electronic detection systems rely on infrared sensors or cameras to detect wildlife on or near highways [56,57,58]. These electronic systems are at an early stage of development, and, in North America, have been used in relatively few locations (e.g. British Columbia, Ontario, Glacier National Park and Idaho [59]). Other systems have been used internationally (e.g. Europe and Australia), but with mixed results [59], mainly due to limited data examining their effectiveness [54]. Examples range from the remote digital infrared-operated camera shown in the the images below, to more expensive sensor-warning array systems. They are expensive to install, maintain and operate, particularly in areas with deep winter snow cover, and as yet, have not been proven to be effective, mainly due to a lack of well designed monitoring studies [40,45]. Such operational considerations have been examined in a study of a warning detection system installed on British Columbia highway systems (ICBC Case Study, Section 3.5).

Innovative approaches trialed in Banff National Park to mitigate railway collisions recognize the capacity for animals to learn and adapt to changing conditions [13]. In a five-year pilot project [underway at time of publication], researchers installed sensors on railway tracks in high collision locations which activated bells and warning lights intended to alert bears and other large animals of approaching trains. The system has been effective in reducing collisions, and its application to date suggests that both drivers and wildlife can be trained to respond to warning systems. In BC, a wildlife detection system installed near Sparwood, on Highway 3 [57], uses nine thermal cameras within a wildlife corridor and radar sensors to detect wildlife and trigger flashing driver warning lights. The system has successfully detected potential crossings by herd animals such as elk, as well as individual animals like a cougar. An evaluation of the reduction in WVCs has not yet been compiled however, and its success rate[6] in deterring collisions is unclear. Such systems offer promise, as they rely on warning both wildlife and drivers of the risk, and allow both to react in a timely way. They do not reliably detect small animals though [40], and thus can be applied in locations with crossings by larger animals.

Figure 5. Animal detection system advisory signs and trailer/camera

(Credit: Trevor Kinley, Parks Canada)

As noted above, animal detection systems are still considered experimental and effectiveness will be better assessed as more systems are implemented and tested. Past studies highlight operational challenges that must yet be resolved for Canadian conditions including snow, dense fog and remote locations (see examples in Text Box 2). Like the St. Clair et al. [13] railway sensor system noted above, this mitigation practice builds on the ability for animals to learn to avoid the area, as well as prompting human reactions. Future studies on the application of such systems may provide more information on long-term reliability, operational costs and overall effectiveness.

Lastly, with advances in new automobile safety technology, some vehicles can detect potential hazards such as large wildlife species and notify the driver of a potential risk. In some cases, the vehicle can take evasive action and initiate braking. Some of these detection systems use a night-vision system based on an infrared detection [60]. Others have developed 'Large Animal Detection Systems' that compare radar detections to a database of animal shapes to identity hazards, in both daylight and evening conditions [61]. The system can be programmed for conditions where the vehicle is sold, based on studies of the animal's behaviour.

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[6] Note that 'success' metrics must also be carefully defined, as this is dependant on the goals of mitigation at a given location. In some instances, 'success' might be measured by lower driver speeds through signed zones (change in driver behaviour). Fewer collisions are not the best metric, since collisions are dependant on the number of animals attempting to cross, crossing frequency and group size. Lower collisions might also indicate a change in animal behaviour to avoid crossing sites.

Despite such advances, these systems also have limitations [61]. They cannot detect partially obscured animals, or fast-moving animals. At night, they can also only detect animals within the range of headlights. Lastly, the radar system is programmed for local wildlife species, and may not work for unexpected animals (e.g. domestic animals, less-well understood animals) or new locations. Since detection technology is not yet available on all vehicles or failsafe, collision avoidance still must largely depend on human reactions to warning cues, or other mitigation measures designed to prevent or mitigate wildlife crossings in particularly risky locations, such as fencing or crossing structures.

Wildlife detection systems – Challenges and successes

A 2002 study by ICBC in Kootenay National Park tested the design of a Wildlife Protection System that incorporated infrared cameras to detect wildlife on or near highways ([56] see TransCanada Highway Case Study in Section 3.6). When animals were detected, flashing lights were supposed to trigger and warn drivers to reduce their speed. Technical difficulties with the system prevented testing the system's ability to detect wildlife near the road, and therefore determine drivers' responses accurately. Testing was to continue after 2002, but the study was suspended due to these technical challenges.

In contrast, the Ontario Ministry of Transportation commissioned a manufacturer to create and study the effectiveness of an new animal detection system [58]. Their system used solar-powered infrared sensors that triggered driver warning signs and flashing lights one kilometer away to allow road users time to react. It later switched to a new Navdar Radar Technology, being less sensitive to adverse weather (e.g, fog, rain or heavy snow). Sensors placed 10-15 m away from the road edge identified animals as they approached, and successfully tracked moving and stationary wildlife near and on the road. Smart wireless devices allowed remote changes to the system settings, reducing maintenance costs. Other reported benefits of this new system were low annual maintenance, low initial cost due to off-the-shelf hardware and ease of equipment installation.

3.2.3 Beneficial management practices

Given the lack of effectiveness monitoring on warning systems in general, it is difficult to recommend specific BMPs relative to warning systems. Instead, authors have suggested planning approaches to consider where and how to use collision warning systems. Often, such systems must be used in conjunction with the other crossing mitigation measures discussed in subsequent sections, since warning systems, by definition, are reacting to wildlife very near to a road, with potential to cross it. Where collision risk is high, relative to human safety or wildlife conservation objectives, other practices that can prevent crossings may be more appropriate. Although a common collision mitigation practice, the role of warning signage is mainly to help alert road users to the risk of wildlife collision, rather than to prevent collisions entirely.

Rytwinski et al. [45] found that the suite of common WVC mitigation measures typically applied in North America reduced roadkill by approximately 40% on rural highways, relative to sites without mitigation. Measures included various warning systems (signage, reflectors and warning systems), applied alone or with other crossing mitigation techniques (notably fencing) and with a focus on large mammals. Standard and enhanced wildlife warning signs alone are unlikely to be effective at reducing WVCs, yet additional measures have an implicit cost [40,45]. Cost implications, and public perception of cost effectiveness both can play a role in the selection of mitigation measures, and often lead to selection of the cheaper, but less effective option [45]. Ironically, transportation managers do not always know whether wildlife warning signage, probably one of the most commonly selected option, is effective [62].

If the problem is many WVCs at a given location, then past studies recommend an animal detection system, along with other mitigation measures such as fences and crossing structures. This is particularly useful where fencing cannot be continuous, and openings may allow animals to cross the roadway. Huijser et al. [21] conducted a cost-benefit analysis of animal detection systems as a stand-alone mitigation measure for ten road sections throughout the United States and Canada, which found benefits exceeded the cost on 4.2% of 77 km of systems. When the detection system was used with wildlife fencing, where gaps were necessary, this ratio increased to 9.4%. A meta-analysis of 50 studies quantifying the relationship between road-kill and employed mitigation measures also noted that a combination of fencing and crossing structures led to an 83% reduction in road-kill of large mammals, compared to a 57% reduction for animal detection systems, and only 1% for wildlife reflectors [45].

Huijser et al. [26] identified other current limitations on animal detection systems that may affect their application for all types of WVC, which include:

- Smaller animals cannot be detected.
- Systems are undesirable on roads with traffic volumes of ≥ 20,000 vehicles per day.
- Snow depth can interfere with the detection system triggers and the system may have to be shut down in the winter7.
- Roadside trees and bushes can increase the incidence of false triggers, and therefore vegetation may need to be regularly cut in the detection area.
- The system may time out if the animal continues to feed inside the trigger zone before crossing.

Availability of a sustainable power source and cellular phone coverage are other limitations to wildlife detection systems. Some systems report operational status and crossing events through cellular networks; a lack of coverage reduces the efficiencies in monitoring the system.

Given the range of options available to manage WVCs, and the need for site-specific designs to manage this risk, Huijser et al. [40] recommend a stepwise approach when developing an animal detection system, which focuses first on defining the problem to be solved and identifying the explicit parameters defining effectiveness (Section 2.1). Step two is to decide on the warning method, additional management practices and monitoring measurements to be used. This system requires more analysis and potentially more investment than the traditionally used warning signage, as it considers the potential requirement to combine standard, enhanced or temporal wildlife signs with other mitigation options, and to monitor effectiveness.

As a final caution, studies assessing the effectiveness of WVC mitigation techniques, including wildlife collision warning systems, have found that establishing a collision warning system based only on past WVCs is not effective in the long term and that there are other variables to consider [45]. For example, both successful and unsuccessful (collision) locations indicate where crossings are likely. Live animal

[7] Note that some transportation agencies adapt for deep snowpacks by mounting sensors and cameras on luminaires to elevate them above the snowpack (e.g. British Columbia Ministry of Transportation and Infrastructure).

sightings provide important information regarding the length of crossing sites and species involved, which can inform development of a comprehensive WVC mitigation plan, including need for fencing, warning signage or, potentially, crossing structures [25]. As noted above, the effectiveness of collision warning systems, especially the animal detection system, improves when used with other collision mitigation measures such as fences [21,25,45]. The British Columbia Ministry of Transportation and Infrastructure prioritizes installation of fencing and crossing structures at known crossing locations to prevent wildlife crossings. But where these mitigations are not feasible, wildlife detection systems are preferred over static or enhanced signage, since they are considered to be more effective.

To identify suitable locations and forms of mitigation, and to support the evaluation of mitigation effectiveness, projects should include data collection before the collision warning system is established. Such data can inform appropriate mitigation options for specific locations, plus support follow-up monitoring of effectiveness. Rytwinski et al. [45] recommend such Before-After-Control-Impact designs for follow-up monitoring, implemented over a minimum of four years.

3.3 Wildlife guidance fencing

3.3.1 General overview

Wildlife fencing is exclusion fencing that prevents animals from accessing roads and assists in funnelling wildlife to other WVC mitigation features, such as crossing structures [41]. Such fencing can be tall, wired exclusion fence used to direct larger animals to a preferred crossing location, or the lower, finer mesh, concrete wall, or solid drift fencing used for similar purpose for amphibians and reptiles. Exclusion fencing for large mammals has been more often studied as a mitigation measure, and as a result, most research on 'guidance fencing' tends to focus on these types of systems. The level of research may also reflect the cost of exclusion fencing as a mitigation measure. Such fences can extend several kilometers, and require substantial investment to install and maintain. Monitoring to determine their effectiveness also helps rationalize future application of such measures [47,54,40].

When both fencing and crossing structures are combined, they reduce the number of WVCs by preventing animal movement across roadways, while also mitigating the barrier effect of the highway. Fencing for large animals installed near wildlife overpasses and underpasses has been shown to reduce WVCs [63,54,40]. Fencing is also valuable along four-lane highways where the road itself may be a barrier; here fencing can direct wildlife to a safe wildlife crossing structure and maintain habitat connectivity at the landscape level [64]. Appropriately designed fences, comprehensively integrated with crossing structures and other collision mitigation measures, can be a cost-effective way to reduce or eliminate WVCs [28]. As an example, the cost-benefit analysis discussed in Section 3.2.4 found that the combination of fencing with animal detection systems almost doubled the benefits on 77 km of roadway system, increasing benefits from 4.2% for the detection system alone, to 9.4% [21]. Work by Lee et al. [23] found that fencing, combined with a wildlife underpass could reduce WVCs on a section of the TransCanada Highway through the Canmore area from 11.8/year to 2.5/year, and reduce annual average cost by 90%, from $128,337/year to $17,564/year.

Although exclusion fencing systems have mainly been established and studied for large animals along highways, recently there has been increased use of fencing to mitigate WVC with smaller amphibians, reptiles and mammals. For example, drift fencing can be utilized to ensure that mitigation enhancement sites for smaller species are linked within habitat zones on the landscape [65]. Fences can vary in height, length and mesh size, allowing them to be designed for a variety of species. However, they must be designed for target species to be effective. For example, a wildlife fence on a highway in Banff created to exclude large mammals, like ungulates, still allowed small mammals to enter the ROW: 58-83% of small mammal tracks crossed the fence [66]. The sections below review design considerations for fencing to mitigate the movement of large and small animals, and associated maintenance and monitoring requirements.

3.3.2 Mitigation implementation in road management

Fencing should be designed for the target species, with specific requirements for animal body size (large mammals or small animals of various species). Fencing options can also be considered at various stages of the road management life cycle, including planning, design, post-construction and operation and maintenance. Past project experience provides considerations relative to each of these aspects, as described in the sections below.

Large mammals

Most fencing mitigation projects in North America are targeted to large mammals, since their extensive home ranges encounter more roads than smaller animals, and a collision with a large mammal is more of a human safety concern [67]. As a result, studies on their application have contributed to some consistent recommendations, beginning with project planning.

Part of the planning process for adding fencing to prevent wildlife from accessing roadways requires considering the potential to create inadvertent mortality sinks with fencing [67]. The location of fence ends, for example, should not lead animals to cross at areas where WVCs are difficult to avoid, or where animals have few options to avoid the roadway. Animals attempt to travel across roads to access habitat, or because they are following existing movement corridors created by terrain or other land features. If corridor features cannot be fenced to prevent access to the roadway (e.g. at rivers), wildlife could still cross the road. If the highway intersects another road, ungulate guards (Texas Gates) can deter animals from moving through the gap, however these guards are typically only used on low volume side roads and are not effective for non-ungulate species [41].

Locations of the fence ends may also be critical, since animals travelling along the fence may now cross the road at the ends, particularly if the road lies between important habitats. An assessment of three to four lane sections of highway through Banff National Park found that fencing effectively reduced WVCs, since ungulate-vehicle collisions declined 80% [10]. However, after the fence was installed, WVCs were distributed nonrandomly and were associated with fence ends. Collisions were greatest within one km of fence ends, but proximity to major drainages also likely influenced collision locations. Again, an understanding of the landscape features influencing animal movements at the roadway is critical to mitigation planning.

The length of fencing should consider fence end treatments, plus known successful and unsuccessful crossing locations, and crossing structures, if installed, that provide access to key habitat areas [10]. Fence height and length will depend on the species of concern. Fence installations for large mammals (e.g. deer, elk, moose and large carnivores) typically range in length from several kilometers to tens of kilometers, while much shorter fences are needed for the smaller animals discussed in the next section [41,68]. Short sections of fence (less than three km) can lead to large animals concentrating their crossings at the fence end, as noted above. Lengths of 5 km or more have been found to reduce WVCs by 80% [68]. Rural and urban context can also play a role in fence design. The Government of Alberta Best Practice Guideline, *Planning Considerations for Wildlife Passages in Urban Environments,* recommends fence heights of 2.4 m for large mammals, and shorter fences for small to medium-sized animals [24]. Wing fencing, fencing that extends from a wildlife passage entrance in both directions to guide animals to a passage and prevent intrusions onto the highway, is also recommended in urban environments [24]. For rural highways, wildlife passages and overpasses may require much longer fences, depending on known movement patterns, the target species and other terrain characteristics [31,41].

These fencing systems will often be combined with other mitigation measures, some of which have limitations that should be considered during the design stage. Longer fences have sometimes included escape measures, such as one-way gates. Designs of such gates and other types of escape openings have been refined over the past years, and several options are now in use. If an animal has breached the fence and is on the road side of the fence, the one-way gate (such as the examples shown in below) allows the animal safe passage back to the protected side of the fence [41,54]. One-way gates have been found to have limited effectiveness, and the use of the gates by animals travelling the wrong way may negate any benefits. Instead, escape ramps or narrow openings with wing wall fences have been used to guide animals through from the road side of the fence (see examples below). In an urban environment, escape ramps are recommended within the first 500 m of length and then at least one per kilometer on each side of a highway thereafter [24]. Such ramps, jump-outs and gaps have also been used in mountainous terrain, with distances between based on terrain and likely movement patterns, as well as human safety factors [31].

Several studies have examined the effectiveness of fencing in reducing WVCs on Canadian highways, including examples included in the case studies in Section 3.5. On Highway Route 175, which crosses the Laurentides Wildlife Reserve in Quebec, about 67 km of the road ROW were fenced to reduce moose collisions. Tall metal fences (2.4 m) and related structures (wildlife crossings, moose emergency exits, anti-deer road crossings, etc.) were installed. More than 50 collisions had been identified annually prior to fencing [70]. Five years after implementation, moose occurrence inside the fenced ROW decreased by more than 95% and the annual frequency of collisions fell progressively over time (7.5 collisions in 2006 and 2007, none in 2008 and 2009). At the same time, moose crossings through wildlife passages increased by 48% between 2009 and 2010 (from 189 to 279 documented crossings). This study highlights the challenge of dealing with wildlife: their ability to adapt to change.

Although the fences did reduce the risk of collisions at this location, regional population growth and changes in the movement patterns of moose created new collision zones further along the redeveloped road [70]. In another example on Highway Route 138 in Quebec, in 2007 ungulate exclusion fences were erected on a 6.3 km section of the road with high moose collisions [71]. Over the following years, the number of moose-vehicle collisions outside the fenced section increased significantly. In 2014, the Ministère des Transports du Québec extended the fences in both directions, modified their ends and built two underpasses for large wildlife. Although the latter had lower openness ratios than those suggested in the literature, moose collisions were still reduced significantly, and moose regularly use the underpasses. Such examples may also justify the additional study required to identify landscape level movement corridors and successful wildlife crossing zones, as well as collision locations.

Figure 6. Wildlife barriers

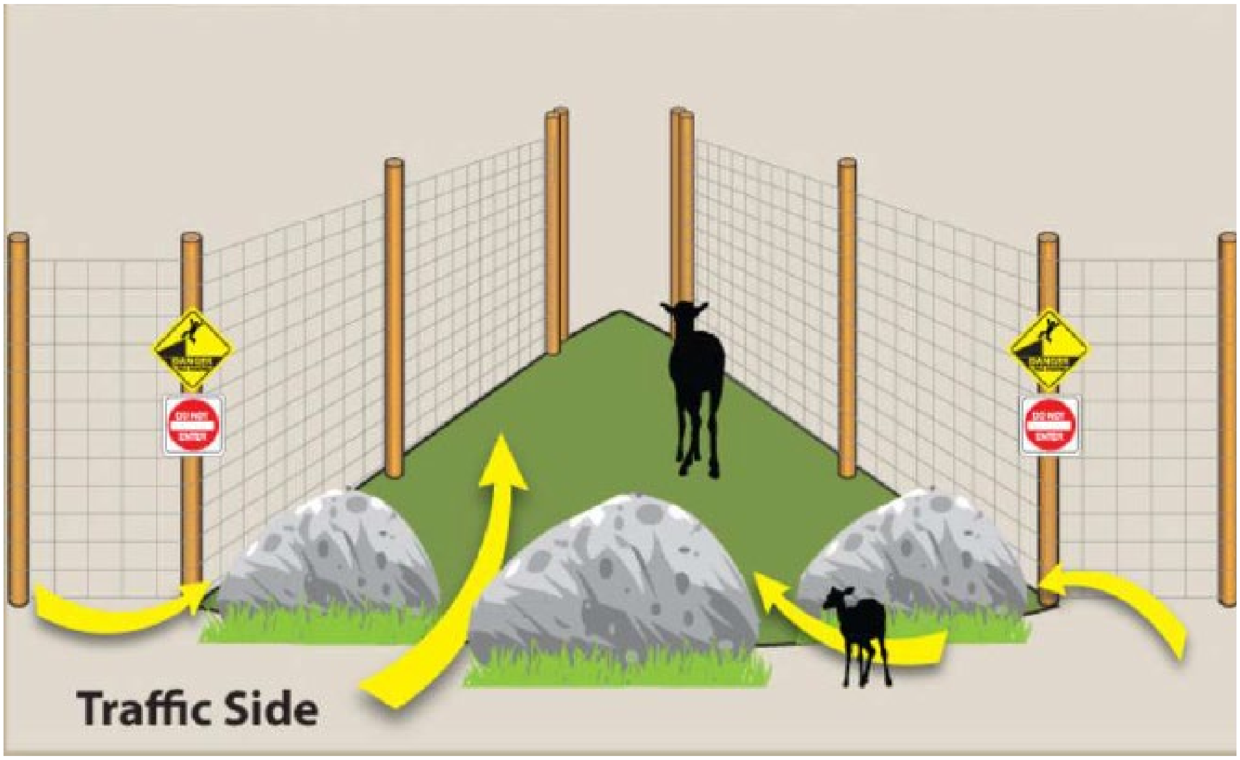
Upper left: In-line one-way gates for wildlife fencing (no longer recommended for use due to performance concerns) [41] (Credit: EcoKare International and Ministry of Transportation, Ontario)

Upper right: Setback one-way gates for wildlife fencing (no longer recommended for use due to performance concerns) [41] (Credit: EcoKare International and Ministry of Transportation, Ontario)

Lower left: Escape ramps for large mammal fencing [69] (Credit: Nancy Newhouse)

Lower right: Ungulate guards for road exclusion barriers [41] (Credit: EcoKare International and Ministry of Transportation, Ontario)

Figure 7. Open escape gate with wing fencing [39]



Credit: Leonard Sielecki, British Columbia Ministry of Transportation

Small animal fencing

WVCs with small animals, particularly amphibians and reptiles, have become a concern in areas with high conservation interest (e.g. national parks), and where some of these species may be at risk (e.g. Ontario, Manitoba, British Columbia). Crossing structures can offer safe passage, but often require drift fencing to direct animals to these locations (see photos of examples, below). This is a relatively new application, and best management practices are still emerging. Studies that have assessed effectiveness are valuable in this instance, and can highlight potential planning and maintenance considerations.

Figure 8. Examples of small animal fencing

Left: Drift fencing used at small animal culvert [69] (Credit: Dr. Tony Clevenger)

Right: Exclusion fencing used for SAR management, Ontario [72] (Credits: Megan Bonenfant and Ontario Ministry of Environment, Conservation and Parks)

Where Provincial Trunk Highway 17 bisected the Narcisse Wildlife Management Area, a key garter snake denning/breeding site in Manitoba, high road collision mortality prompted pilot studies to test mitigation options [73,74,75]. In fall 1992, roughly 10,000 snakes died crossing Provincial Trunk Highway 17 near the overwintering snake den. Several crossing mitigation measures were established, including drift fencing, a culvert crossing, a lighted culvert crossing and use of snake pheromone to attract snakes to the crossing [73]. Fencing proved most effective and was later applied to enhance crossing success at culvert structures. The system included four new culverts directionally drilled under the road, with drift fences connecting three of the four culverts. At the time these measures were applied, estimates suggested pre-fence collision mortality approached 20,000-25,000 snakes annually, but fell to 3,000 snakes after mitigation [75]. Monitoring during the fall migration after the mitigations were installed detected 1,400 snakes using the culverts, but monitoring was not continued in subsequent years, due to budget restrictions [76].

A similar study on frog and toad use of drainage culverts along a paved highway in Ontario also noted that fences connected to drainage culverts had less mortality than culverts alone [77]. However, a highway mitigation study for reptiles in Ontario found that collisions with snakes and turtles increased 20-25% due to breaks in the fence, which corralled the reptiles around the fence ends of the flexible plastic fence [78]. A roadway exclusion fencing project for herpetofauna in Presqu'ile Provincial Park in Ontario [79] noted other adverse effects connected to the fence. Amphibians and snakes were found dead on unburied fencing and possibly died from desiccation and/or heat exposure. The study noted that the fence temperature and design, if not installed correctly, can hinder animals from crossing the road and finding cooler refugia.

Small mammals (e.g. hares, rodents, weasels) are less often managed with crossing structures and fencing, but are of increasing concern in some parts of the country, in both park and urban management settings. Few studies have examined their effectiveness though. Banff National Park assessed the effects on small and medium mammals of large animal fencing installed along Highway 1 to guide animals to overpasses. The fencing, variable-dimension mesh panels intended to block medium-sized animals from crossing along the fence bottom, was installed near hundreds of smaller (<1 m) drainage culverts, which were identified as habitat linkages for small mammals [66]. Past work in the park had indicated that small mammals will use smaller diameter drainage culverts and underpasses to cross highways [67,33], but not overpasses, possibly due to better overhead cover near culverts [33]. The drainage culverts were accessible for potential crossing use, but they were on the road side of the fence, rather than the habitat side.

Variable-dimension mesh fencing is a standard fencing material with smaller mesh size near the ground and larger mesh size at 0.75 m above the ground. The study found the larger mesh sizes higher on the fence became available to small (and medium-sized) mammals during the winter due to deep snow, which enhanced fence permeability. The addition of a smaller mesh size apron (as in the photo below) at the foot of the fence had similar issues. Small and medium-sized mammals could cross the fence in winter, although they more frequently crossed from road to habitat side of the fence. This unanticipated seasonal access becomes a consideration for use of this type of fencing in areas with heavy snow. In areas where snow is not as deep, such mesh designs have been applied, in some cases with smaller fence gates, to allow animals to escape from the highway side of the fence (see photo below [69]).

Recommended improvements include extending drainage culverts beyond the exclusion fence, as well as providing hiding cover near the drainage culvert entrances [33,66]. Such studies suggest that the effectiveness of fencing for small mammals requires further research on species size, the disturbance type, fence design, environmental seasonality, and other contextual factors [66].

Figure 9. Examples of small animal fencing

Left: Small mammal fencing gate [69] (Credit: Dr. Tony Clevenger)
Right: Small animal fencing, showing buried fence barrier [69] (Credit: Nancy Newhouse)

3.3.3 Beneficial management practices

Fencing recommendations for large animals range from contract standard specifications for wildlife exclusion fencing (e.g. by the British Columbia Ministry of Transportation and Infrastructure) to comprehensive studies that have examined the effectiveness of fencing, and other collision mitigation approaches in reducing WVCs in both rural highway [41,10] and urban locations [12,24]. Typically, fencing is used with other mitigation measures, such as crossing structures, but also it also includes means to offer escape for animals accidentally accessing the road side of the fence (e.g. one-way gates, escape ramps and exit/wing fence breaks). Regionally specific studies that offer specific guidance for fencing, and other collision mitigation measures, are provided in Section 3.6 (Key Resources).

General recommendations emerging from studies for fencing use include the following:

- Fence heights for large mammals are typically 2.4 m, but can be lower for medium-sized animals (e.g. 1.5 m to 2.4 m [55]).
- Certain large animals are known to breach fencing systems (e.g. deer and black bear), and heavier gauge wire may be necessary to reduce maintenance and access to the roadway, or to accommodate snow and wind loading [41,80].
- The fence bottom edge, or an additional smaller mesh short apron fence, should be buried to prevent animals from digging under the fence. Black bears have been found to dig under fencing [41].
- Modify one-way gate structure placement inwards from fence, and increase the number and/or spacing of curved prongs so black bears cannot squeeze through [41].
- Alternative designs may be required for ungulate guards that deter animals from walking across and deer jumping over the guard. Electro-mats may also be considered as an option at road

interchanges and other fence gaps [41], although in some parts of Canada they have been found to pose issues for maintenance and with snowfall.

- Consider fence end locations well, particularly where fencing is intended to block movements of animals with large home ranges that typically move over long distances to access key habitats [41,81,54,69].

For small animals, resources are being developed to offer guidance on fencing design, based on local experience. The Ontario Ministry of Natural Resources created a BMP for reptile and amphibian exclusion fences, drawing on some of their past experiences of application [72]. The guidance document provides an overview of proven design and installation techniques and points to site and species-specific design requirements. The British Columbia Ministry of Forests, Lands, and Natural Resource Operations [82] has identified additional design considerations. Suggestions from these, and other similar studies include:

- Burying the fence, retaining an overhang lip on the species side, and backfilling and compacting the soil on both sides of the fence [72].
- Removing tall or woody vegetation on the species side of the fence [82].
- At the end of the fences, installing fences with a turn-around at the end furthest away from a wetland habitat and any access areas, to redirect animals away from fence openings [82].
- Curving the fence ends to face toward habitat and tying them into a natural landscape such as a tree or rock to reduce access to the road at the fence end [82].
- To avoid heat exposure impacts for reptiles and amphibians created by fencing, backfill the road side of the fence with gravel when the fence is installed, limit vegetation removals during dry, hot periods and build one-way jump-outs to allow animals to exit the road and avoid prolonged heat exposure [82].
- Zigzag or WW-shaped drift fences that connect to tunnels at bottom angles can also help guide herpetofauna to the tunnel. If space is limited beside a road, then a “swallow-tail” entrance or one-way entrances are more suitable options [82].
- Select fencing materials with a long lifespan to avoid need for on-going replacement or repair. Flexible plastic fencing may be effective for short-term solutions, but short concrete walls or fine mesh solid wire fence may be more appropriate for more permanent mitigation (e.g. near a wildlife culvert or passage [78].

Limitations with small animal fencing identified in past studies include the following:

- Most drift fences are temporary and must be re-installed every year, with material and labour costs [77,75], or on-going volunteer requirements [82,83]. Biologists are exploring ways to establish more permanent fencing solutions, with lower maintenance cost [75,82].
- In regions with heavy snowfall, long-term maintenance of drift or wire fencing was extremely costly [77].
- Fencing materials should be designed to last the lifespan of the road and the fence material should be durable [78].

Additional BMPs specific to specific road management life cycle stages are summarized below.

Planning and design considerations

Past findings have reinforced the need for sound planning and implementation. Wildlife fences are only effective when well planned, properly constructed and well maintained. Ontario Ministy of Natural Resources [72] recommends consideration of several environmental, cost and logistical variables during the design phase of a wildlife fencing project:

- the home range and movement patterns of the wildlife
- habitat at fence ends
- wildlife body size, behaviour and physical capabilities
- climate and topography
- length of fence along the road, connection to crossing structures and spacing of either a crossing structure or escape ramp
- road type and traffic volumes
- cost of materials and labour
- maintenance costs over the lifetime of the fences / structures
- monitoring strategy
- durability and life of installation

Others have noted seasonal issues with ice accretion, snow and avalanche potential, and associated weight and wind loading, as well as geotechnical characteristics. Results from Ford and Clevenger [66] suggest that fence location and proximity to the roadway should also be considered, particularly for small animals. Extending drainage culverts beyond a fence requires a longer culvert and potentially, additional drainage mitigation (e.g. grading to direct flow toward the culvert end). Such costs are a trade-off to ensure fencing can achieve other objectives. If road safety and animal protection allows it, shifting the fence closer to the road will reduce costs to facilitate movement of a full range of species.

The Ontario Ministry of Transportation [84] notes the specific considerations needed for fence ends. Animals will often follow the fence to its end, especially when they may be attracted to the road ROW (e.g. for foraging / grazing opportunities). Suggestions for design consideration and further testing include the following:

- Extend the fence end past the defined wildlife conflict zone up to a distance equal to the mean daily home range distance of species of concern.
- Site the fence end within inhospitable habitat, or against a natural barrier (e.g. cliff), or where fence ends must be at highway grade, consider the jurisdictional stopping sight line standard to facilitate collision avoidance.
- Construct the barrier to angle away from the road at a specific distance (e.g. up to 100 m for larger animals).
- Place obstructions at the fence end, such as rock pits or rock piles where safety clear zones allow, to prevent animals from easily moving around the fence end (most effective with cervids).
- Place Texas gates, electro-mats or electric fencing at fencing ends to prevent entry to the road area.
- Integrate steep road slopes (e.g. raised roads with embankments) at fence ends to create difficult terrain for some target wildlife species.

Fences can be effective barriers preventing access to crossing sites, or for redirecting movement to crossing locations. But they can also inadvertently block access to important habitat such as natural salt licks or movement corridors, particularly in mountainous habitat. Planning should consider potential, unintended effects of fencing, in a thorough analysis of indirect effects on other wildlife and costs of installing, maintaining and operating fencing systems. Information sources that could be considered for planning purposes include the following:

- Collecting information on both mortality sites and successful crossing sites, ideally through ongoing data collection, can help identify sites where wildlife fencing is needed to prevent collision, but also where it is not required, since crossings are successful [25].
- Collecting observations of live animal crossings of the highway can help avoid inadvertently blocking the successful crossing sites with wildlife fences. A drawback to fencing if improperly installed is that it affects habitat connectivity for wildlife for the duration of the fence [24].
- The introduction of new fencing intended to guide certain animals to a crossing can also negatively affect other non-target species and thus demands assessment of unintended effects. This can be particularly true where fencing effects are not equally well understood, as for small mammals, as discussed above. If indirect effects on other species are not well studied, consider developing pilot studies to test fencing options first.
- Planning reviews should consider the long-term operational aspects of fencing options, as well as their effectiveness.
- Planning should also carefully consider the context of past applications of fencing options. Studies conducted in different climates or ecosystems may not be directly transferable.

Planning tools, such as the cost-benefit assessments discussed in Section 2.4, can be helpful in identifying cost-effective solutions, appropriate to a given context. The decision model proposed by Huijser, et al. [21], for example, evaluated the human, insurance and property costs of collisions against the costs of 13 types of mitigation for elk, moose or deer collisions, over a 75-year lifetime investment (i.e. design, installation, maintenance and removal). Their analysis generated a decision model with a threshold number of collisions, by animal species, and associated breakeven cost-benefit amount that would justify use of mitigation. Their assessment did not assess individual mitigation type; however, the method could be applied in planning assessments for mitigation options.

Most WVC solutions, including fencing options, are supported by field studies of effectiveness, which may not necessarily be transferable to a Canadian context. For example, electric fencing has been suggested to be a more cost-effective barrier for deer compared to mesh wire exclusion fencing, based on studies from the United States. However, since it does not perform well in areas with heavy snow and ice, or where flooding may occur, and requires regular mowing to prevent short-outs [55], electric fencing may be more expensive to operate in Canada. Similar problems apply to electromats.

Formal review has been used by some organizations to ensure that all planning considerations are incorporated into the design process, for example through a formal environmental impact assessment process [15,85]. The Credit Valley Conservation (CVC) in Ontario reviews transportation and planning involved with development projects [85]. The CVC Planning and Development Services Team reviews and assesses each project individually, considering requirements through all stages of the road life cycle. If a crossing structure or fence is warranted based on an ecological assessment, the targeted fish or wildlife group(s) is identified and a design for crossing structure is recommended. Context-specific BMPs are also identified for the construction, operation and maintenance stages, as well as post-construction monitoring requirements determined by CVC and other regulatory agencies.

Operation and maintenance requirements

Maintenance issues with fencing are less often addressed in both academic and practitioner studies addressing this type of mitigation. In part, this is due to a focus on that rationale for fencing use, through the reduction of collisions, or effectiveness of fencing relative to collisions [21,63,86]. Huijser et al. [21] developed a decision tool based on a cost-benefit analysis that considered lifetime costs, including maintenance, but specific descriptions of the maintenance concerns were not described. While the method provides a good model for whole cost analysis of fencing and other WVC mitigations, typical costs are a gap across Canadian road management agencies. Such decision models would likely need to be constructed based on locally relevant maintenance requirements and costs, or on ecological benefits.

Continued success of connectivity structures is dependent on associated fencing and if the fencing fails or is not maintained, then the whole system is compromised [78]. Regular patrols to inspect fence integrity are helpful, and can identify accidental damage (e.g. car collisions, fallen trees), as well as damage or work-arounds caused by animals. Inevitably some animals can find ways to breach fences. Deer have been found to enter highway areas around fence ends and bears entered the highway at ungulate guards, one-way gates and fence ends [41]. During studies along the Trans-Canada Highway in Banff National Park and Canmore, black bears, grizzly bears and cougars appeared to easily climb fencing, while coyotes went under the fence at ground gaps [86]. In a study on Highway 69 in Ontario, black bears could enter the highway ROW by digging under the fence [41].

Preventative measures to minimize maintenance requirements include:

- Burying fence into ground during installation to prevent digging [41] or burying a separate chain-link mesh ‘apron’ (e.g. 120 cm mesh) at the base of the fence [59].
- Installing a top cable along the fence (see photo below) can reduce fence damage from falling trees, and avoid associated maintenance costs [40], as has been done in Banff, Yoho and Kootenay National Park’s wildlife fencing systems [59].
- Modifying one-way gate structures inwards from the fence and increasing the number and/or spacing of curved prongs would reduce the chances of black bears squeezing through[41].
- Modifying jump-outs may also be helpful, to better facilitate exits from the roadway side of the fence [41].
- Alternative designs may be required for ungulate guards that deter animals from walking across and deer jumping over the guard. Electro-mats may also be considered as an option at road interchanges and other fence gaps [40,41].
- Fence end treatments that include fence extensions away from highway, or creation of rock boulder fields (see photo below) that tie-into rocky steep road embankments, may direct animals to move parallel to the highway, rather than across [41].

Figure 10. Wildlife fencing examples

Left: Top cable protection on wildlife fencing [69] (Credit: Dr. Tony Clevenger)
Right: Rock boulder fields at fence end [69] (Credit: Dr. Tony Clevenger)

Post-construction monitoring

Monitoring ideally begins at the project planning stage. Multiple studies have incorporated Before-After-Control-Impact (BACI) analysis into their monitoring design to aid in the design and site selection of the wildlife fencing and follow-up monitoring. Monitoring wildlife movement after fencing installation can help assess whether it has been installed effectively, and inform adaptations for improved performance to maintain regulatory compliance, or project specific objectives [87,39]. In some cases, monitoring has also identified unforeseen responses by wildlife to fencing, or crossing measures, leading to new mitigation practices.

Amphibian mitigations at the Sea to Sky Highway, near Whistler, BC provide an example of the potential consequences, and learnings linked to proper monitoring and maintenance. A 50-cm high, fine mesh drift fence was erected along a wetland complex bisected by improvements to the Sea to Sky Highway near Whistler, to funnel amphibians into one-meter culverts installed during the realignment of the highway ([88,89] see photos below). The highway lay across the migration route of the red-legged frog, a listed species on the *Species at Risk Act*, and the crossing mitigation system was a requirement of the EIA approval for highway works [88].

Although the mitigation design followed accepted practice [82], maintenance was not regularly implemented, prompting public concern as spring migration of the frogs neared. Concerns included fallen drift fencing, which provided no effective guidance to the culvert crossing structures. Letters of concern from the public and ENGO interests demanded accountability to EIA approval conditions [88] and prompted follow-up investigations. Results revealed that the fencing was too flimsy, and collapsed easily, especially with heavy snowfall typical of the region [89]. In addition, some frogs and toads climbed over or crawled under the fence and were still killed crossing the highway [88,89]. These investigations generated recommendations for adaptations to the fencing, including:

- Changing fencing materials to a more rigid fence
- Creating an overhang at the top of the fence to prevent animals from climbing over successfully

- Providing an exit structure to allow animals to cross back from the road side of the fence, should they be able to move past the barrier [88]

British Columbia MoTI worked with the road contractor and British Columbia Ministry of Environment to repair and modify the fencing, adding puck board to the fence bottom to increase durability and prevent climbing [90]. Regardless of the initial challenges, roadkill rates were at least 50% lower on segments with fencing compared to those without, suggesting that fencing could still be effective [89]. The new, redesigned fencing was installed along the highway, with the intent of improving the system and monitoring continued. Results of the updated monitoring were not subsequently published however, and effectiveness was again undocumented. Regardless of the success, or failure, of the mitigation measure, sharing the results of such interventions is essential for improvement and understanding of the limitations of such measures. Monitoring design is discussed further in Section 3.4 below regarding large and small animal crossing structures, as they typically include fencing mitigation as well.

3.4 Crossing structures and other measures

3.4.1 General overview

Collisions between vehicles and wildlife, particularly large animals, are one of the earliest and thus, most well studied aspects of road ecology. Large animals occupy large home ranges and move throughout these areas for a variety of reasons, interacting with roads, traffic and other forms of linear infrastructure (e.g. railways). Road densities, traffic volumes, traffic speeds and types of vehicles have changed, and rates of WVCs have also increased, creating concern about both human and wildlife costs [3]. Every hour, four to eight large animal collisions were estimated to occur in Canada, based on 2017 statistics [91]. In Alberta, based on the 2019-20 Alberta Transportation Annual Report, WVCs result in four to five human fatalities per year, on average, and another additional injury incidents. In British Columbia, 384 road users were estimated to be injured each year from WVCs, with an annual cost of $240 million [91]. The loss of wildlife is also substantial, and is one of the main human-caused forms of mortality [1]. Thus, much research has focused on the factors influencing WVCs and potential mitigative measures to reduce their frequency.

The location and timing of WVCs are influenced by the location of the road in the landscape, traffic volume and vehicle speed [44]. This means that WVC data can be used to identify specific ‘hotspots’ and temporal patterns (‘hot moments’), where such collision information is available [3]. For example, Desjardins Insurance [91] reported that in Alberta and British Columbia, 89% of large animal WVCs were on two-lane roads outside urban areas, 86% were in good weather conditions and 66% were in daylight. Further, they indicate seasonality: most of these collisions were in May to June and October to January, during spring green-up and fall mating season. In some areas, seasonal migrations may increase road crossing frequency, and risk of collision. As discussed in Section 3.1, once collision patterns are identified, and described in terms of the wildlife species involved and their associated behaviours, this information can be used to develop site-specific mitigation measures [3]. However, collisions tell only part of the story. Information on successful road crossings can be just as important in designing safe roads, for people and wildlife. Certain traffic volumes, road speeds or road widths may still allow safe and successful animal crossings [92], information that can also inform mitigation planning.

3.4.2 Mitigation implementation in road management

Large animal crossing structures

Ideally, once crossing locations are identified, specific mitigation recommendations can be developed. However, some agencies (e.g. national parks) may stipulate that mitigation measures, such as exclusion fencing and crossing structures, be included in the design of new roads, such that crossings become a specification based on set spacing of crossing sites, rather than mitigations at specific locations [59]. For most provincial or territorial agencies however, budgets may limit crossings to high risk locations, as determined by crossing events.

Design depends on the site-specific conditions at the crossing and the species of concern. While large crossing structures such as overpasses, underpasses and other large structural solutions often come to mind in discussing mitigation for large animals, other less expensive options exist and can be very effective.

Temporary mitigations for seasonal crossing patterns can be addressed effectively by short-term road closures, speed reductions, wildlife warning signage and public awareness campaigns [3,46,93]. In most cases, due to the disruption to the motoring public, these solutions work best for short term implementation [3]; however, they can be effective in reducing collision risk in high movement seasons and restoring connectivity in areas of good seasonal habitat quality. For example, a study examined the temporary closure of a popular 17 km tourist route in Banff National Park for evening use from March to June, from 20:00 to 08:00 hrs, resulting in a doubling of movements across the highway during this key movement period [93]. The area contained good spring forage and wolf denning habitat, and had experienced considerable growth in traffic volume in recent years, in both day and night time, increasing risk to important conservation species. Additional enforcement has also been used to ensure road user compliance. For example, warning signage and increased road enforcement patrols by park wardens have been used in Kootenay National Park to reduce collisions and human conflicts with grizzly bears attracted to early green-up in roadside vegetation in early spring [94].

As discussed previously, other mitigation measures may be required at crossing locations, for example to reduce roadside attractants, provide driver warning systems or change driver behaviour in high risk zones. Examples recommended for use on Yukon roads can be applied in many locations across Canada [46]:

- Installation of additional wildlife warning signage
- Continued vegetation management along highway ROW, and consideration of experimental trials to determine the most effective time of year for vegetation clearing/mowing
- Use of non-attractive forage species in seed mixes when replanting disturbed areas
- Reduced vehicle speeds in high collision areas
- Modifying snow management to provide escape routes, plus increased signage and reduced speed limits in areas of known winter crossing activity

Some of these solutions are nuanced, and require adaptation to local context to be effective. As noted in sections on warning signage (Section 3.2) and roadside vegetation management (Section 4.1), these methods may lose effectiveness (e.g. passive warning signage [40]) or produce unintended consequences (e.g. mowing can improve forage quality for grazing species [95]).

Design considerations

Wildlife crossing structures are perhaps one of the most recognized mitigation measures applied to large animal crossing sites. Large bridge structures that support overpasses or underpasses can maintain, or restore, the movement of a variety of large animals (carnivores, ungulates, medium-sized animals such as lynx or wolf [11,31,23]). Such solutions have been applied across Canada, in urban to rural and park settings (see Case Studies, Section 3.5). Perhaps the most documented examples are the various overpasses and underpasses constructed in Banff National Park, which have been studied by Dr. Tony Clevenger since their first application in the 1980s [31]. Dr. Clevenger's research on the use of these structures by large animals, and the associated features that can enhance use, spurred applications in both rural and less developed parkland and urban contexts [92,11,24]. As of 2020, guidance documents have been developed for urban [12,24], as well as global contexts [92,96].

Crossing structures have typically been designed to aid movement of wildlife, although in some cases, human use, water flow and livestock may also be accommodated [96]. Their use has been shown to reduce the rate and severity of WVC, improving road safety for people, reducing wildlife mortality, and improving ecological connectivity for a variety of species. Benefits in terms of sustainable wildlife populations, another goal of this mitigation approach, have been less well studied, and require future attention [96].

Overpasses and underpasses are relatively expensive solutions to wildlife crossing concerns, and justify a well-thought out planning process, as discussed in Section 3.1. Specific to crossing structure design, Smith et al. [96] developed a systematic approach intended to identify key design aspects early in the process, and identify cost-effective solutions:

- Define the problem, including the specific ecological impacts associated with a proposed or existing road to be managed with a crossing structure.
- Set SMART (specific, measurable, achievable, realistic and time-framed) goals for mitigation.
- Estimate and plan for maintenance costs throughout the lifespan of the structure.
- Plan and design the mitigation strategy, ensuring that the mitigation will address the specific problem (not all road impacts can be solved with a crossing structure).
- Construct and maintain the mitigation measures, with environmental guidance from design through construction and operational phases of the project, to adjust to unforeseen issues with consistent project understanding.
- Evaluate and adaptively manage the mitigation measures based on a well-designed monitoring program (see next section).

As noted in Section 3.1, collaboration with other stakeholders may be critical to the success of any mitigation measures, and will be particularly important in design of crossing structures, given the cost and coordination involved. Crossing structures by definition, are intended to connect habitats, and thus help to ensure wildlife and plant populations can maintain key life processes. Ensuring that animals can move safely through adjacent habitats is a critical aspect of planning, to help maintain these species and the ecological functions they support.

Accordingly, an understanding of the home range size and typical movement patterns of species of concern is critical. Multiple crossing structures may be important for species with larger home ranges bisected by transportation routes, to ensure access to critical habitat and breeding mates. Locations for crossing structures could alter behaviour of the targeted animals, if positioned in less used habitat within the range, introducing other, unintended effects, or creating potential mortality sinks. Such measures may be more readily incorporated in park settings (e.g., National Parks), given park management mandates, but remain an aspirational goal in other Canadian jurisdictions.

In the context of crossing structures, various options are available in terms of shapes, types and sizes [10]. Structures for large animals can include various design options ([96]; Case Studies, Section 3.5):

- Overpasses or underpasses, constructed as bridges or large culverts, and shapes ranging from round, square, rectangular, oval/arched for underpass culverts, and straight or hourglass shape for overpasses (see photos below)
- Sizes varying in length, width, and height
- Construction materials including concrete, corrugated steel, timber or polymer concrete (mixed materials)
- Interior designs with natural substrate, concrete floor, grated roof, or additional hiding cover such as tree stumps, logs, brush, or rocks
- Associated features to funnel or direct animals toward a crossing structure, such as fencing, hedgerows or earthen or stone walls
- Additional features to accommodate multiple uses, such as streams or watercourses, road, railroad or co-use by livestock or people

Design must also consider species-specific considerations, such as sightlines and light penetration through underpasses (openness ratios), and cover or terrain features that can attract wildlife to the crossing site and encourage crossing (e.g. with hiding cover on an overpass [12]). Landscaping should encourage use of the structure, guide animals toward the entrances and help minimize disturbance effects from traffic [96]. Fencing is often needed to direct animals toward structures, and prevent crossings in other locations (see Section 3.2 above). Of course, these factors must be considered relative to the terrain and habitat adjacent the crossing site, as identified through the planning stage of analysis. In some cases, terrain considerations may prevent construction at the identified site, prompting the need for additional controls such, as fencing to direct animals to a nearby location.

Maintenance, monitoring and adaptive management are important for long-term success of crossing structures, as with any mitigation measures [96]. For example, fencing requires periodic maintenance, as does roadside vegetation adjacent to crossing structures, and potentially also on overpasses to facilitate travel by target species. Vehicle and other damage can trigger more significant maintenance costs for fencing and, potentially, overpass structures, particularly where winter driving conditions may increase the risk of damage from vehicles, or in forested zones, where windfall is a risk. Monitoring and adaptive management can help identify concerns, and are discussed below.

Figure 11. Design features of animal crossing structures

Left: Brush piles for hiding cover on an overpass [41] (Credit: EcoKare International and Ministry of Transportation, Ontario)

Right: 'Stepping stone' aquatic habitat on an overpass [69] (Credit: Dr. Tony Clevenger)

Figure 12. Overpass structure example

(Hwy 69, south of Sudbury near Hwy 637 turn-off to Killarney)

(Credits: EcoKare International and Ontario Ministry of Transportation)

Figure 13. Underpass design options

Upper left: hydrological culvert for aquatic connectivity [60] (credit: EcoKare International and Ministry of Transportation, Ontario)

Upper right: fenced aquatic culvert gap [60] (credit: EcoKare International and Ministry of Transportation, Ontario)

Lower left: corridor trail below bridge structure [60] (credit: EcoKare International and Ministry of Transportation, Ontario)

Lower right: terrestrial underpass with fencing treatment [62] (credits: Martin LaFrance)

Monitoring

Monitoring is an important, but sometimes overlooked, follow-up aspect of both large mammal and small to medium-sized animal crossing mitigation. Arguably most mitigation efforts would ideally be monitored to confirm use and apply adaptive management as required, but this aspect of most projects is not consistently implemented, even those implemented under a legislated EIA process [97]. However, given the significant cost of crossing structures for large animals, confirming that target species are using structures as intended can help document successful implementation of the mitigation.

Depending on the solution, construction and implementation costs can be substantial and monitoring helps justify the initial and on-going funding (e.g. for maintenance). Monitoring results have confirmed expectations relative to use and sometimes exceeded expectations, given enough time for animals to find and use the structure. For example, in two studies completed in New Brunswick, animal use of crossing structures did reduce WVCs soon after implementation, but these structures had significantly higher use a decade later in 2019 [98]. Similar results from several decades of monitoring of the crossing structures (both overpasses and underpasses) in Banff National Park suggest a period of adaptation is required while animals learn to find crossing locations, particularly if structures are not located in locations with preferred terrain, habitat quality and human use levels [11,31]. Similar results were found for elk use of underpasses in Arizona, where use improved over four years of monitoring [99]. While initially, time of day and season affected utilization, underpass structure and placement remained consistent factors in usage by year four. Further, targeted species can be influenced by other species or habitat considerations, and unexpected species can also be detected using the crossings [31]. Well designed mitigation studies can identify such unforeseen effects, including interspecies interactions, design and landscape features and influence of human activity that may affect use of the structure [87].

Small/medium animal crossing structures

A vehicle collision with a small or medium wildlife species is less likely to result in human injury or death, but there is high potential for death of the animal(s) [3]. Mortalities can be a significant threat to local populations, particularly for species at risk [44], triggering federal or legislative requirements for mitigation. In contrast to large animal crossings, most of the Canadian crossing mitigation projects found in this review were often designed to reduce population impacts on a species-at-risk, rather than to reduce mortality on a broader suite of animals, or improve road user safety. The Highway 175 Case Study in Quebec, Section 3.5, is an exception, and targeted a broad suite of small and medium-sized animals. Regardless, mitigation planning follows a similar process to that for large animals. After first identifying and describing crossing sites, appropriate crossing mitigation must be designed, and ideally, maintained and monitored. Unfortunately, maintenance considerations have been less well documented than design and monitoring aspects of roadway management (see Case Study examples in Section 3.5).

Design considerations

Temporary mitigation measures, such as intermittent road closures, speed reductions, wildlife warning signs and awareness campaigns, can be used to reduce the rate of WVCs for both large and small animals [3]. Though, sustained use of temporary solutions can also exceed available resources, or public support. For the Ryder Lake Amphibian Protection Project in the Fraser Valley of BC, initial mitigation included road closure during the migration period, but in 2015 a permanent solution was installed using a crossing structure and fencing [83]. In part, the change was driven by the need for ongoing volunteer support for temporary signage placement and maintenance.

Wildlife overpasses and underpasses designed with fencing have reduced WVCs for both large ungulate species and smaller animals by allowing safe passage across roads in various locations across southern Canada [44,100]. With small and medium-sized animals, however, underpasses are more commonly used, in part due to risk of exposure to predation [34,66]. Home range sizes are also generally much smaller than for large mammals, and the scale of planning must adjust accordingly. Connectivity between small and medium animal populations must be close-by to be accessible. Connected habitats on opposite sides of the road can allow animals to access resources and mates and facilitates gene flow, improving the viability of wildlife populations [96]. Habitats to be connected may also be quite close to the roadway, and hiding cover becomes more critical to allow for safe movements between habitats and underpass or culvert. Typical ROW vegetation features, such as tall grasses and low shrubs, can provide good cover for amphibians, reptiles and small to medium-sized mammals like weasels or hares, with adjustments to mowing and proper fence placement.

Small to medium-sized wildlife crossing structures can be diverse in their design, shape and size (see photos below); and thus, they should be fully described in plans and reports. There is also more potential to retrofit existing structures to enhance use by small to medium-sized animals, providing other, less expensive mitigation options. For example, the risk of collisions at riparian and road intersections can be reduced by using existing culverts, bridges and drainage culverts as pathways for wildlife passage [24,96]. New bridges can be designed to allow for movement within the riparian corridor and culverts can be designed or retrofit with wildlife shelving for small to medium vertebrates. Abandoned culverts are often grouted and sealed for safety reasons, but could potentially be left open, with minor upgrades for connectivity. Parks Canada has used such approaches when replacement culverts are installed and water is diverted from the abandoned one [59].

Ideal crossing structure characteristics are reported to be species-specific, even within guilds of animals such as small mammals [34,100]. An assessment of permeability of road mitigation measures for small mammals across a highway corridor in Banff National Park, Alberta, found that the presence of a culvert within 100 m improved fence and highway permeability [66]. Highway permeability dropped when snow obstructed the culvert entrance, suggesting crossing structures should also consider seasonal functionality in their design. Findings from another study on highway crossing structure use by small mammals in Banff National Park suggested that wildlife corridors, more generally, need to offer sufficient cover and be placed with a frequency that corresponds to the spatial scale over which targeted species move [34]. This study also found that small mammals preferred small drainage culverts, and that enhancing cover at crossing structures increases their use. In a study of a highway underpass use in Nova Scotia, porcupine and snowshoe hare used the structure frequently during road construction, suggesting mitigation can support movement even during this early phase of development [100]. Use was higher at night though, when darkness would provide security from predators.

Figure 14. Underpass design options for small to medium-sized animals

Credits: Dr. Tony Clevenger (upper [69]); Kari Gunson (lower [101])

Figure 15. Underpass design options for small to medium-sized animals

Upper left: Pipe inserts for hiding cover in culvert [69] (credit: Dr. Tony Clevenger)
Upper right: Reptile tunnel under construction (credit: Kari Gunson)
Lower left: Reptile using tunnel culvert underpass (credit: Kari Gunson)
Lower right: Grated roof underpasses for sunlight entry [69] (credit: Kari Gunson)

Underpass designs have been successfully used for crossings of smaller species, including amphibians and reptiles [41]. A study in Ontario found a wildlife crossing system installed to reduce road mortality and aid in conservation of Blanding's turtles was largely effective [103]. The 5.2 km expansion of an urban road passed through sensitive forests and wetlands. To maintain habitat connectivity, 10 box culverts (with skylights) were installed, as well as armored stone guide walls, and wire containment fencing along the perimeter of the roadway. The $958,000 project was effective in mitigating road impacts for these slow-moving animals, and monitoring suggested only minor improvements. Recommendations included using shorter poured concrete walls, maintaining fencing repairs and maintaining access behind the fence on slopes after grass cutting. This project is a good example of the benefits of comprehensive planning, including provisions for sufficient monitoring, which in this case suggested cost-savings for future designs.

In contrast, an example involving amphibians highlights the importance of understanding animal behaviour, and animals' abilities to adapt to environmental change, as well as the benefits of avoidance through planning. Realignment of a highway near Pinecrest Estates, south of Whistler, BC fragmented an existing wetland complex, resulting in the salvage and relocation of 1,037 amphibians, including 683 red-legged frogs (*Rana aurora*), a federally-listed Species at Risk [89]. Wildlife cameras were used to track use of passageways installed to facilitate crossing under the road, and found only 9% of frogs and toads and only 4% of salamanders used them. Although fencing had been installed to direct animals toward the passageways, 51% of individuals were observed climbing or jumping over fences. Population modeling indicated that at these rates of mortality, the population could not be sustained, prompting adaptations to mitigation design. Suggestions included increasing culvert diameters, installing grates and increasing moisture input, but a chief recommendation was for better routing initially, to avoid fragmentation of high quality amphibian habitat.

In some cases, a comprehensive mitigation plan that combines several mitigation options, including habitat modification, may be required. For example, a study of proposed conservation strategies for North American badgers, a federal species at risk, in the Thompson and Okanagan regions of British Columbia noted that WVCs were a substantial mortality source [104]. Given the large home range sizes of badgers, individual survival was thought to be linked to road density and road type in their home range. Three long-term strategies were identified to reduce road mortality, including a combination of crossing structures and other mitigation measures:

- Increasing the number of crossing structures incorporated into new and existing highway developments, using culverts, wildlife/cattle underpasses, or other structures for crossing under highways, including the associated changes:
  - Reducing the use of concrete road barriers (CRB) along only one side of the road or central meridian, or use of CRBs with scuppers that will allow passage
  - Increasing use of CRBs, where appropriate, to allow animals to exit the road safely
- Reducing traffic speeds to increase the effectiveness of wildlife detection systems to alert drivers to wildlife on roads
- Changing habitat conditions near roads to discourage badger use where crossing structures were not possible

Monitoring

As with any collision mitigation measures, long term monitoring and maintenance (e.g. of fencing) is required to ensure success. One of Canada's first amphibian collision mitigation programs for turtles was installed at Brompton Lake marsh in Quebec. A new highway had bisected the marsh and mitigation was installed in 2000 to restore connectivity, with roadside plastic diversion fences connecting three concrete tunnels [105]. Follow up monitoring noted that the installations were effective for many years, however eventually the fences became buried under vegetation because of lack of maintenance. The fences became useless and the tunnels unusable [106]. The project was dismantled in 2019.

Wildlife cameras offer a cost-efficient way of monitoring wildlife passages and overpasses, for small [89,34,107,66] to large animals [92,64,66]. Camera data can reveal the same patterns of demographics and spatio-temporal variation in tunnel use for small animals as trapping, but are a more cost-efficient and non-invasive alternative to survey field costs [108]. Analysis costs can be expensive though, particularly with longer monitoring timeframes. Survey design must consider carefully the survey objectives, and the analysis approach required to achieve those goals in a cost-effective but scientifically defensible manner.

3.4.3 Beneficial management practices

Design Considerations

Beneficial Management Practices for amphibians and reptiles have been developed in some provinces and provide guidelines to prevent road mortality. British Columbia MFLNRO [84] guidelines address placement of tunnels and fencing, as well as a description of culvert passage structures. Eco-Kare International [41] offer similar recommendations based on study of crossing mitigation for mid-sized (as well as large) animals, developed for Highway 69 in Northeastern Ontario. Carruthers and Gunson [109] describe the Wildlife Management Strategy, a system designed to integrate available data, tools and expertise into a framework to help prioritize road mitigation along Ontario's 19,000 km of highways, for both large and small animals, with a particular focus on turtles, snakes, small mammals, and birds protected under species-at-risk legislation. The Small Animal Mitigation Planning Tool (SAMPT) uses habitat models that predict where road mortality will occur for habitat specialists. The SAMPT has been used to place warning signs along provincial highways, and preliminary findings have shown that road users notice signs and slow down after signs are initially placed [109]. Given past studies on warning signage, follow-up studies to confirm longer term effectiveness would be useful. Drivers generally tend to quickly become accustomed to and ignore warning signage [21,40].

Jaeger et al. [107], in their four-year study (2012-2015) of crossing structures installed on Highway 175 in Quebec, to mitigate WVC impacts to small to medium sized animals, tested the effectiveness of four types of crossing structures with exclusion fencing. Their project assessed 18 of 33 crossing structures installed along 74 km of highway during a widening project for a two to four lane highway (see Case Study in Section 3.5). Crossing structures included a round concrete pipe culvert, a box culvert with wooden ledge, box culvert with concrete ledge, and box culvert with concrete walkway. They found pipe culverts and wooden ledge culverts were more effective than concrete ledge culverts. Overall, they detected 14 species using the crossings, ranging from semi-aquatic species such as beaver and otter to snowshoe hare, weasels, and micromammals (mice, voles).

Their study generated several recommendations to improve crossing design [107]:

- A variety of crossing structures and experimentation with new passage types can facilitate use by a range of medium-sized animals (e.g. beaver, red fox, porcupines, snowshoe hares, marten, fisher and Canada lynx).
- Box culverts with a concrete ledge were less effective than pipe culverts or box culverts with a wooden ledge. Adding wood sheets to cover the concrete ledge might improve use.
- Passages should be installed without a median opening if possible.
- Add vegetation cover between forest edge, and passage entrance, and minimize forest clearing near passage sites (see also [34]).
- Add passages (with fences) at mortality hotspots and where vegetation is close to the road (e.g. as culverts are replaced or repaired).

- Install passages with fences to guide wildlife to crossings (about 100 m on each side), and budget for on-going maintenance of fences for good operation (e.g. repair holes and breaks).
- Consider fencing road sections with several mortality hotspots or extending existing fences to the next drainage culvert to mitigate on-going mortalities.
- Explore fence end treatments to minimize fence end effects.

Monitoring and evaluation

Monitoring design is important, to move beyond simple counts of species use of mitigation structures toward evaluation of effectiveness [87]. Standard experimental design, with proper control sites, and variables that allow comparison among multiple crossing sites (e.g. fencing locations, vegetation management, jump out types) will not only demonstrate use and achievement of conservation goals, but link use to specific features incorporated into mitigation design. Other key factors include:

- A clear articulation of the intended type (daily, seasonal or occasional) and frequency of use for target species, factors that ideally were incorporated into initial mitigation design and founded on an understanding of species density in the crossing area, and past frequency and types of use, gained from analysis of past crossing incidents, as described in the sections above.
- Control sites near the road, but beyond the road-effect zone for the target species, which will again depend on prior knowledge of the species behaviour relative to the road type.
- Measurement of other explanatory variables, such as road noise, road types (for study of multiple mitigation sites), crossing structure design, use by people, domestic animals or livestock, structural features of the landscape and weather conditions (e.g. snow depth, rainfall).
- Sampling techniques that can monitor several species at once are more cost-effective, and thus preferred. This may require use of multiple techniques to reduce impact of sampling biases (e.g. use of camera traps and track beds together provide information on species, direction of travel and gait, as well as age and sex of animal). Other techniques that have been used include survey of animal sign or direct observation, and hair trapping for visual identification or DNA analysis.
- Sampling frequency, timing and duration based on the objectives of both the mitigation and monitoring (e.g. seasonal use will require comparison across relevant seasons; daily use will require more intensive sampling). Monitoring over several years will help confirm use where annual variation is expected. Duration of sampling should also consider the lag time before wildlife learn to find and use the structure, which in some cases has occurred over several years.
- Thorough statistical analysis, with sufficient sample size (from survey frequency, timing and duration, or from multiple mitigation sites) to detect statistically significant differences.

To ensure that monitoring is completed post-construction, project budgeting must include not only design and construction costs, but post-construction monitoring. Further, monitoring programs should consider and secure funding for surveys immediately after construction is completed, but also follow-up studies at appropriate time intervals to show patterns of use over time. As noted in the examples above, use may change positively or negatively over time and collected information can help to support further use of crossing mitigation or adaptive management.

A well-designed study can help to demonstrate effectiveness of crossing mitigation options, and expand our understanding of maintenance requirements and population management, particularly for species-at-risk. Road mitigation is not just a matter of driver safety, but also an important means of preventing biodiversity loss, and meeting international requirements for biodiversity conservation [107]. Monitoring can help demonstrate the value of crossing mitigation for small and medium-sized animals, many of which are at risk in southern Canada, but admittedly may not garner as much support for mitigation as bears, wolves and moose. Jaeger et al. [107] identified additional recommendations for monitoring and research that could help to fill gaps that limit the current standardization of designs and application:

- Investigate the influence of the length of fence on mortality at fence ends, to help inform fencing design, and minimize fence end effects. The length of fence can be a challenge – long fences can minimize fence end effects for large animals, but the ideal length for the small and medium sized animals is not well understood.
- Continued monitoring will help determine if animals habituate to less used culverts over time, which can help inform future designs.
- Monitoring of regular drainage culverts would help determine effectiveness as passages (with addition of fencing).

3.5 Case studies

CASE STUDY

Insurance Corporation of British Columbia (ICBC) Wildlife Warning System

WHAT'S THE ISSUE?

Wildlife/vehicle collisions (WVCs) have negative consequences for public safety and animal welfare. Northern British Columbia (BC) has seen a doubling in the number of WVCs from 1995-2006 (Road Health-University Wildlife Collision Mitigation Research Team, 2006). Similarly, material damages and human injuries from WVCs are on the rise. Mitigation techniques such as wildlife fencing and crossing structures are costly and hard to construct in some regions. Other mitigations such as signage, and speed reductions, are often ineffective as humans become habituated to their presence. Deer reflectors have also been shown to be ineffective at keeping deer and other wildlife away from transportation corridors.

To prevent a continued rise in WVCs, the Wildlife Protection System (WPS) was designed to detect wildlife on or near highways and provide early warning to drivers (Kinley, Page, and Newhouse, 2003a; Kinley, Page and Newhouse, 2003b).

QUICK FACTS

Category: Wildlife warning system

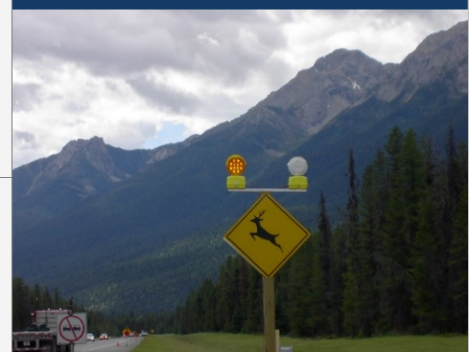
Location: Kootenay National Park, BC

Completed: 2002

Costs: $600,000 (2002)

Objective: Wildlife collision reduction

Species: Deer species



WHAT'S THE APPROACH?

- The WPS aimed to detect wildlife and provide drivers with early warning of potential crossing by wildlife on Highway 93 in Kootenay National Park.
- Infrared cameras were used to detect wildlife on or near the highway. Detection of an animal triggered warning lights, prompting drivers to reduce speed and anticipate wildlife on the roadway.
- Effectiveness evaluation for WPS (Kinley, Page, and Newhouse, 2003a; Kinley, Page and Newhouse, 2003b):
    - Monitor species presence near roadways
    - Monitor driver response to warning system (speed change)
- Wildlife data collection: 24-hr infrared and conventional video footage.
- Driver data collection: radar guns, computer with tracking software and conventional video footage.
- Evaluation goals: Evaluate the effectiveness of WPS to detect and warn drivers of wildlife on or near the highway.

WHAT'S BEEN OBSERVED?

- Infrared cameras detected wildlife within 1 km range, which provided a unique insight into wildlife behaviour.
- Deer presence near the highway right-of-way was highest during the night and intermediate during the evening. Similar patterns applied to the duration of animals' presence in the right of way.
- Success in tracking individual deer during the night averaged about 70%. Limitations of software and infrared technology at the time of testing did not allow effective tracking of stationary animals, especially when on the road surface. Performance of the system was better for movement of groups of deer and with a lag in shut off of warning lights after tracking ceased.

CASE STUDY

Insurance Corporation of British Columbia (ICBC) Wildlife Warning System

- Behaviours of concern to drivers such as running approaches, stepping onto the highway surface and attempted or successful crossings were more prevalent during the midday.
- False detections were problematic, particularly with warmer ambient temperatures.
- The presence of test-section infrastructure (trailers, towers, signs) appeared to dampen driving speeds even when lights were not flashing. When warning lights were flashing, speeds were further reduced to a total of 10 – 21 km/h.
- Driving during the day may increase visibility for drivers but the increased traffic may actually reduce a driver's field of view.

WHAT'S BEEN LEARNED

Key results from WPS testing in 2002 and 2003:

- **Wildlife behaviour should be recorded** to further understand highway crossing activity
- **Focus on changing driver behaviour rather than animal behaviour** – this prevents habituation to scents, reflectors and other deterrents
- **WPS does not force wildlife to alter their behaviour** to use locations of wildlife crossing structures
- **A portable system allows for relocation** to areas of high risk (e.g., seasonal changes or due to land use changes)
- **A warning system that operates 24-hr** can mitigate potentially higher risk wildlife behaviours during midday
- **The WPS provides a potential research tool** for development of new transportation corridors or testing the effectiveness of other mitigation tools
- **Technological limitations** at the time of testing limited the ability to differentiate wildlife from other warm objects, with the lack of a reliable power source also limiting success

Photo Credit: Trevor Kinley, Parks Canada

CASE STUDY

Wildlife Crossing Structures – Engineering Design

WHAT'S THE ISSUE?

Wildlife crossing structures are increasingly incorporated into road mitigation at the road design stage to reduce wildlife vehicle collisions (WVCs). Options involve passing either beneath or over the road.

Underpasses (animals cross beneath the road) range from small size culverts used by small to medium-size animals, to large diameter culverts and bridge structures that can accommodate large-size animals.

Overpasses (animals cross over the road) consist of either large diameter culverts or bridge structures that span over the road and can accommodate animals of all sizes.

These structures need to be designed with consideration for the **species of concern**, the **unique demands** of the crossing site, future **maintenance** requirements, and **long-term function**. Decisions made at the functional planning and early design stages influence capital and life cycle costs of the project.

Understanding the design process can help in identifying crossing solutions that are both financially and operationally feasible.

QUICK FACTS

Category: Various wildlife crossing structures

Location: Various

Completed: Ongoing

Costs: Not available

Objective: Wildlife collision reduction

Species: Multiple species, including large ungulates and medium and large carnivores

DESIGN CONSIDERATIONS

Primary design considerations for wildlife crossing structures include:

- utility of the structure
- site topography
- site conditions/constraints
- durability

Utility speaks directly to the needs of the species of concern and determines the size of the structure, whether terrestrial or hydraulic connectivity is required, and the degree to which light and noise shielding (such as noise attenuation barriers or landscaped berms) is required along the sides of the structure.

Site topography is usually the determinant in deciding between crossing under or over the road. If the road sits sufficiently above the elevation of the surrounding ground, the site is a candidate for an animal underpass. Conversely, if the road sits at or below the elevation of the surrounding ground, an animal overpass is likely the better choice.

Site conditions/constraints typically inform suitable foundation types and drainage requirements, and impact constructability in terms of access, available working space and detour options. Design can take advantage of such items as natural rock outcrops and local drainage gullies.

Durability involves maintaining the integrity of the structure, and focuses on protecting the structure from the long-term effects of water. Culverts need good **internal drainage**, and sufficient **depth of bury** to distribute the traffic loads. Animal overpass structures need good **waterproofing** to protect against the ingress of water and avoid leaking onto the road below, good drainage to effectively manage run-off and convey flow away from the structure, and **enhanced protection** such as concrete liner walls and/or increased concrete cover and premium reinforcing steel for any

CASE STUDY

Wildlife Crossing Structures – Engineering Design

parts of the structure that are exposed to salt-laden water in the splash zone in cold weather regions. Current bridge design practice is to eliminate joints in the deck by using **continuous spans and integral abutments**.

CULVERT CROSSINGS

Small size culverts that are installed beneath the road typically consist of corrugated steel pipe (CSP), concrete pipe or rectilinear concrete boxes.

Medium size culverts that are installed beneath the road typically consist of corrugated steel pipe (CSP) or structural plate corrugated steel pipe (SPCSP) with either a closed or open bottom.

Culvert underpass structures can be sized to accommodate the passage of various species up to and including large ungulates, suitable in almost any location for terrestrial or hydraulic connectivity, not easily seen from the road so present little visual impact or driver distraction, and are relatively inexpensive to install and operate.

Single or multi-span bridge underpass structures are typically used when a wide wildlife corridor needs to be accommodated beneath the road.

LARGE ANIMAL STRUCTURES

Large structures are used when wildlife crossings need to span over roads, and options include SPCSP culverts, concrete arch structures and overhead bridges.

The **height of crossing structures** over roads is governed by the minimum clearance envelope requirements of the authority having jurisdiction.

The **width of wildlife crossings** depends on the utility of the structure and the selected edge treatment (noise attenuation barriers or berms) and can vary from just a few metres up to 60 m, as in the case of Parks Canada's double-barrel culvert structures in Banff National Park (see left photo).

Double-barrel culvert overpasses provide a cost-effective grade separation solution on four-lane divided highways in flat terrain, have a rolling profile and sculpted surface that includes edge berms to shield animals from light and noise, are visually interesting, and minimize the tunnel effect.

Overhead bridges can span greater distances than culverts and can be used to cross multiple-lane undivided roads.

WHAT'S BEEN LEARNED

SPCSP culvert structures can be assembled relatively quickly using relatively small equipment, whereas **concrete arch structures and bridges** require larger equipment and take longer to build.

Bridges are a viable alternative to culverts and concrete arches in cases where large structures are needed, especially where the surrounding ground is higher than the road.

Bridges tend to be less wide (measured in the direction of traffic) than their large diameter culvert and concrete arch counterparts. This may be an owner preference rather than an operational or engineering derivative.

Bridges that carry vehicular traffic over such features as rivers and rail tracks can also **effectively contribute to improved wildlife mobility when dedicated corridors are incorporated into their original design.** While increasing the length of existing bridges to facilitate wildlife mobility is possible, it is expensive and disruptive.

Maintenance and operations issues related to buried culvert and arch structures and culvert overpass structures are minimal due the absence of bearings and joints. Bridge underpass structures have the same issues as other highway bridges, while bridge overpass structures are less problematic because they are not exposed to heavy dynamic loading from vehicular traffic.

Photo Credits: Parks Canada and Terry McGuire

CASE STUDY

Highway 69, Parry Sound to Sudbury, Ministry of Transportation of Ontario

WHAT'S THE ISSUE?

When animals – small or large – cross busy roads, they often don't make it. Roads on the landscape can affect habitat connectivity and wildlife/vehicle collisions have negative consequences for public safety and animal welfare.

Reconstruction of Highway 69 to widen from two lanes to four lanes, in southern Ontario (south of Sudbury and north of Parry Sound), offered an opportunity to incorporate a variety of wildlife crossing structures to facilitate movement for both small and large animals and monitor their effectiveness.

QUICK FACTS

Category: Various wildlife crossing structures

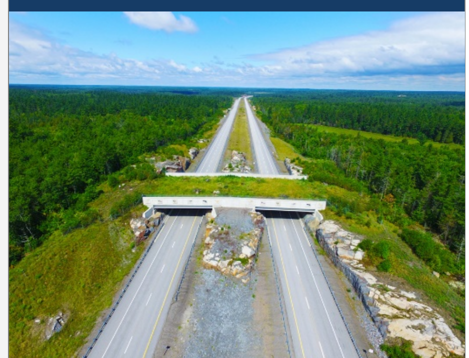
Location: Southern Ontario

Completed: 2014

Costs: Not available

Objective: Wildlife collision reduction

Species: Multiple species, including: white-tailed deer, moose, black bear



WHAT'S THE APPROACH?

- Installation of multiple wildlife crossing structures: one wildlife overpass, one wildlife underpass, one creek bridge pathway, and two wetland underpasses
- Installed fencing measures: Total 20 km, 16 km of wildlife deflection fencing, 27 one-way gates, and two ungulate guards
- Effectiveness evaluation (Healy and Gunson, 2014):
  - Before-and-after impact (BACI) design monitoring study
  - Collected wildlife use data for 1 year before and 4 years after construction of mitigation
  - Study area: 10 km section of highway widened from two lanes to four lanes
- Wildlife data collection: Snow tracking and infrared motion activated cameras to assess animal behaviour, interactions and movement
- Evaluation goals: Evaluate crossing structure use and passage success for large animals (white-tailed deer, elk, moose, black bear, wolves), and mid-sized animals (Canada lynx, coyote and red fox)

WHAT'S BEEN OBSERVED?

- By far, the most common species observed was white-tailed deer, followed by red fox, moose and black bear. Coyote, elk and wolves were observed at far lower frequencies.
- All the target species, with the exception of elk and Canada lynx (no observations), were observed using at least one crossing structure.

CASE STUDY

Highway 69, Parry Sound to Sudbury, Ministry of Transportation of Ontario

- There was a strong usage preference among all observed species for the wildlife overpass relative to any other structure and passage rate for the overpass structure was generally high for all species that approached it.
- Both white-tailed deer and black bear were able to breach the deflection fencing regularly – deer went around fence ends, while black bear entered the highway right-of-way at ungulate guards, one-way gates, fence-ends, and under the fencing.
- White-tailed deer and moose vehicle collisions were reduced by 87%, while black bear collisions increased by 25%.
- Passage rates for the wildlife underpass structure were highly variable between species.
- Crossings at the overpass structure were more frequent during the night, even for animals that typically display diurnal activity patterns.
- A few cases recorded of white-tailed deer and black bear using one-way gates to exit the road-side and access the safe-side of the fencing; white-tailed deer were frequently observed approaching the one-way gates but passage rate was very low.

WHAT'S BEEN LEARNED

Key results from effectiveness monitoring (Healy and Gunson, 2014):

- **Wildlife/vehicle collisions were reduced** in the fenced sections.
- **Most animals preferred the wildlife overpass** relative to the other structures.
- **Animals tended to cross the overpass more at night** – suggesting that typical diurnal behaviour may not be ameliorated or further disrupted by the structures.
- **The number of species and rate of use can change with time**; some species may take longer than others to adapt to using the crossing structures. Multi-year monitoring is important to determine effectiveness of structures and adjust design as needed.
- **Underpasses can provide passage opportunities for mid- to large-sized animals** if overpasses are not feasible, albeit the passage rates may be more variable.
- **Fencing should be buried into the ground** to inhibit animals from going under the fence.
- **One-way gates did not prevent black bears from entering the highway right-of-way**. Potential design improvements include modifying one-way gate structure placement inwards from fence and increasing the number and/or spacing of curved prongs so black bears cannot squeeze through.
- **Future research on alternative designs** for ungulate guards that deter animals from walking across and deer jumping across.
- **Electro-mats may also be considered** as an option at road interchanges and other fence gaps.
- **Apply improved fence-end treatments**, including fence extensions away from highway, or creation of rock boulder fields that tie-into rocky steep road embankments.

Photo Credits: Eco-Kare International and Ontario Ministry of Transportation

CASE STUDY

Trans-Canada Highway 1, Mountain Parks Wildlife Crossing Structures

WHAT'S THE ISSUE?

Roads can affect landscape and population connectivity, and WVCs have negative consequences for public safety and animal welfare. The Mountain Parks (Banff, Yoho, and Kootenay National Parks) have continued to see expansion of the Trans-Canada Highway (TCH) transportation corridor. Since 1982, phased expansion of the TCH has included dozens of crossing structures. These structures are to improve cross-highway movement for both small to large animals. This is the largest road mitigation complex in the world and longest research dedicated to assessing performance, offering insights on effective design, operation and maintenance.

QUICK FACTS

Category: Various wildlife crossing structures

Location: Alberta/British Columbia

Completed: Ongoing

Costs: Not available

Objective: Wildlife collision reduction

Species: Multiple species, including large ungulates and medium and large carnivores

WHAT'S THE APPROACH?

Installation of 39 crossing structures including underpasses and overpasses, with fencing, in Banff National Park to reduce mortality and increase connectivity of wildlife on the TCH.

Effectiveness evaluation for large mammals:

- Monitoring species use of crossing structures within Banff National Park (Clevenger et al., 2001; Clevenger and Waltho, 2000, 2005; Clevenger and Barrueto, 2014)
- Study area: TCH through Banff and Yoho National Parks in areas widened from two lanes to four lanes
- Data collection: Track pads, hair and camera traps to detect passage, assess animal behaviour, determine genetic connectivity
- Evaluation goals: Determine efficacy of structure at population level
- Effectiveness evaluation for small mammals (McDonald and St Clair, 2004; Ford and Clevenger, 2019):
- Monitoring the response of small mammals to various types of crossing structures and fencing by testing use of structures to return to home ranges after relocation
- Evaluation goals: Determine small mammal responses to crossing structure size, vegetation cover and distance between crossing structure and home ranges

WHAT'S BEEN OBSERVED?

- Over the 17-year monitoring period studied by Clevenger and Barrueto (2014), 152,154 crossing detections of 11 species of large mammals recorded at wildlife underpasses and overpasses.
- Grizzly bear family groups were more selective than singletons and strongly selected overpasses. Structure designs targeting the selection of grizzly bear family groups are effective at restoring population connectivity (Ford et al., 2017).

CASE STUDY

Trans-Canada Highway 1, Mountain Parks Wildlife Crossing Structures

- Wildlife passage by all large mammal species was negatively affected by human use at and near structures (Clevenger and Waltho, 2000).
- Species-specific patterns of use were documented, but all species used all crossing structure types (Clevenger and Waltho, 2005).
- Species exhibited a learning curve or adaptation period; 3-4 years for ungulates, ≥5 years for carnivores.
- Human use of crossing structures affected wildlife activity, yet found congruent overall activity patterns for most species between crossing structures and backcountry sites (Barrueto et al., 2014).
- Gene flow was documented by showing migration, reproduction and genetic admixture, concluding that wildlife crossings allow sufficient gene flow to prevent genetic isolation (Sawaya et al., 2014).
- For small mammals (McDonald and St Clair, 2004): return to home ranges was most successful near drainage culverts under 3 m diameter, intermediate with 3 m underpasses and least successful with 15 m wide overpasses.
- Overhead cover correlated to small mammal crossing success; sparsely vegetated overpasses and the height gain from the entrance to the center may be perceived as a predation risk (McDonald and St Clair, 2004).
- Fence age, proximal culverts, vegetative cover and snow depth were all correlated to TCH permeability for small mammals (Ford and Clevenger, 2019).

WHAT'S BEEN LEARNED

Key results from effectiveness monitoring for large mammals (Clevenger et al., 2010; Clevenger and Waltho, 2000):

- **Wildlife-vehicle collisions were reduced by >80%** (95% for ungulates) in the mitigated road sections
- **Underpasses and overpasses** were proven effective at individual and population level
- **Long term monitoring (>5 yrs)** is needed to accurately assess use and species adaptation to use of crossing structures

Key results from effectiveness monitoring for small mammals (McDonald and St Clair, 2004; Ford and Clevenger, 2019):

- **Road culverts are a cost-effective strategy for small mammal movements** across large transportation corridors
- **Enhancing cover at crossing entrances and along fences** increases use by small mammals
- **Culvert ends should be outside fencing,** beyond throw of snowplows to reduce drifting at entrances

Photo Credits: Parks Canada

CASE STUDY

Highway 175, Quebec City to Saguenay, Ministère des Transports du Québec

WHAT'S THE ISSUE?

Roads and traffic negatively impact wildlife populations because they increase wildlife mortality, are barriers to animal movement and reduce the amount and quality of available habitat. Fatal collisions and other safety issues led to the widening of Highway 175 from a two-lane undivided road to a four-lane divided road, in southern Quebec (north of Quebec City, Jaeger et al., 2016).

This offered an opportunity to incorporate a variety of wildlife crossing structures to reduce wildlife mortality, increase roadway safety and maintain ecological connectivity.

QUICK FACTS

Category: Various wildlife crossing structures

Location: Southern Quebec

Completed: 2015

Costs: Not available

Objective: Wildlife collision reduction

Species: Multiple species of small and medium sized animals

WHAT'S THE APPROACH?

- Installation of wildlife crossing structures: 33 wildlife underpasses: pipe culverts (PC), box culvert with a wooden ledge (WLC), box culvert with a concrete ledge (CLC) and box culvert with a concrete walkway (CWWC)
- Installed wing-fencing measures: exclusion fences 100 m long and 90 cm high with 6 cm x 6 cm mesh size on both sides of each underpass entrance
- Effectiveness evaluation (Jaeger et al., 2017):
  - Collected wildlife use data for four years after construction of mitigation
  - Study sites: 18 completed wildlife underpasses on Highway 175
- Wildlife data collection: Road mortality surveys, Reconyx digital cameras at the entrance of 18 wildlife underpasses, radiotelemetry and genetic analysis
- Evaluation goals: Evaluate crossing structures based on their ability to reduce wildlife collisions, their use by wildlife, permeability and gene flow (American marten)

WHAT'S BEEN OBSERVED?

- Collision mortalities most often involved American porcupine, then red foxes, woodchucks, striped skunks and snowshoe hares.
- Higher numbers of medium sized wildlife roadkill were found near forested areas and medians with shrubby vegetation.

CASE STUDY

Highway 175, Quebec City to Saguenay, Ministère des Transports du Québec

- More road mortalities were observed during morning surveys except for the red fox, porcupine and woodchuck – which were higher during evening surveys.
- PC-type underpasses were used more frequently followed by WLC-type underpasses and the least used were CLC-type underpasses.
- A full crossing in any of the wildlife underpasses was not observed for American marten, Canada lynx and northern flying squirrel. One full crossing was documented for river otter, six for red fox and ten for North American porcupine and raccoon.
- Road mortality was higher at fence ends, and lower in fenced sections, however the combination of these two had mortality rates similar to unfenced sections.
- New wildlife underpasses were used by small and medium-sized mammals, only four to six years after their construction (depending on their time of construction). After three years of study, 7% to 27% of radio-collared martens had crossed HWY 175 compared to 55% at the two-lane HWY 381 control site. On HWY 381, martens used the regular drainage culverts that were installed more than 25 years ago.

WHAT'S BEEN LEARNED

Key results from effectiveness monitoring:

- Longer fence sections, fencing in mortality hotspots and where vegetation is close to the road **will help reduce fence-end effect.**
- **Use a variety of different types of wildlife crossing structures** to accommodate different wildlife such as porcupines, red foxes, river otters, snowshoe hares, American martens, fishers and Canada lynx.
- Box culverts with a concrete ledge are less effective than **pipe culverts and box culverts with a wooden ledge**. Adding sheets of wood onto the concrete ledges could improve performance.
- Crossing structures should be constructed with a **higher opening ratio and without an opening in the median** or have better fencing between the two sections.
- **Avoid street lighting** in the vicinity of wildlife crossings.
- **Increase the vegetation cover** between the forest and the entrances of the crossing structures and avoid forest removal in sections with wildlife crossing structures.
- **Additional studies are needed** to determine the optimal fence length to reduce fence-end mortality, degree of wildlife habituation to exiting crossing structures and effectiveness of regular drainage culverts as wildlife crossings. Future road mortality surveys should include a combination of morning and evening readings.
- **Gene flow may be reduced at HWY 175 (four lanes) since it is a stronger barrier than the HWY 381 (two lanes)** despite the wildlife crossing structures.

Photo Credits: Concordia University Montreal, Jaeger et al. (2017)

CASE STUDY

Terry Fox Drive, City of Ottawa

WHAT'S THE ISSUE?

Expansion of 5.2 km of Terry Fox Drive between Richardson Side Road and March Road in Ottawa required the removal of roughly 10.5 ha of forest and wetlands habitat, fragmenting existing habitats, disrupting wildlife movement corridors and creating the new hazard of roadkill.

Blanding's turtle, a species at risk, was found in the area, triggering mitigation of the construction phase and roadway operations under the *Species at Risk Act*.

The primary mitigation objectives were to reduce mortalities, reduce habitat fragmentation, offset barrier effects and maintain wildlife population viability.

QUICK FACTS

Category: Various wildlife crossing structures

Location: Ottawa

Completed: 2011

Costs: $958,000

Objective: Wildlife collision reduction

Species: Blanding's turtle, meso-mammals, small mammals, amphibians and reptiles

WHAT'S THE APPROACH?

- Installed wildlife crossing structures: four terrestrial, six hydraulic concrete box culverts (0.9 m tall x 1.8 m wide x 52 m long), with 907 m of armour stone guide walls. Nine had catch basin skylights (60 cm x 60 cm) every 13 m.
- Installed fencing measures: 2.1 km exclusion fences on either side, top 40 cm angled towards the habitat and bottom 40 cm entrenched. Top mesh (5 cm x 10 cm), bottom 30 cm of mesh (hexagonal 1 cm). Fence ends wrapped back on themselves.
- Effectiveness evaluation (Taylor, Stow, Hasler, Robinson, 2014):
  - Collected wildlife use data for three years after construction of mitigation, from 2011 to 2013
  - Study area: Six roads that surround or pass through South March Highlands (Terry Fox Dr., Huntmar Dr., Old Carp Rd., Goulbourn Forced Rd., Richardson Side Rd. and Second Line Rd.)
- Wildlife data collection: mounted trail camera traps in culverts, roadkill surveys and a decibel meter for sound level recordings
- Evaluation goals: Assess the use of the culverts, assess roadkill mortalities and aid in the development of wildlife passage technology

WHAT'S BEEN OBSERVED?

- Frogs were most commonly observed at the structures, then racoon, muskrat and porcupines. Also used by Great Blue Heron and for fly throughs by bats and birds.
- Terrestrial wildlife culverts were used more frequently than the hydraulic culverts, but water levels may have prevented recording of swimming species (beaver, muskrat, turtles, amphibians).

CASE STUDY

Terry Fox Drive, City of Ottawa

- Reptiles (snakes, common snapping turtle, painted turtle and Blanding's turtle) were found basking below the skylights in the terrestrial culverts.
- Frogs passed through all culverts equally well, with some seasonal differences.
- Primary movement periods were early morning, evening and late night, suggesting movement avoided the peak vehicle travel periods. More amphibians and reptiles moved through the culverts during the day.
- Most road mortalities occurred on Terry Fox Drive, at an unprotected gap in the fence associated with a railway crossing. Mostly small animals, followed by racoons, midland painted turtles and porcupines.
- Blanding's turtles were observed twice in the culverts in 2011 and eight times in 2013.
- One Blanding's turtle mortality was found on each surveyed road except for Richardson Side Rd., and three were on Terry Fox Drive. Two were in the unfenced railway tracks area.

WHAT'S BEEN LEARNED

Key results from effectiveness monitoring:

- **Many species used the culvert crossings** despite the low openness factor (0.108-0.271) and limited headroom.
- **No usage difference was observed between the types of substrates** added to the culverts, ranging from large cobblestone, crushed gravel and organic topsoil. No problems related to topsoil washout were observed.
- **Mammals preferred the drier crossings**, particularly when located on moist valleys, whether along ridgelines or in the lowlands.
- **Both upland and wetland crossing sites enhanced** wildlife connectivity.
- **'Skylights'** were helpful to animals migrating through the culverts and were low cost ($2,038 each).
- **Placing logs in the culverts** may effectively diversify the habitat, retain moisture and provide cover from predators. They are cost effective, since log debris is available during construction.
- **Guide walls made of poured concrete** with reinforcing steel and proper footings instead of armour stone blocks would counter the loss of stones through theft.
- **Use a rigid top bar on fence** to ensure tautness instead of 16-gauge tension wire at top of the central fence panel, which was ineffective and needed maintenance.
- **Angling the top 40 cm of fence 45°** towards habitat prevents animals from climbing over.
- **Burying 40 cm of fence** in crushed gravel prevents digging under.
- **Install gates in the fence** to allow for vegetation clearing near fences, to discourage animals from approaching and climbing over the fence.

Photo Credits: Amy MacPherson, City of Ottawa

3.6 Key resources

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4. Vegetation management

Although ROWs occasionally consist of non-biological substrates (e.g. pavement or gravel), they most often support planted vegetation communities. In past practice within North America, these vegetation communities comprised a relatively small selection of non-native plants suited to roadside environments, which would be managed through mowing, brushing, mulching and/or spraying to maintain appropriate height and species composition. Many jurisdictions in North America and Europe have recently shifted to use native grass species in reclaiming ROWs, or naturalization of existing ROWs, particularly in municipal areas. This section examines alternative methods of establishing and maintaining roadside vegetation communities, with the aim to enhance the local environment and broader landscape, without compromising other ROW functions.

4.1 Conventional right-of-way management

The functions performed by ROW vegetation communities are diverse, and cover a range of concerns, such as driver safety and visibility, erosion control, and visual and other aesthetics such as buffering of noise, dust and light. ROWs may also support other land use, including utilities and recreation facilities. In some jurisdictions across Canada, areas of ROWs may be leased for hay production. In most Canadian jurisdictions, environmental legislation also requires control of invasive and weedy species. These various functional roles and regulatory requirements of roadway ROWs have all influenced management decisions, from design through operations and maintenance stages of roads. In particular, management decisions have focused on the species planted along the ROW, and the maintenance regime applied to them.

Conventional approaches to ROW revegeation across North America have relied on planted non-native vegetation on ROWs, due in part to perceived benefits relative to other land uses (e.g., less potential for weed spread due to rapid seed catch and hardiness), but also a lack of sources of native grass seed for reclamation and associated costs of native seed. Increasing availability of native species, and a heightened level of concern for loss of native habitats and associated ecological benefits, has prompted alternative management practices such as naturalization and wetland conservation, discussed in subsequent sections. However, most of Canada’s existing roadways are still typically managed under conventional regimes, and management practices that focus on broader ecological values (e.g. biodiversity conservation) have only recently emerged.

4.1.1 General overview

Despite the varied functions that can be incorporated into roadway ROWs, the primary function of their management in North America and Europe has remained safe and efficient transportation. Conventional management of ROW vegetation in these jurisdictions historically also included human-focused aesthetics of ROWs. Today, ROW management expectations held by both transportation agencies and the public include a blend of historical and current influences on ROW reclamation and mowing practices.

Historical objectives include the 1930s declaration by US transportation agencies that that roadsides should be maintained as if they were “our nation’s front yards”, the 1960s emphasis on “beautification” and the 1970s shift to sustainability goals such as reduction of herbicide use [5]. As ecological functions began to be included in ROW management through the late 20th century, unintended consequences, like increased rates of WVCs, led to extensive discussion on appropriate vegetation height, species composition and maintenance practices (i.e. mowing). As a result, the broader environmental context of ROW use now receives more attention, in terms of the wildlife species potentially attracted to the ROW, the land uses anticipated within the ROW and public expectations of roadway aesthetics. The current conventional approach to ROW vegetation management is based on a combination of ecological knowledge, roadway safety, other land use requirements and cultural expectations of public and transportation agencies.

The road ROW can vary in width, but is typically managed in several zones with different land use objectives [5]:

- The **immediate safety zone**, maintained for clear view of the road edge and to reduce fire risk
- The **recovery zone**, where vehicles that accidentally run off the road can safely come to a stop
- The **managed zone**, which may be used for utilities, trails or other complementary purposes, including conservation of wildlife habitat

Given varied land use, management requirements also differ, which can influence the choice of vegetation retained (or not) in each zone, and maintenance requirements, such as mowing.

ROW vegetation management begins with the choice of seed mixes used in reclamation, which in turn may be influenced by potential human use, wildlife or aesthetics objectives. Weed management is always a concern, particularly after construction, or if other ground disturbance occurs on road ROWs (e.g. utility repair). While innovative approaches have been adopted in some Canadian and American jurisdictions for sustainable ROW vegetation management (see Sections 4.3 and 4.4, and Case Studies in Section 4.6), in many locations conventional techniques for reclamation seeding, mowing and herbicide treatments are used to control roadside vegetation. Across Canada, ROW management also varies from north to south, and in urban and rural or less developed locations. Northern Canada, in particular, faces greater challenge relative to management of permafrost, wildlife habitat and Indigenous traditional land use, than issues with invasive species, and loss of pollinator and wetland habitat (see Section 5.1). Regardless, conventional practice in all Canadian jurisdictions now includes practices developed to promote sustainable ROW ecosystems.

4.1.2 Implementation in road management

Reclamation seeding

A first step in reclamation planning is to identify the broader ROW management goals that must be addressed, as these in turn influence choice of seed mix and species composition. Conventional ROW reclamation has focused mainly on operational concerns and overall cost; newer approaches have broadened to address sustainability concerns within the ROW and beyond it. Factors influencing reclamation planning, from a historical and current perspective, are outlined below. Naturalization, an emerging technique encompassing various sustainability goals, is discussed in Section 4.3.

Reclamation of road ROW has both regulatory and operational considerations [110]. In many jurisdictions, erosion and sedimentation control is required under environmental legislation (i.e. for soil conservation or protection of aquatic ecosystems), as well as to protect road integrity. Control of weeds and invasive species is also required by provincial and municipal governments (but less so in Northern Canada, Appendix A). Lastly, planning can consider other potential benefits of a vegetated ROW, including providing habitat that can support biodiversity, but also unintended consequences such as increasing wildlife mortality [110].

ROWs disturbed during construction are typically reclaimed by seeding to a vegetation community deemed appropriate for site-specific land use and operational requirements. For example, where utilities such as power lines or pipeline corridors may run within the ROW, or across it, grasses, or low forb species, including agronomic species have often been selected. Shrubs and trees may hamper utility maintenance requirements (especially trees), and so are not usually permitted within these parts of the ROW. Agronomics are also recommended in areas near agricultural land use [111]. Trees and tall shrubs are often removed from the immediate ROW and recovery zones during construction, and are not replaced during reclamation [5]. Sightlines and collision risks are a key reason for discouraging or removing trees and tall shrubs adjacent the roadway, particularly along high-speed routes (highways, freeways) or areas where wildlife may attempt to cross the roadway. Vegetation that impedes sightlines is typically recommended to be removed [110]. Trees and tall shrubs can also help improve visual aesthetics and reduce noise impacts of roadways though, and may be retained or planted in the managed zone [5].

Perennial grasses and forbs provide low cover that satisfies many operational concerns, and such species have traditionally been selected for ROW reclamation [5,110]. Non-native species have typically been preferred over native species, due to their faster establishment, commercial availability and lower cost [112]. Rapid establishment is a key concern, to provide erosion and sediment control and prevent establishment of invasive species [5,113]). Most jurisdictions across Canada have specific seed mixes for reclamation of road ROW (Parks Canada, provinces, territories and municipalities, Appendix A). The species composition may differ depending on site conditions, adjacent land use and transportation agency management objectives.

Manitoba Infrastructure has had considerable success with native perennial seed mixes, which have been used on roadway, bridge, culverts, drains, and northern airport and marine construction projects since 2013 [114]. Exceptions are urban areas that are regularly mowed. Seed mixes are selected from one of four provincial native seed mix zones, ensuring species are native to the regional climate and growing conditions. Successful adoption of the practice as a standard by the department lay in explaining the benefits: reduced mowing, weed suppression, reduction of herbicide use, slope stability, water and soil conservation, long-term sustainability and biodiversity. The initiative was supported in part by the proven effectiveness of the native reclamation program in Iowa Roadside Vegetation Program (see Case Study in Section 4.6).

Manitoba Infrastructure has had successful plant establishment with specific site preparation steps: stripping and stockpiling topsoil prior to construction, replacing it after construction, harrowing, seeding, then harrowing the site again (often with the harrows turned upside down and simply dragged over the site, to ensure native seeds aren't buried too deeply). In areas of potential erosion, exposed soils are then covered with a 100% biodegradable erosion control blanket. Post-seeding weed treatment has further improved revegetation at more challenging sites. The department hopes to improve monitoring to quantify specific variables contributing to successful revegetation with native species.

The roadway ROW is a harsh zone for plant survival, for all forms of vegetation including ornamental trees used in urban rights-of-way. Road salt and gravel, mowing, soil compaction and other disturbances (e.g. vehicle emissions, herbicides, road runoff) can affect plant survival [5]. Bare and low vegetation areas are exposed and subject to dry soil conditions. Species must be tolerant of disturbance to establish and thrive, which also affects decisions on seed mixes. Seed mixes ideally include species that could compete well against weeds, with little management intervention (and cost), and historically included species grown for human use, since factors contributing to their success were well understood. Nitrogen fixing species, such as alfalfa and clover, were often used to help compensate for soil nutrient issues, and minimize need for fertilizer. Such species are still preferred near agricultural lands (especially hayland, e.g. in Saskatchewan and Alberta [112]), which also allows transportation agencies to contract mowing to local farmers for hay harvest. In urban areas and along some rural highways, turf grass (red fescue and Kentucky blue grass) is still applied (Appendix A). Such mixes are often recommended for park and boulevard locations, for both aesthetic and cost-management objectives (Appendix A).

Increasingly though, native mixes are being used on urban and rural ROWs, particularly near natural areas, or adjacent Crown lands (Appendix A). The City of Calgary has six different seed mixes for its roadways that include native and non-native grasses and wildflowers; Alberta Transportation recommends native seed mixes selected for the specific ecoregion [111]. The adaptations of native grasses and forbs to local climate and soil conditions is increasingly recognized as a maintenance cost-saving, as well as supporting local biodiversity [112,113]. Loss of native grassland has been extensive in the Prairies in particular, driving the retention of native grasslands and restoration by many provincial agencies [113]. In some locations, reclamation has gone beyond use of commercially available native seed cultivars, to propagation of native species and habitat specific restoration for projects (e.g. Herb Gray Roadway case study, Section 4.6). Such naturalization approaches are discussed further in Section 4.3 (ROW Naturalization).

Success of such programs has driven a positive feedback loop that has helped promote broader adoption of native seed mixes. A good example of this process is the Tall Grass Prairie reclamation project along the new Herb Gray Parkway in Ontario. The project required replacement of at-risk, native habitat and species as a condition of project approval, under provincial and federal environmental impact assessment processes [115]. Propagation by partnering nurseries was required to provide the 15 native seed mixes originally designed for the 60 ha of naturalized ROW required, since commercial supply of local genetic stock was unavailable. Based on follow-up monitoring of establishment success, the seed mix was later narrowed to three habitat-specific blends (wet tall grass, dry tall grass and roadside), which were used for on-going maintenance and supplementary seeding. That requirement provided sufficient incentive for commercial nurseries to begin growing these native species. Subsequent province-wide adoption of those mixes by Ontario’s Ministry of Transportation, based on the success, and maintenance and ecological benefits of the Tall Grass Prairie project, helped establish a provincial market for native seeds and grow commercial supply, that in turn supports the native reclamation policy. Central to the success of this program was the on-going monitoring program for the project, which included five years of initial intensive study (for research and adaptive management), and subsequent monitoring at less frequent intervals (annual maintenance surveys and full research survey every five years).

Poor vegetation establishment, for both native and non-native species, has been reported by transportation and land management agencies, and issues are often linked to pre-construction (planning) and construction practices. Examples include the following reclamation practices:

- Poor soil salvage and replacement practices, which can reduce soil fertility due to mixing of topsoil and subsoil layers [116]

- Poor selection of reclamation species, or a lack of consideration of environmental conditions, relative to species-specific habitat and growing requirements [113]
- Reluctance to use soil amendments to improve nutrient or organic levels can also play a role, particularly on existing ROWs, where soil quality may be depleted ([116,113]
- Proper monitoring during construction, including quality control checks by environmental specialists, who can check soil handling and preparation, seeding rate and seed mix quality, and recommend improvements to enhance vegetation establishment prior to seeding, or in areas with poor catch [116]
- Providing adequate budget to support successful reclamation, based on materials and labour and including reclamation specialists [116]

This last point is a critical, underlying factor influencing transportation ROW revegetation, well explained by a study completed by Hirsch and DeJoica [116] for the Colorado Department of Transportation. They found the need for specialist advice and site-specific planning and preparation is typically not recognized, nor funded in projects, a gap often resulting in higher reclamation cost for rework during construction, post-construction and maintenance phases. In one example, non-project rework (i.e. during operations and maintenance) cost over $660,000 for twelve projects, due to erosion repairs, reseeding and weed management, plus additional monitoring, documentation and regulatory liaison. Soil amendments were not historically seen as necessary for reclamation success, and neither preliminary testing nor amendments were generally required in construction contract specifications. As of 2020, many jurisdictions in Canada require site-specific seed mixes, erosion control measures and follow-up monitoring be done by qualified personnel, and also include fertilizer application, at a minimum, in standard tender specifications ([111] Appendix A).

While ecological planning can restore ROW habitat for use by certain plant and wildlife species to support biodiversity conservation objectives (e.g. the Herb Gray Roadway Case Study, Section 4.6), poor planning can have unintended consequences, including the potential creation of ecological traps. Animals select habitat based on environmental cues that normally indicate high-quality habitat. Ecological traps exist where ecosystems have been altered by humans, rendering the cues unreliable. The result is that animals are lured into theses areas of low-quality habitat, and consequently experience reduced survival or reproduction (Hale and Swearer, 2016). Careful planning, and forethought is required to ensure that reclamation plans do not inadvertently create mortality risks, or policy challenges, for example if species at risk begin to use road ROWs more frequently.

ROWs act as ecological traps primarily by their proximity to high-speed, or high-traffic, ‘dangerous’ roads [110]. The National Wildlife Federation [117] recommends the following ways of avoiding creating ecological traps:

- If the creation of compensation habitat is required (e.g. wetland compensation for the removal of a wetland), place newly created habitat away from roadsides.
- Avoid the placement of roads in sensitive habitats such as wetlands and forests.
- Avoid planting invasive species, as they contribute to ecological traps.

The Tall Grass Prairie encountered an unintended consequence of rare plant establishment within the ROW, with potential need for on-going regulatory permitting for ground disturbance for routine ROW and utility maintenance [115]. Such regulatory issues should be considered during early planning stages, and established in operational plans for reclamation areas to avoid future potential regulatory conflicts.

ROW mowing

Many jurisdictions across Canada, and the United States use mowing to control encroaching woody vegetation to protect road integrity, and improve road user safety. In some cases, public expectations for managed landscape aesthetics may also play a role, particularly in determining the width of mowed area (e.g. along urban freeways). The cultural expectation of roadways managed 'as our frontyards' [5] has persisted since the early phases of road development from the 1930s through 1960s, and change to a more naturalized landscape has sometimes encountered resistance. Current mowing requirements appear to be based in part on safety sightline requirements for road users, but also historical practice. Accordingly, there is considerable variation across Canada, not always based on explicit management objectives, and an evidence-based approach.

Traditionally, many Canadian transportation agencies have mowed the ROW adjacent to the roadway; the actual width varies based on local management goals or perceived benefits. Forman et al. [5] mentions a 'standard' mowing distance of 9 m adopted by many jurisdictions for safety purposes, with variations based on road speed and traffic levels. However, based on a survey of Canadian transportation agencies represented on the TAC EIC (Appendix A), mowing widths vary considerably across Canada, and across road classes. Many agencies mow at least the adjacent 1.8 m on freeways and highways (see Appendix A). In New Brunswick, the width extends up to 15 m from highway road edge, but falls to 6 m for arterial, then 3 m for lower road classes. In Quebec, widths vary from 1.8 m to 3.0 m, regardless of road class. Saskatchewan highway ROWs are mowed to their full width, while other roads are cut to a 4.0 m width. The largest mowed buffer reported in this survey was in the NWT, where width increases to 60 m on most road classes, and may extend to this width on local or gravel roads. Municipalities also mow ROWs, at a minimum along the road shoulder or up to the adjacent property line (Appendix A).

In addition to the width of mowing, frequency and timing during the growing season are often stipulated by transportation agencies, to manage costs and meet safety or aesthetic expectations [5]. Both frequency and timing can have ecological implications. For example, mowing spring nesting season can affect migratory birds, a consideration addressed in other TAC publications[8]. Frequent mowing would be expected to lower plant species diversity, according to ecological theory, by favouring disturbance adapted species that can outcompete other native and non-native species [5]. However, mowing twice annually, in early and late growing season promoted higher diversity than no mowing, or mowing only once per year in one study, which counters theoretical expectations [5]. Some agencies, including Canadian agencies, have mowed in strips, alternating timing to foster higher diversity, but monitoring has not confirmed this outcome ([5], Appendix A). The contradictory findings from these past studies suggest more research is needed in this area to identify appropriate timing and frequency, and climate and ecosystem specific variations.

Often mowing widths are established to reduce wildlife hiding cover [5]. Wooded and shrubby areas adjacent roadways provide hiding cover for wildlife, and often form part of landscape level movement corridors, particularly in developed lands where such cover may be limiting. In rural and less developed areas, however, ROW mowing practices inadvertently increase the likelihood of WVCs, by sustaining

[8] *Migratory Birds Practices and Operational Guidance Documents Package: Beneficial Practices for Compliance with the Migratory Birds Convention Act and Regulations (2019), Operational Guidance for Migratory Birds and Vegetation Management for Existing Transportation Facilities and Infrastructure (2019).*

high quality browse for various large animals (e.g. moose, deer and bear). Mowing prevents the gradual spread of trees and large shrubs from the adjacent lands, but also maintains young, constantly regenerating grass, forb and low shrub communities. Current research suggests that woody plants mown mid-year produce high quality nutritionally dense browse for up to two years after mowing [95]. Conversely, woody vegetation mown in the spring produces lower quality browse. In areas where ungulate collisions are a problem, and woody vegetation is present within the ROW, mowing earlier in the year may remedy this problem, and ultimately decrease collisions [95].

Invasive and weedy species management

In most parts of Canada, legislation requires control or eradication of invasive and weedy plant species, for both economic and conservation objectives. The spread of invasive and weedy species can impact adjacent lands, including agricultural croplands and crop values. Biodiversity can be reduced by these same species, which can often outcompete both native and non-native species. Past weed control was mainly done using herbicides, but as management shifted to consider biodiversity and concerns about chemical pollution, other management approaches were required [5]. Mowing can help control invasive and weedy species, by cutting back growth before flowering stages develop. Unfortunately, seeds of invasive species can be carried on equipment and deposited in other areas, contributing to the spread of these species. Many jurisdictions have incorporated equipment washing requirements before transport to new sites, which is helpful, but not always practical on long ROWs. Weed control and eradication has become an essential, on-going aspect of ROW management, with various innovations designed to meet cost and operational goals, as well as biodiversity, pollution and habitat management goals. These practices are discussed in more detail in Section 4.2 below.

Integrated roadside vegetation management

Integrated Roadside Vegetation Management (IRVM) is an alternative approach to ROW vegetation maintenance that combines management techniques with ecological principles to establish and maintain safe, healthy, functional roadsides. Methods include the judicious use of herbicides, spot mowing, prescribed burning, mechanical tree and brush removal and the prevention and treatment of erosion and other disturbances within the ROW. The long-term goals of IRVM are the establishment of a diverse native plant community that provides the following ecological and safety services, in addition to traditional aesthetic services:

- Increased biodiversity
- Increased pollinator populations (for specific information regarding pollinators, see Section 4.4)
- Improved soil and water quality
- Effective weed competition from established native communities
- Improved road safety, by acting as living snow fencing to trap blowing snow
- Enhanced erosion control through slowing of runoff, thus enabling increased infiltration of rainfall and trapping of sediment
- Reduced maintenance cost through weed reduction, natural snow fencing and lower long-term replacement planting costs

In extensively cleared or developed landscapes, roadsides can provide the majority of available habitat for native wildlife, and in some cases, they provide critical movement corridors for both plants and animals [110]. Implementation of IRVM can increase the quality of this habitat to bolster native wildlife populations [119].

In North America, certain native grassland plants are particularly suitable for roadside environments. These plants have evolved in conditions similar to roadside habitats and can thrive in temperature extremes, drought, high light intensity, impoverished soils, and high winds. Grassland species generally have more extensive and deeper root systems than their non-native counterparts [120,121,122], resulting in enhanced roadside functions listed above, and lower maintenance costs. Most native grasslands in southern Canada have been lost to farming, urban development and degradation. Canadian roadsides offer potential to replace native grassland habitats during road reclamation [112].

In a survey conducted as part of this synthesis amongst federal, provincial, territorial and municipal transportation agencies across Canada (see Appendix A), some agencies actively promote the use of native seed mixes. Those that do often emphasize the use of such mixes near environmentally sensitive areas (e.g. within wetlands, or protected areas). Even fewer agencies actively manage rare species, including grassland species that may be present in existing ROW. In those cases, prohibitions against mowing and herbicide use may be applied (e.g. Parks Canada Agency, City of Calgary, Appendix A). For new roads however, most agencies conduct rare plant surveys and require some form of mitigation to move any plants discovered within the construction footprint to another location in the ROW, but more typically off the alignment. Seed collection, transplanting or topsoil salvage and reuse are some of the mitigation measures used to ensure rare species are re-established elsewhere. Few of the agencies surveyed require follow-up monitoring to confirm success, or encourage re-establishment within the road ROW as standard practice (although case specific mitigation may be applied, Appendix A). Two projects recently completed in Ontario provide excellent examples of alternative approaches to mitigation for rare plant species, as well as wildlife species of concern (see Herb Gray Roadway Case Study, Section 4.6). Work in Iowa provides another example of the benefits of integrated management (Case Study, Section 4.6).

Interestingly, most of the surveyed Canadian transportation agencies have topsoil salvage and replacement requirements, erosion control requirements and weed management requirements (including compliance with weed control legislation enforced by other agencies, Appendix A). Most transportation agencies do not explicitly manage herbicide use, as this falls under other ministry's control (typically environmental agencies). As noted above, mowing requirements are generally applied, but with varied distances and limited explanation of management intent or assessment of effectiveness. Such standards and requirements could incorporate native species use and conservation, but typically focus on soil conservation and management of invasive species with commercial, aesthetic or human health effects[9]. As explained in a case study of IRVM applied by the State of Iowa (see Section 4.6), these traditional, established patterns of management can be a significant barrier to promoting new approaches to roadside vegetation management [123,124].

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[9] *Quebec mows the right-of-way to 1.8 m width to limit establishment of ragweed, in part due to its effect as a human allergen. The plant has been found to readily establish adjacent roadways, and mowing helps to control its growth.*

4.1.3 Beneficial management practices

Conventional ROW management has evolved with the development of roadway systems and social and environmental expectations. Modern ROW management requires a balance among operational, aesthetic and environmental management objectives that vary based on local context. As a result, specific management practices are often fit to local conditions and requirements. Despite the influence of local needs, as summarized below, certain recommendations have emerged as beneficial management practices, transferable across jurisdictions.

Reclamation seeding plans

- Ensure reclamation specialists are involved from planning to implementing/monitoring stages of ROW revegetation plans, ideally with the same staff for continuity [116,113,115].
- Provide sufficient funding for design and implementation of reclamation plans, including both labour and materials costs [116].
- Design ROW reclamation seed mixes that include ecologically and operationally appropriate species, plus relevant site preparation methods (e.g. soil amendments, grading, tilling), seeding rates, application methods and post-seeding treatments, such as erosion and sediment control [116,113].
- Consider future regulatory needs and conflicts (e.g. with species at risk) and establish processes to address future maintenance and operational requirements with relevant regulatory departments [115].
- Document the design principles and operational aspects of the reclamation area, including any regulatory arrangements as soon as possible after construction, to protect against organizational turnover and loss of institutional memory for long-term management considerations [115].
- Ensure adequate time for seed propagation, monitoring and adaptive management, particularly with use of native species [115].

ROW mowing

- In areas where ungulate collisions are a problem, and woody vegetation is present within the ROW, mowing earlier in the year may reduce collision risk, since it tends to promote less nutritious growth than mown shrubs cut later in the summer [95].
- Reducing mowing frequency can help promote plant diversity in the ROW (e.g. twice annually, in early and late growing seasons [5]).
- Clearly articulate the rationale for mowing widths, to ensure that maintenance objectives are well understood, and effectiveness can be confirmed. Different widths may be required based on road size and traffic speeds to ensure road user safety, but specific widths are not easily transferrable to other jurisdictions without such context. Further, cost-benefits of specific widths, always a concern of government agencies, cannot be evaluated for effectiveness without clear objectives.

Integrated Roadside Vegetation Management (IRVM)

- Consider development of an IRVM that identifies site-specific vegetation management, and provides a 'toolkit' of recommended herbicide, mowing, prescribed burning, mechanical vegetation removal and erosion controls, with guidelines for appropriate use.
- Identify wildlife habitat important for management protection, including corridors, wetlands, and native grassland sites, and develop appropriate vegetation management methods for those specific sites [110,119].
- Consider sites within the ROW where rare plants might be successfully conserved, including intact patches of native grassland. Ensure vegetation management controls maintain those sites, and that all maintenance and operations personnel are aware of those controls. Regulatory permitting arrangements may be needed to accommodate potential future disturbances for maintenance needs [115].

Weed and invasive species control

- While specific management approaches can be developed to manage weeds and invasive species (see Section 4.2 below), regularly cleaning maintenance equipment to remove seeds and propagules can help prevent spread of these species during ROW management.

4.2 Invasive and weed species control

Invasive (or alien) species are defined as plants or animals that have been introduced, accidentally or deliberately, from another geographic region and whose spread negatively impacts native biodiversity, the economy or our society and culture [125,126]. Some invasive species do not pose immediate risk, and can provide ecological benefits, but others can displace native species, degrade habitat, introduce disease, or change genetic populations through interbreeding [125]. Currently, the proliferation of non-native plant species poses one of the greatest threats to our biodiversity, second only to habitat loss [127]. Invasive alien species cost the global economy billions of dollars each year, due to cost of control, but also reduced revenues from impacts to affected industries (e.g. tourism, fisheries, agriculture, manufacturing, etc. [73,125]).

Invasive and weedy plant species are often lumped together, but the two terms differ slightly in ecological and legal meaning. Invasive species are non-native species that have few natural competitors or predators. As a result, they can overwhelm the plant communities where they are introduced, creating an extensive monoculture that can damage infrastructure, as well as reducing biodiversity. Weedy species are considered economic and ecological pest species, or they may simply be undesirable in certain locations [128]. Weeds can be non-native, or native species with natural competitors or predators that limit rate and extent of spread (e.g. lambsquarters or crab grass). Noxious weeds are a designation assigned by a level of government to species considered harmful to public health, agriculture, recreation, wildlife, or property (e.g. purple loosestrife). Not surprisingly, noxious weeds are often also invasive, alien species. Both weeds and invasive species can easily be spread by accidental introductions of seeds or propagules, or 'seed banks' in soils, and thus can be difficult to completely remove.

As described in the sections below, invasive and weed species management approaches include techniques that aim to totally remove these species, a daunting and often unsuccessful effort. More progressive approaches include means to prevent the spread of such species through a comprehensive integration of practices into ROW management (integrated pest management).

4.2.1 General overview

Invasive plants present significant stewardship challenges in the creation and maintenance of roadways. Roadway ROWs are human-created ecosystems that differ from surrounding plant communities in terms of drainage, light availability, stem density, and substrate composition [129,130]. They provide a distinctive habitat, often supporting weedy species absent from natural communities, and ideal conditions for invasive species: abundant sunlight, disturbed ground, little competition of established communities, and abundant water from roadside ditches. Non-native plant species have been found to occur in higher frequency within transportation corridors than in control sites away from these corridors [131]. Transportation corridors not only offer ideal habitat, but act as major pathways for spread into adjacent ecosystems and across the country [132]. This results in more widespread problems such as reduced health of adjacent agricultural lands and impacts on forest health, and therefore, their productivity and economic value. Other effects include impacts to populations of native plants and wildlife, and in some cases threats to human health. Certain habitats are more susceptible to invasion from transportation corridors, such as sensitive wetlands, grasslands and prairies [133].

Mechanisms of spread within and adjacent to roadways include both natural and anthropogenic factors, such as:

- Natural dispersal of seeds by wind, or carrying of seeds by animals (e.g. burrs, eaten berries)
- Seed dispersal by wind from vehicles moving along the road [134,135,136,137,138]
- Dumping of horticultural species [139]
- Introduction of seed from aggregate used during road construction [137]
- Introduction of seed from mulch used in establishment of roadside vegetation communities [137]
- Transportation of seeds or roots on construction and maintenance machinery [133]
- Intentional planting [5]

Weed management includes long-standing practices, such as use of herbicides, mowing, and in some cases hand removal, but despite an abundance of practical experience and extensive scientific literature about invasive species management, lessons learned are often unshared or unheeded [140]. Prevention efforts are rare compared to eradication, and site restoration is often forgotten. Additionally, major operational barriers to management remain unresolved. Funding and staff resources are limited, practitioners lack access to information on BMPs and public aversion to herbicide use is widespread [140].

In Canada, the federal government has initiated an Invasive Alien Species Strategy for Canada, which has supported 170 projects across the country between 2005 and 2012 with nearly $5.6M in funding through the Invasive Alien Species Partnership Program [125]. The uniqueness of this funding effort helps to underscore a frequent critique of invasive species management: resources assigned to management are often smaller than the problem warrants [141]. Roadsides are critical conduits for many invasive and weedy plant species across Canada, and therefore transportation management policies are critical in controlling the establishment and spread of these species and encouraging native counterparts instead.

4.2.2 Implementation in road management

As the network of paved roads increases across the country, the movement of invasive plant species is facilitated across these ideal dispersal corridors. Prevention and control of invasive and weedy species along Canada's roadways can play a key role in reducing the spread of invasive species across the country. Opportunities exist through all stages of the road management life cycle, from planning through to operations and maintenance, or upgrading existing roads.

Planning

In the context of the road management life cycle, any given stage requires planning considerations. Relative to invasive and weedy species management, planning can identify the opportunities to integrate management during design, construction, operations, and maintenance stages. Early detection and prevention are by far the most cost-effective ways to control invasive plant proliferation within transportation corridors (Leung et al., 2020). This can be done by ensuring the following preventative measures are in place:

- Ensure vehicles and equipment (including mowing equipment) active during construction, operations and maintenance are clean of invasive plants and seed, for example, see *Clean Equipment Protocol for Industry* [137]).
- Minimize soil disturbance in all construction and maintenance activities where possible, and otherwise promote the establishment of a healthy plant community to hinder invasive species colonization.
- Use certified weed-free seed mixes or vegetation in disturbed areas to provide competition for any new weeds.
- Contain infestations and restrict spread to adjacent areas. Roadways, railways, and waterways are often corridors for spread and should be monitored for invasive plant establishment. If a new infestation arises, control it quickly.
- Develop policies or guidelines for staff and contractors, including staff training, to identify invasive species.
- Schedule maintenance mowing in transportation corridors before invasive species have gone to seed to reduce further spread.
- Dispose of invasive species waste in an appropriate manner (i.e. send to municipal composting facility, bagged to the landfill or incinerated).
- Ensure soil, fill, and mulch used during a project are "invasive-free" by using certified clean materials, or testing imported materials.
- Avoid work in areas of invasive infestation – begin management before work begins. For example, establishing weed-free staging areas for construction equipment can avoid transporting weed seeds or propagules to other sites.

Operations and maintenance

Controlling Established Populations

While prevention is ideal, once a population is established, efforts must shift to monitoring, managing, and if possible, eradicating the species. Controlling invasive plants is no easy feat and eradication often takes multiple years and a variety of control methods to be successful. Control methods for an established population include the following:

- **Mechanical** – Mechanical methods of plant removal include all physical means of removing or destroying plants, including cutting, pulling, mowing, flooding, solarisation (smothering vegetation with plastic), girdling (removing outer layer of bark from around a stem), and controlled burning. Some also consider grazing to be a means of mechanical control since it has similar effect to mowing. With mechanical control, results are immediate, however the effort or cost is generally high and repeated treatments are often needed.
- **Biological** – Biological methods suppress specific invasive species populations through the introduction or encouragement of predators. Predators are most often insects (for example the black-margined loosestrife beetle, which preys on purple loosestrife), but other biological agents may be used, such as fungi. Grazing is also considered a biological control by some (e.g. goats will eat a variety of weedy species). Extensive research is required to determine the suitability of insect or fungal predator introduction, which can be very time consuming. But this method can have widespread impact and thus can be very cost-effective. Novel introductions of such biological agents are strictly regulated though, and must be approved by federal and provincial authorities.
- **Chemical** – The application of chemical herbicide treatments designed to selectively or broadly eliminate vegetation species. This method tends to be economical and effective, but it is also controversial. Chemical control is typically used in conjunction with other control methods. Application requires certification and permits, and depending on the herbicide treatment, can be restricted for use in sensitive locations (e.g. over or near water).
- **Cultural** –Modification to habitat by specific intervention can also prevent the introduction or reinvasion of an invasive species and promote desired native plants. For example, if an invasive plant species is intolerant of shade, planting shade trees will give competitive advantage to native species. Cultural control methods may include irrigation, fertilization or planting of shade species.
- **Integrated Species (or Pest) Management** – A management system that integrates the above described control methods to effectively address infestations while optimizing the use of resources and minimize the use of pesticides. IPM is the most effective control method, however it requires extensive planning and can be time consuming (see the separate discussion below). IPM is a complex approach and may require hiring a licensed contractor to ensure IPM practices are followed properly.

Integrated Species (Pest) Management Plans

Successful invasive plant management is more complicated than simply killing weeds—it requires a strategic and adaptive approach. An Integrated Species (or Pest) Management Plan (ISMP) is a conservation tool that creates a clear strategic framework for the management of an invasive species. An effective ISMP will include the project vision (ultimate goals of the project), scoping (the spatial and temporal extent of the project), and tailored priorities and objectives. When developing a ISMP for transportation corridors, no single approach is correct; an effective plan will be project specific. Starting out with an understanding of the existing ecological conditions, and determining what is possible/feasible allows for the creation of tailored goals and the strategies to achieve them. The following steps to create an ISMP demonstrate the decision-making process regarding the management of invasive species proliferation [140,142].

1. **Identify Project Vision and Scope**: The project vision identifies the spatial and temporal extent of the project. These two factors set the stage for the information required for the framework of the plan.
2. **Document Existing Conditions**: A thorough understanding of the ecology of the project area should be done by qualified professionals (e.g. terrestrial ecologists, botanists or invasive species specialists), as an understanding of the species' life history and potential trajectory will inform future management. Documentation should include:
   - A **detailed inventory** of all plant species (native and invasive) and vegetation communities in the management area, as well as wildlife usage, and local hydrological conditions
   - **Invasive species information** including infestation size, age, location, number/ density of a population, as well as any outlying pockets on adjacent properties that could colonize the project area
   - Relevant research on **species-specific BMPs**. Species-specific BMPs have been developed by organizations such as invasive species councils (listed in Step 6). BMPs are a key resource (e.g. used in 75% of ISMPs in Ontario [140]) and are a critical tool in informing the choice of control method(s).
3. **Consult Relevant and Enabling Legislation** – Identify legislation that impacts the ISMP. For example, the management of invasive species such as phragmites is now legislated in Ontario within a stand-alone Act, the *Invasive Species Act* (2015), to prevent and control spread to new areas. In some other provinces and territories, legislation for the control of invasive species is embedded in other acts such as weed control acts, among others. Other relevant legislation includes various provincial and territorial pesticide and pest control acts.
4. **Identify Management Priorities**: Choices must be made regarding what population, area, or species to deal with first. This may involve prioritizing the protection of sensitive features, or addressing areas that will have a better return on investment of limited resources. This prioritization exercise will rely heavily on information gathered in Step 2. The following are examples of commonly identified management priorities:
   - **Sensitive ecosystems (prairie, wetland, alvar, savannah, etc.)** – Not only are sensitive / rare ecosystems high priorities for protection, they also tend to be more prone to invasion [131].
   - **Species at risk (SAR)** – While control of invasive species ultimately benefits plant and animal SAR, certain control methods may pose a short-term risk. For example, plant SAR may be threatened by the use of broadcasted herbicide, or nesting or hibernating SAR turtles may be impacted by excavation. Step 2 should have identified the presence of SAR, potentially requiring a more targeted management approach.
   - **Provincially, territorially or federally protected areas (parks, conservation areas)** – As these areas serve as refuges for biodiversity, intact ecosystems or aesthetically beautiful landscapes, they may warrant higher priority than other areas.
   - **Areas of high biodiversity** – Although not always formally recognized, areas of high native biodiversity may be identified during field investigations and warrant higher priority.
   - **Risks to public health** – Invasive species can pose threats to human health, both directly (for example Giant Hogweed [*Heracleum mantegazzianum*] can cause serious burns to skin) and

indirectly (Japanese knotweed [*Fallopia japonica*] obstructs sightlines on roadways and attract wildlife [143]).

- **Risks to the economy** – Invasive species can negatively impact property values, agricultural productivity, public utility operations, native fisheries, tourism, and outdoor recreation [144,145].
- **Risks to project operations** – Invasive plant species can disrupt the usual operation of roadside infrastructure; for example, common reed (*Phragmites australis*) is known to clog storm culverts and drains [146], and knotweed (Polygonum spp.) can penetrate concrete, damaging roads, foundations and drainage systems and creating increased maintenance costs [142].

As another example, the *Invasive Reed Canary Grass Best Management Practices in Ontario* [147] provides a framework useful to prioritize sensitivities and inform management planning.

1. **Develop Management Objectives / Goals**: Once invasive species and management priorities have been identified, feasible goals can be set. Key decisions include containment / management or eradication of the invasive species, and will be based heavily on availability of resources. A survey conducted by the Ontario Invasive Species Centre [140] found that organizations carrying out management plans in Ontario spent up to $5,000 / year, invested up to 20 staff days and relied on internal employees to administer control programs. Assessing financial and staff resources will support effective allocation of resources to achieve project goals. In the initial stages, focus on two to five cost-effective objectives in priority areas. Follow-up monitoring of these efforts can help determine the effectiveness of management decisions, without wasting valuable resources [148]. By the end of this step, specific, measurable, achievable, results-oriented, and time-bound (SMART) management objectives should be set.
2. **Build Partnerships**: An effective ISMP will include plans to build partnerships with existing organizations to better deliver invasive species management. Pooled resources may include funding, expertise, human resources, and other services. For example, invasive species councils across Canada (see Section 4.7) and local governments may have existing programs or may develop a program jointly to achieve goals without duplication of effort. Invasive species councils fulfill many functions, especially public education, technical advice and land manager coordination [142].
3. **Create a Working Plan**: With an understanding of project ecology and resources, a working plan can be developed to efficiently meet the objectives outlined in Step 5. While developing your working plan keep in mind the management priorities (Step 4) and objectives (Step 5). The plan should incorporate the following aspects:
    - **Prioritize prevention** where possible – Concentrating efforts on the initial phases of management (prevention and early detection) is the most cost-effective approach, and if possible should be the basis for a ISMP strategy. Refer to above listed prevention methods above.
    - **Identify Species-Specific BMPs** – Include control measures appropriate to biotic and abiotic conditions of the site. Species-specific BMPs should have been identified in Step 2, but others may be available from local invasive species councils. Evidence-based approaches capitalize on species vulnerabilities and are a key resource.
    - **Avoid affecting non-target plant and animals** – Use control methods only during certain timing windows (i.e. outside of the breeding bird or turtle hibernation period), or use

targeted implementation of a chosen control method (i.e. foliar wicking instead of broadcast spraying of herbicide).

- **Plan appropriate plant disposal** – If manual removal is used, disposal of the plant material must be planned carefully; invasive plants spread readily via seeds or vegetative fragments and can often regrow even after high-heat composting. Incineration of plant material is ideal, however bagging for landfill is often the most feasible.

4. **Restoration**: Where an invasive species population is sparse, native plants may spread naturally after implementation of controls and restoration may not be necessary. However, where populations are dense, their removal can result in the loss of all vegetative cover, creating ideal conditions for invasive plants to recolonize [149,150]. Restoration through planting or seeding can reduce risk of erosion and re-establishment of invasive species. The *Ecological Restoration Guidelines for British Columbia* [151] offers an example of restoration guidelines after removal of invasive species.
5. **Ongoing Monitoring**: Biological monitoring to assess the outcomes of the program should be ongoing throughout the process, ideally annually. This allows for adaptive management, and evaluation of the feasibility, cost-effectiveness and ultimate success of the program. Allow for reassessment of the control method(s) and / or reapplication of the original or an adapted strategy. The ISMP is a living document that can be adapted as needed.

4.2.3 Beneficial management practices

Despite significant challenges, preventing or minimizing the establishment and spread of invasive species along Canada's roadways is achievable. The suitability and ultimate choice of prevention / control method are determined through an understanding of the site ecology, the context of the project and resource constraints. To be truly effective long-term, these prevention and control methods require clear and carefully planned implementation. Preventing, controlling and eradicating invasive species can be best achieved through the creation and of an adaptable and context-specific Invasive Species Management Plan (ISMP), which capitalizes on local resources and knowledge regarding species of concern.

4.3 Right-of-way naturalization

4.3.1 General overview

As previous sections have noted, road ROWs can serve multiple functions, including user safety, but also biodiversity conservation, recreational use and aesthetic benefits [5]. Increasing interest in the ecosystem services and benefits offered by natural ecosystems has spurred interest in the potential for naturalized habitat, including that within road ROWs, and particularly those within urban areas [152]. In addition to providing wildlife habitat, other ecosystem services include stormwater filtration and flow moderation, as well as carbon sequestration [153,121,110,154].

Traditionally, road ROWs were reclaimed to non-native monocultures, with commercially available, relatively inexpensive species such as crested wheatgrass (*Agropyron cristatum*) or smooth brome (*Bromus inermis*) [103]. These species can spread quickly to adjacent areas, and attract wildlife to the road edge. Mounting costs for mowing and herbicide use to control weedy species and limit spread of these grass species to adjacent lands has promoted interest in reclamation using native species

[103,104]. Naturalization, the conversion of ROW to native grasslands, offers viable and cost-effective alternatives to traditional roadside vegetation management.

In response to these ecological and operational concerns, transportation agencies across North America have gradually shifted to the use of native plants for ROW revegetation, often supported by high level strategic initiatives for environmental stewardship. Examples include the *2008 Performance Plan* of Saskatchewan Ministry of Highways and Infrastructure, and the City of Calgary's *Municipal Development Plan* and *Transportation Plan*, which emphasize environmental goals as well as cost-effectiveness. The TAC (2014) *Synthesis of Environmental Management Practices for Road Construction, Operations and Maintenance* recommends using as many native species as possible in the seed mix, and preferably seed derived from local genetic stock [155].

4.3.2 Implementation in road management

Jurisdictions across Canada are increasingly incorporating biodiversity conservation objectives in their ROW management planning, which turns attention to naturalization approaches in reclamation and seeding planning. Biodiversity conservation works in hand with conservation of native habitat, and road ROWs offer extensive areas for naturalization. Such initiatives can access funding not traditionally available to transportation agencies, including innovation funding, species at risk conservation funds, and habitat conservation funding through government sources, but also a wide range of private and public granting agencies.

As an example, Ontario's Ministry of Transportation has leveraged its Highway Infrastructure Innovation Funding Program in partnership with Ontario universities to explore approaches to incorporate Biodiversity Best Practices into road planning, including ROW reclamation [84]. The City of Calgary has developed a pilot road boulevard naturalization project, funded through an application for the City's Innovation Fund, by linking naturalization to objectives in its *Municipal Development Plan*, *Calgary Transportation Plan*, *Biodiversity Strategic Plan*, *Climate Resilience Strategy*, and *Resilient Calgary Strategy* adopted by Council.

Key elements of such projects include partnerships. As described in the Case Study in Section 4.6, MTO has completed several naturalization projects whose success involved partnerships. This includes the Tall Grass Prairies project along the Rt. Honourable Herb Gray Parkway, which conserved and restored tall grass prairie during planning and construction phases of the project. Partnering with an ecological restoration company operated by the Walpole Island First Nation and the Essex Region Conservation Authority, the project propagated native plant seeds for species at risk, and planted them in restoration areas along the road ROW. Working with McMaster University, the MTO tested pollinator friendly seed mixes to enhance avian and insect pollinator habitat along the East 407 Extension Project. The project involves developing and testing pollinator-friendly seed mixes that include milkweed, a species specifically used by Monarch butterflies. The mix has been applied to a section of the 407 East Extension project, and research included a cost/benefit analysis of the native seed mix approach, versus standard roadside mixes.

Similarly, the City of Calgary's Roadside Naturalization Pilot Project aims to explore unconventional landscaping methods on public ROWs, to achieve operational cost-savings, but also to add value through natural infrastructure, ecosystem services and enhanced biodiversity [156]. Proposed partnerships will leverage the scientific expertise of researchers to assess naturalized sites relative to changes in plant communities.

Carbon can be sequestered both through the establishment of specific plant communities, as well as their active management. While the establishment of woody vegetation is an effective means of capture carbon, these plants pose problems with attracting wildlife, reducing sightlines and increasing WVCs [95]. Both natural and planted grasslands have been found to be as effective or more effective than treed habitat at sequestering carbon [153,121,154]. A study by Tilman et al. [157] supports the use of low-input high-diversity mixtures of native grassland perennials, as they are extremely effective at greenhouse gas reductions. Indeed, the use of native grasses in ROWs may be advantageous as they tend to be drought tolerant, and may generally thrive in the local ecosystem better [120,121]. Critically, they also typically establish large root systems, resulting in significant storage of below ground organic carbon. Lastly, the establishment of native species may be desirable for other environmental/wildlife benefits. These can include propagation of rare plant species or provision of habitat for wildlife species at risk, such as the use of milkweed in native restoration projects in Ontario to support monarch butterfly [84].

Monitoring and, more importantly, sharing the results and learnings of such programs will be important in advancing the practice of naturalization techniques. Naturalization techniques will vary with the ecological and climatic conditions applicable to a specific geographic region, and thus region-specific guidelines are likely to be more successful. Such regional guides have been developed based on practitioner experience and research. So, for example, the native reclamation guide developed for Alberta's Fescue and Central Parkland Natural Regions [113] outlines guidelines applicable to a continental climate with cold winters, and moderately warm, wet summers. The *Saskatchewan Guidelines For Use Of Native Plants In Roadside Revegetation – Reference Manual* [112] identifies other context specific considerations for successful naturalization. Research programs offer in-depth evaluations of specific programs, or sometimes broader comparisons, and can provide more specific advice, on both the ecological aspects and policy planning elements of naturalization [158].

4.3.3 Beneficial management practices

Although a new management approach, some general advice is emerging from published studies and guidelines for naturalization. Examples of BMPs transferable to other jurisdictions are summarized below.

- Naturalization is innovative, and will present a deviation from traditional ROW management from an internal agency and public perspective. Partnerships can secure resources, but also broader interest and support for the program [158,115].
- Similarly, an alignment of the proposed program with other established initiatives can convey a sense of shared commitment to progressive, global efforts [158]. For example, the City of Calgary's pilot ROW naturalization program aligned itself with internal policy, but also global initiatives such as the Durban Commitment to Biodiversity Conservation, and the City's recent 'Bee City' designation[10].
- Share the concept and results of new programs with stakeholders, to demonstrate how change is making a difference [158,115]. This can be particularly important when benefits may not be clear, whether ecological or economic.

[10] Bee City Canada aims to inspire municipalities, First Nations, businesses and other organizations to protect pollinator habitat. Municipalities can apply for Bee City designation through the Bee City City Partner Program.

- Although native species are often a better alternative to non-native communities, in some locations, significant effort may be needed to completely eliminate the original non-native community [115]. For example, ROWs adjacent to hayfields that have been seeded using perennial species like crested wheatgrass, brome, alfalfa, and clover, or near turf areas with Kentucky bluegrass or quackgrass, will likely be recolonized from wind-blown seed or rhizome encroachment [112]. Such sites may also have an extensive seed bank in the soils that will continue to regenerate and propagate for many years.
- Similarly, areas with high levels of past infestation by noxious weeds or invasive alien species will require extensive weed management to eliminate these species [112,115].
- Frequent mowing may weaken plants and can negatively affect successful establishment of species less tolerant of disturbance [112]. Mowing schedules should be scheduled to allow normal growing cycles to be completed, to facilitate seed generation and propagation of desired species (see also Section 4.4, Pollinator Habitat Management below).
- When purchasing native seed or having it collected from other native areas, test seed mixes through an accredited seed analysis lab to establish proper seeding rates based on viable seed, and species percentages [112].
- When reseeding an area, provide erosion controls until plant cover is sufficient to stabilize soils [113]. Native plants may establish more slowly, and controls will also require periodic monitoring and maintenance (pers. comm., J. Charlton).
- Timing of seeding is also important, and should be suited to the species and the environmental context. Some species may require specific soil moisture or temperature levels for germination [113].
- While both native cultivars and ecovars™ are commercially available, testing for seed purity by a certified agency is still recommended [113]. Note that native suitability for cultivars and ecovars™ in one natural subregion does not imply suitability elsewhere. Additional monitoring should be used to evaluate success when seed is used outside originating regions.
- Natural recovery, by allowing native plants to colonize from adjacent habitat or establish from soil seed banks after stockpiled soil replacement, is possible in some cases, but may be slower than direct intervention [113]. Soil type, site conditions, proximity to undesirable species (e.g. invasive, or weedy species), length of soil storage (if stockpiled), seasonal timing of soil placement and risk of wind or water erosion will all play a role.

While carbon storage occurs naturally in all vegetation communities, ROW management practices can increase potential carbon sequestration. Beginning in 2008, the Federal Highway Administration (FHWA) conducted a Carbon Sequestration Pilot Project in New Mexico, USA [159]. The project sought to assess effectiveness of carbon sequestration through modified maintenance practices, with a focus on the practicality and cost effectiveness of alternative management regimes. Up to seven times more carbon than was currently stored could be added to the soils using the following three management strategies:

- **Increased mowing height** – Mowing to a height of >15 cm facilitates carbon capture. When cut lower than 15 cm, grasses use carbon stores to regrow, thus decreasing carbon returned to soils.
- **Seeding legumes** – Legumes fix soil nitrogen, which promotes carbon capture by boosting plant growth and indirectly increases carbon sequestration.

- **Soil imprinting** – Soil imprinting equipment physically alters the shape of the soil surface to capture and retain more water and nutrients. This promotes plant growth, which indirectly increases carbon sequestration [159].

The FWHA reported an increase in carbon capture within the ROW, as well as lower maintenance costs, and a potential revenue source from the sale of carbon credits in regions with cap-and-trade systems in place. Such benefits could be applied in Canadian regions offering carbon credit programs, such as Quebec. Although many activities associated with roadway building necessarily result in greenhouse gas emissions, native grasslands in ROWs offer at least some potential carbon offset, and can serve as an innovative example of climate adaptation.

4.4 Pollinator habitat management

As discussed in Section 4.1, conventional ROW vegetation management in Canada involves measures that can discourage growth and diversity of flowering plants, including mowing, herbicide treatments or reclamation with non-native grasses. Roadside ROWs also have the potential to facilitate non-native plant invasion, as many non-native plants prefer open and disturbed conditions. Although pollinators (bees, butterflies and other invertebrates, and some birds) use non-native flowers, pollinator visitation is greater on native species. As concern mounts relative to the declines in pollinating insects and bees, the effects of these traditional maintenance approaches in transportation corridors has come under scrutiny, and prompted consideration of new, more integrative practices.

4.4.1 General overview

There is debate on whether the effects of roads on pollinators are positive or negative. The literature suggests that effects are likely site-specific and depend on many factors including the quality of the roadside habitat, differences in topography, traffic speed and volume, and surrounding land use [160,78]. However, considering the extent of vegetated ROWs beside the 1,130,000 km of two-lane equivalent, paved and unpaved roads in Canada [161], Canadian transportation agencies have good potential to increase pollinator habitat where such use is sustainable.

Native vegetation along roadsides can provide important habitat for pollinators, especially in landscapes dominated by monocultures created by agriculture or in urban areas where natural areas are at a minimum [110]. Sustaining pollinators has significant social and economic benefit. Bees in Ontario alone are responsible for $897 million of agricultural crops grown in the province every year [162]. The effect of healthy, diverse naturalized areas on people is an additional benefit of maintaining more native plant habitat in urban areas. Experiments in England have shown that redesigning urban green-spaces and parks through the creation of species-rich meadows provides mental health benefits that are a win–win strategy for biodiversity and people, and potentially improve connections between the two [163].

Figure 16. Examples of pollinator habitats

Upper left: Rural highway with traditionally mowed right-of-way (courtesy Ohio Department of Transportation)

Upper right and lower left and right: Rural highway with pollinator habitat, unmowed and seeded to wildflowers used by pollinators (courtesy Ohio Department of Transportation)

4.4.2 Implementation in road management

Road ROWs in urban and rural contexts have been found to be hotspots for flowering plants and pollinators [164], but in an urban setting, road ROWs can provide considerable habitat benefits for pollinators [165]. Further, when urban ROWs are viewed as part of an interconnected network, enhancement of pollinator habitat can have considerable benefit [165]. Unlike large mammals, pollinators generally have short lifecycles and require small habitat ranges within a road network [166]. Maintained ROWs seeded to tame grass plant communities are typically a focus for management of pollinator habitat, but forest roads and roadsides also offer an opportunity to create pollinator-friendly habitat and convert non-native species into native habitat [160]. While maintaining pollinator habitat is a relatively new form of road ecology mitigation, key practices have emerged relative to habitat restoration and conservation, applicable to road design, construction, operation, and maintenance.

Planning

Naturalized ROWs along urban roads can provide important habitat for bees and other insect pollinators and help enhance the abundance and diversity of native species in urban and rural landscapes [166,160,164]. A restoration project involving native species profoundly affected bee species, resulting in higher species richness along restored road ROWs, likely because roadsides with native species have more floral species and more patches of bare ground used by ground nesting bees than weedy roadsides [167]. Bee species richness and abundance of these restored roadsides were found to be similar to a prairie remnant habitat. Others have found that roadsides managed and restored to mimic natural prairie grasslands have increased richness and diversity and are used more by pollinators [162]. Urban areas, including road ROWs, have the potential to be important pollinator reservoirs if both bloom and plant diversity is considered during sustainable urban planning [168]. Similar benefits can be derived from conserving, restoring or enhancing pollinator habitat along rural road ROWs.

There is concern that with an increase in quality of ROW habitat for pollinators, comes potential for more pollinators to be killed by vehicle collision [169]. However, a meta-analysis of studies on pollinator habitat found the benefits of ROW pollinator habitat outweighed the mortality risk [164]. Pollinator mortality has been found to increase with larger traffic volumes and road widths, but it can also increase depending on the schedule and frequency of ROW mowing [169]. The width of the ROW does not appear to affect bee richness and abundance, but it has had a negative effect on different invertebrates. A two-year study along a two kilometer stretch of highway in Ontario with moderate traffic levels recorded road mortality of hundreds of thousands of invertebrates and then extrapolated the results across several landscape scales [170]. The extrapolated results estimated total mortality of hundreds of billions across North America, and speculated that such impacts could be one of the causes of pollinating insect declines. However, research in Europe has indicated that along ROWs with high-quality habitat, pollinator mortality is reduced because the insects naturally move along the roadside and not across [169]. Larger ROWs with high plant species richness also reduced mortality. Conservation efforts, accordingly, have focused on maintaining good habitat quality within the ROW, through the design and construction of roads and ROWs, and during their maintenance.

Design and construction

Avoidance, as always, should be the first step in mitigating road construction impacts, considered before minimizing or compensating for habitat loss through enhancement or restoration. Maintaining existing habitat can be very effective mitigation, since mature natural areas can provide a diverse range of plant species, used by various pollinator species [162]. Maintained habitats may require modified maintenance, such as less frequent mowing, and avoiding, or limiting use of herbicides nearby and within the habitat (see next section on operations and maintenance). Relatively simple enhancements such as leaving old branches and woody shrubs for nesting habitat, and allowing woody shrubs and trees to grow within the managed parts of the ROW (i.e. beyond the recovery zone), can also help to maintain existing habitats. Retaining even small areas such as boulevards, through to larger extents of ROW can help sustain pollinators within a ROW.

Where impact cannot be avoided, enhancement of remaining habitat areas and restoration can be effective means of replacing pollinator habitat. Restoration and enhancement can also be applied on existing ROWs (e.g. during road upgrading), or as a stand-alone habitat conservation project. A key requirement of selecting potential enhancement and restoration sites is ensuring pollinators can access flowers throughout the growing season, find nesting sites and travel through the available habitat [162]. Luckily, most pollinators have small territories, so these management actions can be applied on any parts of the ROW with adequate sunlight and water to support flowering plants.

When considering restoration after construction, the TAC (2014) *Synthesis of Environmental Management Practices for Road Construction, Operations and Maintenance* [155] recommends using as many native species as possible in the seed/seedling mix, and preferably seed derived from local genetic stock [155]. To enhance pollinator use, native plant seed mixes for roadside restoration should include flowers with differing, but overlapping phenologies, to provide bees with continuous floral resources over the growing season [167]. Non-native species can be planted for pollinators, but some research has indicated that pollinator visitation is greater on native species [160]. At some restoration sites, testing soil characteristics and soil amendments may be necessary for the development of healthy vegetation. While standing water is often available in road ditches, other parts of the ROW may receive only precipitation. Successful restoration will depend on soil type, soil chemistry and surface and groundwater conditions [155].

Restoration and enhancement can be challenging on ROWs that currently support degraded grassland habitat, and such projects will require sound planning to ensure support and resources required for implementation are available [162,85]. Identifying feasible and effective techniques to reduce the negative impacts of invasive and non-native species and promote self-sustaining native populations is an essential part of the planning process. Where native communities currently exist, particularly plant populations or communities of significant conservation value, they should be identified, mapped and integrated into future road planning and maintenance requirements. Involving other stakeholders, including regulators or not-for-profit community groups, and promoting community project activities (e.g. using social media) can help build local engagement, as well as provide potential resources and other support for restoration projects [162,85].

Recognizing the need for specific approaches for managing pollinator habitat, some jurisdictions have begun to experiment with pollinator restoration and maintenance techniques designed as site-specific solutions. The Herb Gray Roadway Case Study in Section 4.6 describes efforts to restore and enhance pollinator habitat through native plant propagation, an innovative and successful approach, but one requiring considerable resource and support gained through partnerships (e.g. with seed growers, university research programs). Lanark County in Ontario has identified a long-term goal of restoring pollinator habitat along roadsides by improving and maintaining diverse pollinator habitat [171]. Its approaches include measures that can be readily implemented by a transportation agency, such as controlling invasive plants that negatively impact pollinator habitat to facilitate restoring the habitat.

Lastly, when an area of degraded roadside has been selected for enhancement or restoration of pollinator habitat, plant selection should also consider how climate change will affect the roadside [172,173]. Ecological restoration techniques, including reforestation, afforestation and rehabilitation of degraded land, offer various means to adapt to predicted effects of climate change [173]. While afforestation (planting in areas not previously forested) may not be feasible in rural contexts, especially in areas crossing private lands, in urban lands or park areas it can restore connective habitat for a range of species, including pollinators. In Alberta, municipalities within the growing Edmonton Capital metropolitan region are all considering how to create restoration habitat through new land development and re-development projects, including transportation works. In October 2020, the City of Edmonton announced an ambitious project to plant two million trees to its street boulevards and parks, mainly for urban green space enhancements, but also to support other habitat enhancement goals [174].

Operations and maintenance

Ecological restoration and rehabilitation to enhance or add pollinator habitat can be done on the ROW for new or existing roads, but such efforts must continue through to operation and maintenance phases. Strategic management of ROW habitat, for example by adjusting mowing schedules and changing herbicide use, is a proven means to enhance habitat [164].

Next to proper selection of native plants, the mowing schedule during operations has the largest impact on species diversity, abundance and risk of mortality [160]. Hanula [160] highlights the need for research aimed at optimizing the timing and frequency of vegetation control, as well as understanding the effects of planting and maintaining native plant species in favor of exotics. Some form of rotational management will almost certainly benefit insects; however, this is confounded by operational management of roadside ROWs by contractors unfamiliar with conservation goals [175]. The mowing schedule and frequency can actually cause more invertebrates to be killed by forcing them to leave the mowed habitat. Road mortality did increase with increased traffic volume, road width and ROW mowing [169]. Mowing such areas less frequently, and only during the dormant season, may help minimize negative impacts on butterflies, as an example.

Generally, lawn habitats, including those within urban road ROWs, are a monoculture of grasses that lower the biodiversity potential for pollinators [176,177,178]. Lawns are ubiquitous in urban areas, comprising 70–75% of urban green space worldwide [179]. The intensive management of vast swathes of lawn in yards, public parks and road ROWs is a principal barrier (after habitat destruction) to biodiversity provision in urban landscapes. As noted above, mowing can reduce insect biodiversity in particular [180]. Reducing mowing to twice a year improves species richness in both urban park and road ROW settings, and in lawn spaces and hay meadows, by supporting plant flowering cycles throughout summer months [175,180].

Monitoring

Monitoring of restoration efforts to evaluate long-term success is not always included in post-construction operations, but is essential to understanding how initial outcomes change over time. Monitoring can also help confirm cost-benefit evaluations, and support evidence-based planning for future efforts. The indirect effects of operational management, including a lack of management, are very important in the long run and might eventually lead to the disappearance of suitable habitat [175]. As an example, a study that revisited degraded patches of Pacific Northwest prairie habitat six years after experimental restoration efforts ceased, examined plant community composition to determine the lasting effects of supplemental native seeding and disturbance treatments (burning, mowing and herbicide to reduce exotic species [173]). Plots that received supplemental seeding had higher native species richness than those left unseeded, and both seeding and disturbance treatments positively influenced native species abundance over the long term. Monitoring results also confirmed challenges in restoration of degraded grasslands, including dispersal limitations of native species and difficulties with sustained control of exotic grasses [173].

4.4.3 Beneficial management practices

While still a relatively new mitigation approach, various agencies have developed guidelines for retention, enhancement and creation of pollinator habitat. Pollinator Partnership Canada [162] has identified three key means used to sustain pollinator habitat, which generally capture the methods used in these efforts:

- Maintain habitats using methods that minimize disturbance and harm to pollinators
- Restore natural vegetation and habitats
- Enhance habitats using methods that promote pollinator richness and diversity

They, and other Ontario agencies, have done much work to promote BMPs applicable to other locations in Canada. The Government of Ontario has also created a *Pollinator Health Action Plan,* based on a Pollinator Health Strategy that includes steps applicable to large scale projects, such as maintenance of highway ROWs, as well as on small-scale residential streets [181]. Like the guide produced by the Pollinator Partnership Canada [162], it recommends various small and large actions that can create benefits at local, regional and national scales.

Specific restoration BMPs include the following:

- Planting or encouraging growth of a range of native flowing plants, forbs and shrubs that will bloom throughout the growing season [162].
- Adding logs, nest blocks or ‘bee hotels’, constructed nests with several hollow tubes, to provide additional nesting habitat [162].
- Planting specific flowering species required by other targeted conservation species (e.g. planting milkweed for monarch butterflies) [162].

Other measures apply to operational and maintenance activities, which can be modified to accommodate pollinators. An example from Lanark County in Ontario offers suggestions [171]:

- Since mowing weakens native pollinator-friendly plants, the County has reduced its mowing efforts to allow native plants to reseed into the roadsides. Mowing dropped from 1,700 km in 2015 to under 1,100 km in 2018.
- Over 25 native plant species were planted in two pollinator patches created in 2017 and native plants are expanding within the patches.
- The county also improved its hydro-seeding mix to include 12 pollinator-supportive plants, since grass seed mixes were previously applied to bare soil following construction project completion. The county plans to reseed other disturbed areas across the county in this way to improve pollinator habitat.

The Lanark County project has generated other innovations including planting plugs, which survived better than did seed [171]. They also found certain seed mixes could outcompete certain invasive species. Using a seed mix of 19 native grasses and wildflowers, staff restored a 124-km section of road from which invasive wild parsnip had been removed. The mix out-competed the wild parsnip, and successfully excluded the invasive species. In recognition of the County’s efforts to implement the integrated vegetation management plan with long-term goals for pollinators, they were awarded Canada’s first Pollinator Roadside Managers Award for Counties from the North American Pollinator Protection Campaign (NAPPC).

A study in the Netherlands tested the effects of different management treatments on pollinating insects along road ROWs, and offers suggestions for mowing schedule and frequency [175].

- Mowing twice a year with hay removal was the most beneficial treatment for flower-visiting insects, but these plots had not flowered for a period right after mowing. A rotational scheme might further promote insect diversity and abundance.
- Mowing during the early summer proved to be important to pollinators due to the re-flowering of plants later in the growing season.
- Dividing a ROW into two longitudinal strips of the same width, each of which receives two mowings, but with a small-time delay between the strips (e.g. three weeks) was beneficial for insect feeding and plant diversity[11].
- A second strategy managed almost the entire ROW with two mowings, while a narrow strip only (e.g. 10% of the total width) was mowed only once, which increased chance of successful pollinator reproduction.

The operations and maintenance actions described above can be supported by an Integrated Roadside Vegetation Management (IRVM) Plan [162], a systematic maintenance approach with integrated methods designed to manage areas restored with native vegetation (see Section 4.1). Specific road maintenance BMPs in an IRVM plan promoting pollinator habitat include developing site-specific operational guidelines for mowing, insecticide applications, beautification and restoration, and replacement plant selection. An IRVM plan can also be shared with contractors and others involved in managing ROWs, to ensure that all involved parties understand the goals and objectives of the modified, non-traditional maintenance requirements.

Other efforts aim to recruit public support through 'citizen projects'. The Ontario Horticultural Association [182] has prepared *Roadsides: A Guide to Creating a Pollinator Patch* that provides details for urban residents on how to choose the site and ask permission for approval from the local authorities. The guide recommends coordination of restoration projects along the provincial highways in Ontario through the Ontario Adopt-a-Highway program. Working in consultation with the Ministry of Transportation, an area of highway will be identified, and a plant selection and planting plan will be approved. The booklet provides direction on how to create or restore pollinator nesting patches; cloverleaf interchanges around on and off ramps have been identified as good project locations for restoration with native plants. The booklet also provides planting guidelines and after care for up to three years.

A last consideration in restoring or creating pollinator habitat is the potential for conflicting management interactions. Conservation of rare plants and habitat on roadsides may require special management that could negatively affect pollinators or their habitat. For example, plant species that require fire for regeneration may need to be burned periodically [175]. Plant selection needs to consider the risks of planting species attractive to wildlife, creating conditions that can increase the risk of fire and vegetation that can pose risks to drivers by obscuring oncoming vehicles, signs and large animals approaching the road. Again, an IRVM Plan will facilitate review of conflicting objectives, and transparent deliberation on the trade-offs involved.

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[11] *Note that New Brunswick cuts their ROW in two swaths on collector roads, while most other transportation agencies, both urban and rural mow the applicable ROW width at the same time (Appendix A).*

4.5 Wetland management

Wetlands are ecosystems that are intermittently or permanently saturated, with excess water causing low oxygen levels in soils where aquatic plants thrive and other biological activity adapted to wet environments occurs. Wetlands provide a myriad of invaluable ecological goods and services to society, including the following:

- Maintaining and improving water quality [183,184]
- Flood control and drought mitigation [185]
- Groundwater recharge and discharge [186,187]
- Erosion control [186]
- Climate change mitigation [186,187]
- Recreation and tourism [186,184]
- Provision of valuable wildlife habitat [26,101]
- Provision of educational and scientific opportunities [187,185]
- Provision of agricultural and commercial products (i.e. cranberries, wild rice, peat) [187,185]

Regardless of their many values, wetlands have been drained or converted to other uses at an astonishing rate. As of the 1990s, about 68% of wetlands in southern Ontario, 70% of the lower Great Lakes-St. Lawrence River shoreline marshes and swamps, 70% of wetlands in Prairie agricultural areas, and 65% of coastal saltmarshes in the Atlantic region have been lost [188,189,187,185]. Given the irreplaceable services they provide and their relative scarcity, protection of remaining wetlands is both ecologically and economically critical.

4.5.1 General overview

Transportation through and around wetlands is far from new; ancient wooden trackways, or corduroy roads, are found throughout European wetlands [190]. Modern roads are vastly more complex, more heavily used and have greater potential to impact wetlands. The following impacts can result from the creation and maintenance of roadways within or adjacent to wetlands:

- **Hydrological impacts**: Even small changes in the amount or timing of incoming surface water can cause changes in wetlands. Hydrological changes may create or eliminate wetlands or alter the functions of existing ones. Hydrological changes can be triggered by defoliation, windthrow, slope failure, and changes in rainfall interception that follow tree loss, all of which can occur with the creation or maintenance of roads [191,192].
- **Water quality**: Recent research suggests that presence and density of roads within a landscape is the greatest predictor of water quality, specifically with regards to nitrogen levels, phosphorus levels, sediment deposition, and heavy metals [193,194,195]. Oils, fuel and de-icing salt are also problematic pollutants that have the potential to exceed allowable levels in road runoff, and may impact receiving wetlands [196].
- **Impacts to wildlife**: General impacts to wildlife, and road mortality specifically, are greatly increased where wetlands are adjacent to roads, with amphibian and reptile populations particularly at risk [197,101].

- **Wetland isolation**: The geographic isolation of wetland ecosystems caused by roads is extensive in Canada and globally [198]. There is no point in southern Ontario that is further than 1.5 km from a road [26,101]. The result is the potential for hydrological changes, as well as impacts on wildlife. Findlay et al. [197] found that amphibian richness is negatively correlated with the density of roads in a landscape.

These impacts are interconnected, and can result in devastating consequences for wetlands, wildlife, and the broader landscape. However, proper management of roadways adjacent to wetlands can significantly lessen these impacts.

4.5.2 Mitigation implementation in road management

Canada's 1991 *Federal Policy on Wetland Conservation* identifies a goal of "no net loss of wetland functions on all federal lands and waters." This policy applies to projects involving federal funding, or on federal lands, but not private or provincial Crown lands. Some provinces have also adopted a similar wetland policy that attempts to reduce the loss of wetland habitat through a standardized assessment and mitigation process based on the mitigation hierarchy:

Endorsement of the mitigation hierarchy is nearly universal in wetland programs across Canadian and international jurisdictions [199,186,200,184,201]. Yet, the actual wetland assessment and mitigation process in Canadian provincial policies is in various stages of development. Most have some form of wetland policy that outlines a mitigation process; a few are linked to legislation that requires non-discretionary compliance:

- British Columbia Environmental Mitigation Policy
- Alberta Water Act and Wetland Policy
- Saskatchewan policy under development
- Ontario Endangered Species Act; wetland offset policy under development
- Manitoba Sustainable Watersheds Act (2017) The Water Rights Act and Wetland Policy
- Quebec Wetlands Program
- New Brunswick Wetland Policy
- PEI Wetland Conservation Policy
- Nova Scotia Wetland Policy

Yukon, Northwest Territories and Nunavut, as well as Newfoundland and Labrador, currently have no explicit management policies for wetland impacts.

Wetland mitigation emphasizes avoidance as a first step, yet in many jurisdictions this is rarely the case. In Alberta for example, Clare [202] found that despite provincial wetland policies in place since 1993, avoidance was rarely achieved in most development activities. Clare et al., [20], in their meta-analysis of

North American practice, and interviews with Alberta wetland regulators, found several factors contributing to the lack of avoidance in most projects:

- a lack of agreement on what constitutes avoidance
- land-use planning approaches that did not identify high-priority wetlands in advance of development
- consistent economic undervaluing of wetlands
- a reliance on wetland creation and restoration that results in increased natural wetland loss [12]
- inadequate enforcement of compensation requirements

They identified proactive ways to implement avoidance in wetland management, including watershed-based planning; comprehensive economic and social valuation of wetlands; and long-term citizen-based monitoring schemes. While many of these actions are beyond the management scope of most government transportation and infrastructure agencies, some have adopted internal environmental assessment practices that address wetland loss explicitly (e.g. Parks Canada, Alberta Transportation, Manitoba Infrastructure). In some cases, innovative approaches have attempted to replace wetland and upland habitat at a landscape level within road ROW, by integrating road drainage, landscaping, and environmental design processes (see Northeast Stoney Trail Wetland Compensation example in Section 4.6, Case Studies). Even citizen-science has been applied to specific road projects near wetlands (e.g. the Ryder Lake Amphibian Protection Project in the Fraser Valley, BC [83]). Due to the number of species at risk that can be associated with wetlands, including both animal and plant, specific attention to wetland impacts can avoid contravention with the federal *Species at Risk Act*, the federal *Migratory Birds Convention Act* and provincial wildlife protection legislation (e.g. the Sea to Sky Highway wetland impacts on red-legged frogs discussed in Section 3.3).

4.5.3 Beneficial management practices

Despite the past weaknesses in management of wetland impacts, Canadian and North American transportation agencies have developed recommendations for each stage of the mitigation hierarchy, applicable to various stages of the road life cycle [199,186,200,184,201]. Key recommendations from those sources are summarized below.

Avoidance

Avoidance of wetlands should be an integral part of designing, building and maintaining roads within or near wetlands. Avoidance may include:

- changing road alignment
- avoiding widening or extending roads into wetlands
- considering alternative designs that will fulfill the same purpose

Building roads through wetlands creates challenges in design and construction, while avoiding wetlands enhances construction efficiencies and mitigation costs. Avoidance methods may also include scheduling

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[12] *Costs to construct or restore wetland habitats are generally lower than avoidance costs (e.g. for realignment), leading to reliance on compensation to replace natural habitat, rather than conserving natural wetlands, and their associated biodiversity values. Such values are difficult to replace through creation or restoration efforts.*

construction or maintenance outside specific timing windows to avoid hydrological or ecological events, such as winter turtle hibernation, spring breeding bird season or spring runoff.

Minimization

If avoidance is not possible, the next step is minimization, or reducing the duration, intensity or extent of impacts. Methods of impact minimization are extensive and variable depending on project specifics. Categories that are commonly addressed in road construction include:

- the use of buffers (e.g. water quality set-backs are often a minimum of 30 m)
- alternative slope treatments
- alternative alignments for wetland crossing
- management of roadway runoff through stormwater systems (e.g. stormwater ditches and ponds, including naturalized ponds)
- erosion and sediment control
- protection of wetland riparian vegetation
- protection of wildlife (particularly species at risk and migratory birds)
- reducing use of de-icing compounds near wetlands, or using eco-friendly alternatives

The minimization approach can be simple, such as realigning crossings at large wetlands to narrow locations that reduce the area impacted. Such measures are often also more cost effective, since wetland crossings may require additional fill, culverts and ice management. While many BMPs to minimize the effects of roads are commonly implemented across Canada, others are more innovative and less frequently used. For example, while 15-20 m wetland buffers are common, research suggests that a minimum buffer of 20 – 30 m, and up to 100 m, are required to consistently remove common pollutants [203]. Resources related to minimization BMPs are listed in Section 4.7.

Compensation

As discussed above, the final step and last resort in the mitigation hierarchy should be compensation. Compensation is defined as the creation or restoration of habitat to compensate for loss that could not be avoided or minimized. Standard compensation guidelines are recognized as lacking at both the provincial and federal levels [204,199,205], so prescribed forms of compensation rarely exist. Determining what is required for compensation instead typically requires working closely with regulating agencies. Rubec and Hanson [205] provide a summary of Canada's federal and provincial wetland conservation policies, and current compensation regimes.

The ultimate goal of wetland compensation is to preserve the numerous and expensive ecological functions performed by wetlands in a given area. Generally, most jurisdictions use the following steps to determine compensation requirements:

- determine the area or functions that have been lost and the mechanism of replacement
- apply the compensation activity on an appropriate site in a practical manner
- track the success or failure of the compensation efforts [206,201]

Although there are no standardized guidelines across Canadian jurisdictions for the actual form of compensation, wetland experts in Canada generally agree on the following principles as important factors for success in wetland compensation projects [204].

- **Compensation mechanism**: Mechanisms by which compensation can be completed include, in order of most to least effective/desirable: restoration, enhancement, creation, in-lieu fees, preservation, and mitigation banking. Key considerations include the following:
  - Restoration is often the preferred option from an environmental standpoint as it is consistent with the target of no-net-loss. There are often many opportunities for restoration within projects, and it can also be cost effective for proponents.
  - Wetland creation is expensive, and not possible for all wetland types (e.g. peatlands, saltwater marshes), although some innovative approaches have been attempted (see Peat Inversion Case Study in Section 4.6). It is difficult to predict how a newly created wetland will eventually provide ecosystem services, to satisfy compensation accounting processes [204].
- **Compensation ratio**: In many cases, the area of compensation required to re-establish similar ecosystem services is larger than the area that was impacted or removed [199,201].
  - Compensation ratios (i.e. the ratio of compensation to wetland loss, measured as area) generally range from 1:1 to 8:1, however regulating agencies may require more or less based on case specific circumstances [207].
  - Rather than a set ratio, required land area may be calculated based on the type of impacted wetland. For example, the Toronto and Region Conservation Authority uses basal area to determine compensation area for forested wetlands [201]. The basal area lost must be replaced within 10 years, and given the lag time in tree growth, the compensation ratio may need to be increased, effectively using land area to make up for lost basal area. Others use fixed ratios based on the compensation mechanism (e.g. 1:1 for restoration, 2:1 for creation, etc., [208], Alberta Wetland Policy).
- **Location of compensation**: Most agencies and experts agree that compensation should be located as close to the impacted wetland as possible, and ideally within the same sub-watershed or watershed, and not out of province [204].
  - Compensation that considers the ecosystem services provided on a landscape scale will best achieve the ecological goals of compensation [204].
  - Expansion or contribution of new or restored compensation areas to an existing natural heritage system, such as parks is also desirable [200].
- **Timing**: To address lag time between impacts to a wetland and the full achievement of compensation gains, the compensation works should ideally be completed before the impact occurs [199]. However, re-establishment of lost wetland services in a reasonable time frame is, in part, dependent on the type of wetland.
  - Some functions of marsh ecosystems can be established quickly, since vegetation growth does not have a significant lag time [201]. Ducks Unlimited Canada and other restoration agencies (e.g. Manitoba Habitat Heritage Corporation) offer marsh restoration planning in the Prairie Provinces.
  - Peatlands, in contrast, may require longer timeframes to fully restore ecological services and values, and this restoration practice is generally at an early stage (but see the Peat Inversion Case Study in Section 4.6).
  - Comparatively, newly created forested (swamp) wetlands are slow to grow to maturity, and a certain lag time in ecosystem services can be expected [201]. Toronto and Region Conservation Authority guidelines partially address this issue by requiring that mature

forested wetlands be replaced with larger, young forests [201]. In addition, replacement proposals should ensure that compensation wetlands are protected in perpetuity, or at least as long as the project's adverse impacts [199].

- **Polluter pays**: Most jurisdictions require the proponent of wetland restoration to be responsible for all costs associated with a project (i.e. labour, resources and risk). Ensuring that the compensation price reflects the true costs of wetland loss is intended to serve as a deterrent to wetland alteration, and to prioritize avoidance and minimization [204]. Often though, compensation costs are relatively low and risk can be transferred to restoration agencies, making compensation a preferred option [20].
- **Monitoring**: The compensation project should use an adaptive management approach that incorporates monitoring and evaluation of success, to inform program improvements [201]. This may include reapplication of the original or an adapted strategy.

The importance of conserving wetlands while promoting appropriate economic development is clear, however it is not simple. Lessons learned from other jurisdictions include the need for reliable tracking, reporting and record keeping of compensation projects. In both Canada and aboard, projects regularly fall short of agreement upon compensation ratios, and therefore replacement of wetland functions [207]. As noted previously, avoidance and minimization are not typically applied, or perhaps, are not well documented [202,20]. In some cases, projects were not even undertaken, or if initiated, were poorly designed or carelessly implemented, and failed to meet permit conditions [207]. Despite Canada's relatively progressive environmental policies, wetland habitat compensation, as currently implemented in Canada, is slowing, but not stopping, the rate of wetland habitat loss.

4.6 Case studies

CASE STUDY

Integrated Roadside Vegetation Management, Iowa Transportation Department

WHAT'S THE ISSUE?

Roadside vegetation management programs in Iowa have changed substantially, from weed management control with herbicides in the 1980s to the adoption of its Integrated Roadside Vegetation Management (IRVM) in 1988.

Vegetation management strategies that relied solely on blanket spraying herbicides weakened vegetation communities and reduced biodiversity.

Iowa recognized the importance of integrated management that uses multiple methods to enhance roadside vegetation growth and reduce weed prevalence.

QUICK FACTS

Category: ROW vegetation management

Location: IOWA

Completed: Ongoing

Costs: unknown

Objective: Sustainable management

Species: Native and non-native plants

WHAT'S THE APPROACH?

Iowa's IRVM program combines management techniques with ecological knowledge to maintain functional and healthy roadside habitats through several means:

- Using species diversity to create strong, weed-resistant plant communities.
- Using herbicides sparingly for spot treatments. The overuse of herbicides weakens grasses and broadleaf species.
- Preventing disturbances such as farm field runoff.
- Mowing patches of weeds to prevent seed production and dispersal.
- Conducting prescribed burns to promote healthy native vegetation and fire adapted prairie species.

WHAT'S BEEN OBSERVED?

- Native plants are durable, long-lived and provide benefits including slowing water flow, increasing infiltration and reducing runoff.
- Balanced seed mixes (1:1 grass to forb) outperformed other mixes and may be best suited to sustaining ecosystem services (Meissen, 2018).

WHAT'S BEEN LEARNED

- Key Lesson: IRVM is often stifled by **reliance on traditional methods and a lack of understanding of IRVM techniques**

Photo Credits: Iowa Dept. of Transportation

CASE STUDY

Right-of-Way Reclamation, Herb Gray Parkway

WHAT'S THE ISSUE?

Revegetation of highway rights-of-way (ROWs) during reclamation have historically reduced biodiversity through use of non-native plant species. Jurisdictions are increasingly considering biodiversity conservation in ROW reclamation planning, through native vegetation selection and reclamation practices.

The Ministry of Transportation, Ontario has recognized the importance of native vegetation conservation along transportation corridors and has piloted a project to mitigate environmental impacts of highway ROWs.

QUICK FACTS

Category: ROW reclamation

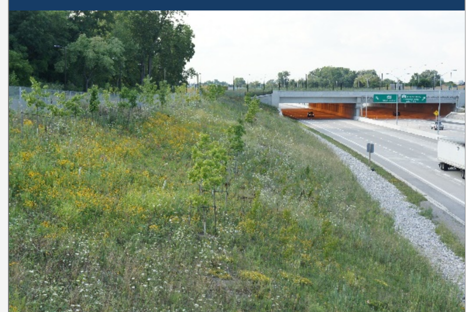
Location: Rt. Hon. Herb Gray Parkway, Highway 401, Windsor ON

Completed: 2017

Costs: unknown

Objective: Native species reclamation

Species: Native plants



WHAT'S THE APPROACH?

Recognizing the ecological importance and high concentration of species at risk in the project area, requirements were put in place to ensure only native and locally sourced material could be used to revegetate the Rt. Hon. Herb Gray Parkway. Like-for-like replacements were used for all vegetation typologies that were disturbed, resulting in the creation and enhancement of 184 acres of ecological communities.

Other strategies included sustainable design principles, protection of sensitive ecological areas, increasing soil infiltration, low-impact design and sustainable, use of low-maintenance plant materials.

Project Scope:

- Grass and forb seeds for species at risk (SAR) were collected from the future highway footprint and grown in greenhouses
- Once viable, SAR plants were transplanted to three Conservation Authority restoration areas adjacent the ROW
- Initially planted 119,000 native trees and shrubs and forbs for site restoration
- Developed 15 native seed mixes, specific to each vegetation typology being replaced within the ROW, incorporating 106 different prairie species
- Public engagement program to identify initial restoration options, and inform on progress

The project also incorporated monitoring for adaptive management and scientific evaluation of methods.

WHAT'S BEEN OBSERVED?

- As of year seven of a ten-year monitoring program, a population of 700,000 species at risk has been established at restoration sites adjacent to the ROW, through both successful establishment of seeded species, and natural colonization from adjacent conservation areas.
- Native tallgrass species required more time to establish (three to five years) than traditional turf mixes, which led to longer duration of use of annual cover crops for weed and erosion control. Annual cover species reseeded themselves, but did not outcompete native species.

CASE STUDY

Right-of-Way Reclamation, Herb Gray Parkway

- Successful establishment of seeded species, plus natural colonization of native species from adjacent high-quality conservation areas.
- Based on observations of species growth and success from the 15 initial seed mixes, the mixes were refined down to three (wet and dry tall grass, and roadside) to be used for long term maintenance needs.
- Invasive species did migrate onto restored sites. Early coordination on weed management was needed with adjacent landowners, especially at early stages of revegetation.
- Public engagement helped build support for the program, and local champions.
- Program success led to adoption of Native Restoration Policy by ON Ministry of Transportation, better availability of commercial seed supply and receipt of the 2016 TAC Environmental Achievement Award.

WHAT'S BEEN LEARNED

- **Early engagement with key stakeholders**, including local municipalities, public and internal managers, is essential to set realistic expectations and develop long-term support.
- **Early planning should consider long-term requirements,** such as future operational requirements, and potential regulatory implications (e.g., utilities repair/disturbances).
- **Design seed mixes with long-term and short-term goals in mind.** The initial seed mixes were selected for biodiversity restoration at landscape scale (i.e., maximum diversity), but colonization is also possible. Initial plans should also consider future reseeding required for other land use (e.g., utilities) to be sustainable.
- Where species at risk are a focus of restoration, consider **long-term management and potential regulatory conflicts**. Successful restoration and spread by such species could create future issues with on-going maintenance, which should be incorporated into regulatory conditions/exceptions.
- **Build consistency into design and management teams** to retain institutional memory, and document key decisions and agreements. Such projects will have long-term operational requirements that rely on original project understandings.
- **Design monitoring to inform adaptive management and scientific understandings.** Frequency of monitoring, monitoring design and areas of focus may differ for each objective, but both provide important information for the current and future projects.
- **Identify an appropriate monitoring timeframe.** Native species take longer to establish than non-native reclamation species. Adaptive management and successful completion of restoration should set appropriate timeframes.

Photo Credits: Jaclyn Charlton, Ministry of Transportation, Ontario

CASE STUDY

Peat Inversion Reclamation, Chénéville and Sainte-Eulalie, Quebec, Utility Arborist Association

WHAT'S THE ISSUE?

Mineral roads within a peatland affect the substrate, the water table level and the physicochemical characteristics of the composition of wetland plant communities.

Access roads built in Chénéville and Sainte-Eulalie, Québec crossed a peatland, which provided opportunity to evaluate the Peat Inversion Technique (Pouliot, Rochefort, Beauchemin, 2019).

This technique can restore peatland conditions by confining the nutrients introduced, conserving a peaty surface elevation similar to adjacent areas and re-establishing typical peatland vegetation.

QUICK FACTS

Category: Peat inversion reclamation technique

Location: Southern Quebec

Completed: 2012 (Sainte-Eulalie), 2014 (Chénéville)

Costs: Not available

Objective: Peatland restoration

WHAT'S THE APPROACH?

- Excavated access road materials and underlying peat in small sections, creating a pit. Road materials (clays, gravel) were put in the pit and covered with 40 cm minimum of peat (52 cm at Sainte-Eulalie and ≈ 45 cm at Chénéville).
- Peat surface was level with surrounding average peatland elevation and revegetated using adapted Moss Layer Transfer Technique (1:5 to 1:10) from diaspores harvested along the road.
- Effectiveness evaluation (Pouliot, Rochefort, Beauchemin, 2019):
  - Environmental monitoring one-year post-restoration in Chénéville and three years post-restoration in Sainte-Eulalie
  - Study area: 3 km access road at Sainte-Eulalie and 70 m access road in Chénéville
- Monitoring data collection: Groundwater using self-recording pressure sensors, water sampling using piezometers at differing depths, pH and conductivity using HANNA device, soil elevation surveys and vegetation surveys.
- Evaluation goals: Evaluate efficacy of the Peat Inversion Technique to restore peatland conditions by confining introduced nutrients from the mineral soils, conserving a peaty surface elevation compared to adjacent areas and re-establishing typical peatland vegetation.

WHAT'S BEEN OBSERVED?

- Lowest level reached by the water table was 30 cm below the surface at both sites.
- One-year post-restoration at Chénéville, all nutrients except for calcium and chlorine had concentrations similar to the reference ecosystem.
- In one growing season post-restoration at Chénéville, sphagnum comprised half the cover observed in the reference ecosystem.
- At Chénéville, vascular plant cover was low in comparison to the reference ecosystem, however the plant groupings were proportionate to the reference ecosystem.

CASE STUDY

Peat Inversion Reclamation, Chénéville and Sainte-Eulalie, Quebec, Utility Arborist Association

- At Sainte-Eulalie, water sampled 20 cm deep had similar concentrations as the reference ecosystem for most nutrients, three-years post-restoration. Water sampled 50 cm deep had concentrations at least 10 times higher than the reference ecosystem, confirming that the buried mineral material is in the catotelm layer (peat-containing dead plant material).
- At both sites, elevation differences were similar to those observed in the reference ecosystem.
- At Sainte-Eulalie, three years post-restoration, vegetation was significantly different from the reference ecosystem with sphagnum cover at five percent or less and high herbaceous cover.
- At Sainte-Eulalie, total vascular covers were similar, but the repartition in function was different compared to the reference ecosystem, with most cover from wetland plants and plants that colonize disturbed areas, and low peatland plant cover.

WHAT'S BEEN LEARNED

Key results from effectiveness monitoring:

- The Peat Inversion Technique **limits peatland enrichment and access of wetland plant species to nutrients** found in the mineral soil layer by restricting these nutrients and creating and sustaining a peat layer elevation similar to the adjacent areas
- The **thickness of the peat layer is an important factor in the effectiveness** of the Peat Inversion Technique to restore peatlands
- The proven Moss Layer Transfer Technique can give **great results if the water table is high**, and the **harvested diaspores are of good quality**
- The extremely **fast recolonization** results at Chénéville was the result of **substrate elevation, a high-water table, diaspore quality, and an attentive contractor**
- The **low colonization** at Sainte-Eulalie may be explained by **the low water table** caused by the ditching of the right-of-way and might have been **improved by adding a layer of straw** as part of the Moss Layer Transfer Technique to increase moss cover
- The Peat Inversion Technique is **cost effective compared to the alternative of complete removal** of the mineral material

Photo Credits: Utility Arborist Association

CASE STUDY

Northeast Stoney Trail, Calgary, Alberta Transportation

WHAT'S THE ISSUE?

New four and six-lane freeway segments were built on the Calgary Northeast Stoney Trail (NEST) ring road system in 2007-2009. Due to the number and location of wetlands within the right-of-way, the project was expected to result in extensive wetland impact.

As part of a public-private partnership (P3) design-build approach, the constructor (joint venture of Flatiron Constructors Canada, Graham Constructor and Parsons Corporation) was responsible for wetland compensation under the Alberta Wetland Policy. Extensive wetland habitat was required to offset construction related impacts.

QUICK FACTS

Category: Wetland compensation

Location: Calgary

Completed: 2009

Costs: $472M (Total roadway project)

Objective: Replace wetland losses due to road construction

Species: Wetland plants and animals

WHAT'S THE APPROACH?

Through an integrated design process, the constructor, and their highway and drainage engineers, worked with environmental planners and landscape architects, plus provincial and municipal environmental regulators, to replace wetland and upland habitat within the road right-of-way.

Drainage engineers designed a master drainage plan to meet Alberta Transportation and City of Calgary standards, which included several Low Impact Development (LID) innovations:

- Wider ditches than standard, to hold storm flows within the right-of-way (ROW) as required under Alberta Transportation requirements
- Higher soil infiltration and evaporation to replace temporary marsh habitat
- Adjusting Calgary wet and dry pond guidelines to allow storage depths > 2 m to replace open water wetlands

Environmental specialists and landscape architects designed 10 naturalized ponds (110 ha total), 16 constructed (enhanced) wetlands (33 ha total), and 28 ephemeral wetlands (evapo-transpiration ditches, 64 ha total), linked with 262 ha of native upland grasslands.

- Compensation objectives: Creating a functionally connected system of upland and wetland habitats within 21 km of an urban freeway right-of-way
- Effectiveness evaluation: Five years of post-construction monitoring of wetland vegetation and wildlife use
- Study area: Freeway ROW, 21 km long, 50 m wide from centerline, adjacent urban neighbourhoods and agricultural lands
- Data collection: Annual vegetation surveys, and frog, breeding bird and winter tracking surveys
- Evaluation goals: Assess restoration of naturalized stormwater ponds to full wetland function

CASE STUDY

Northeast Stoney Trail, Calgary, Alberta Transportation

WHAT'S BEEN OBSERVED?

- Shallow topsoil depth in some areas resulted in slow plant establishment and new topsoil and reseeding to meet the contractual requirement of 80% plant cover.
- Early wildlife monitoring found waterfowl and amphibians used the wetlands.
- Weed management was needed in early years of establishment, given the slower catch rate of native vegetation species.

WHAT'S BEEN LEARNED

The NEST project was awarded an Alberta Transportation Minister's Award of Excellence for Innovation (2009) for its approach to design and regulatory approval review, which reduced the regulatory review and approval process by 10 months (AECON, 2011).

Key results from review of the project and monitoring:

- **Weed management** was important during initial years of restoration, as native grass species required several seasons to become well-established
- **Use of high-quality topsoil**, properly placed with adequate depth is essential to establishing native wetland and upland plant communities
- **Post-construction wildlife monitoring** design aimed to document habitat use, but not other ecological parameters of success (e.g., successful breeding or rearing use)
- **Incorporating studies** to demonstrate ecological functions into monitoring is critical for naturalized stormwater systems, which have been often criticized for providing lower quality habitat

Photo Credits: Flatiron Constructors Canada Limited

4.7 Key resources

Invasive Species Management

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Invasive Species Councils:

- Canadian Council on Invasive Species (https://canadainvasives.ca/)
- Invasive Species Council of BC (https://bcinvasives.ca/)
- Alberta Invasive Species Council (https://abinvasives.ca/)
- Saskatchewan Invasive Species Council (http://www.saskinvasives.ca/)
- Invasive Species Council of Manitoba (http://invasivespeciesmanitoba.com/site/)
- Ontario Invasive Plant Council (https://www.ontarioinvasiveplants.ca/)
- Québec Invasive Species Council (https://cqeee.org/)
- New Brunswick Council of Invasive species (http://www.nbala.ca/new-brunswick-council-of-invasive-species)
- Invasive Species Alliance of Nova Scotia (https://www.invasivespeciesns.ca/)
- Prince Edward Island Invasive Species Council (http://peiinvasives.ca/)
- Newfoundland and Labrador Invasive Species Council (http://nlinvasives.ca/, www.mun.ca/botgarden)
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5. Emerging road ecology concerns

As interest in road ecology develops, a variety of new concerns have emerged. Often these new issues relate to changes in the broader regulatory or environmental context. For example, climate change effects on northern roads have driven changes in the management of ice roads. Recent at risk listing of caribou and several species of bats has influenced road and bridge operations and maintenance. New understandings of the impacts of night lighting on nocturnal species has spurred mitigation to reduce impacts. Lastly, a growing acknowledgement of roadway impacts on habitat connectivity has created new interest in restoration of connective habitats.

Many of these concerns are regionally specific. For example, ice road management is specific to northern Canada, while bats are a concern in the south. Night lighting is linked more to urban locations, where street lighting is more prevalent. Restoration efforts, in contrast, are more readily incorporated during roadway rehabilitation projects, where replacement or abandonment of culverts or bridge structures offers opportunity to enhance wildlife connectivity. Despite these differences, emerging concerns share a key characteristic: mitigation efforts are at an early stage of development, with limited information on their effectiveness, particularly within Canada. Beneficial management practices have largely been developed based on ecological understandings of the concern, predicting measures that should minimize impacts. Monitoring data from application of these measures across Canada will be important to document their short-term or long-term effectiveness.

5.1 Northern road management

Northern transportation systems in Canada and other panarctic regions include all-weather and winter roads built on permafrost, and ice roads and ice bridges built across frozen waterbodies. Design and operation of such systems has historically required specialized engineering and environmental advice, given the frozen substrates on which they are constructed. Specific wildlife concerns must also be considered, given the undeveloped, natural landscapes across which these roads pass. Hiding cover can be limited in some areas, and winter road maintenance, as well as traffic, can disrupt natural patterns of movement, in turn affecting survival of species used by Indigenous communities (e.g. caribou). Dust and road salt use can impact adjacent vegetation, as well as the permafrost on which some roads maybe built.

Climate change is increasingly important in building, constructing and maintaining northern roads. Climate change has been recognized as an emerging concern in Canada over the past several decades, but generally, the global rise in temperature has not been as evident in temperate climates of southern Canada. The situation is much different in the Canadian North, where effects of a warming climate have been increasingly evident. For example, a study examining past and future predicted climate change effects in northern Canada predicted that recent observed trends of reduced snow cover extent in the north, glacier recession and surface run-off, and thawing permafrost would continue over the next several decades [209]. Climate models suggest temperature shifts will be highest in northern latitudes, particularly in the northwest (Yukon), and the most pronounced change will be during the fall and winter months. Warming temperatures have different implications for road integrity in the north, whether built on ice or permafrost. Climate adaptation in road design, construction, operation and maintenance is increasingly relevant in the Canadian North.

These same concerns affect road management in many Arctic, and Antarctic regions. In the Scandinavian Arctic regions, management of caribou (reindeer) movements has a commercial, as well as an Indigenous cultural aspect, since caribou there are managed as free-roaming, herd animals by the Sami [210]. Dust and permafrost concerns are similarly important in such regions, and can interact due to the albedo effect. However, a keyword search of the US Transportation Research Board's (TRB) global resource database found much more published research on permafrost engineering issues than wildlife and other road ecology concerns, and much of that work has been completed in Canada. Northern road ecology concerns have been explored mainly through environmental impact assessment work, through innovative mitigation recommendations for project specific concerns.

5.1.1 General overview

The impacts on Northern roads are contradictory in some sense. Existing all-season roads and winter roads provide critical transportation links in the continuous permafrost zone of Canada's North, but they are becoming increasingly vulnerable to the impacts of climate warming and permafrost thaw [211]. In contrast, climate change is creating opportunities for construction of all season roads in northern Canada in areas where they were previously not practical. Roads have recently been constructed to access remote communities and mine sites (e.g. the Old Crow Winter Road [212]; the Inuvik to Tuktoyaktuk road completed in 2017 [213]). With new road development comes potential impact on the adjacent habitat and wildlife, and need for mitigation where those effects will be significant.

The engineering effects of melting permafrost on road integrity has received considerable attention. TAC has recognized the challenges faced by Northern transportation agencies relative to climate change, and has developed a guidance document on climate impacts on road construction and operation in permafrost regions, and a discussion paper on data needs to address climate change impacts.[13] Importantly, these TAC documents note that transportation infrastructure has traditionally been designed based on historical climate trends. In the context of predicted future changes, existing roadways may experience premature wear, and future designs must rely more on climate predictions than past trends. Existing roadways, in the meantime, may require adaptation to both maintenance and use guidelines. Current research is limited on climate change effects on Northern roadways, but both design and operational guidelines incorporate adaptive measures, where sufficiently well understood.

Effects on wildlife and vegetation have been far less studied, and mitigation has instead been proposed as part of the environmental impact assessment process, for impacts triggering scientific, regulatory or public concern. Examples include management of caribou mortality and disruption to migration, which affect traditional hunting and cultural use of Northern Indigenous communities. Vegetation impacts have also been addressed, to mitigate habitat and biodiversity degradation effects on longer highway developments, but also concerns related to permafrost protection. Given the expansive, natural landscapes crossed by many Northern roads, many of the road ecology concerns discussed previously are not relevant; in Southern Canada mitigation focuses on protection and conservation of habitat remaining on a largely developed landscape. Instead, Northern road mitigation is focused on the

[13] *TAC 2010, Guidelines for Developing and Managing Transportation infrastructure in Permafrost Regions. TAC 2010, Climate Data Needs for the Transportation Sector: Climate Change Task Force Discussion Paper.*

ecological changes associated with road construction and operation, which will in turn affect infrastructure development and land use.

5.1.2 Implementation in road management

Winter roads constructed on frozen bodies of water and ground are protected by layers of ice and snow, and specific construction measures are required to minimize permafrost melting and ground subsidence. Recent work has identified the types of impacts that may emerge for construction and operation of winter roads in Canada's North. Others, including the TAC resources discussed above and the territorial government agencies, have developed guidelines for safe road construction, given the challenges presented by the uncertainties of future climate change.

Design

Although northern road management, particularly in the context of climate change is a relatively new aspect of road ecology, territorial transportation and environmental agencies have been actively studying the concern and creating development guidelines to minimize the potential negative effects of new roads. For example, before the alignment of a northern road can be finalized in the Northwest Territories, field investigations are required to understand the environmental conditions along the route. Generally, in southern Canada, route selection may be done only with desktop analysis, with field verification done only to confirm sensitivities on preferred route options. To facilitate early planning steps for all forms of roads, Northwest Territories Lands [214] has created a guideline for the route selection, design, construction and operations of roads and trails. The document also includes guidelines for surface preparation and stream crossings for all-weather roads and ice roads. The last section of the document has a reclamation guide and outlines monitoring requirements. The new TAC (2020) *Geometric Design Guide for Canadian Roads, Chapter 11 – Special Roads* and the TAC (2011) *Guidelines for the Construction and Operation of Winter Roads* provide additional guidance for winter road design and operations applicable across Northern Canada.

Canada's three northern territories (Yukon, NWT and Nunavut) are managed jointly by federal, territorial and Indigenous governments, under regionally negotiated land claims agreements. As a result, community engagement is an important aspect of any new project design, including roads, and a stringent requirement under the respective federal, territorial and co-management environmental impact assessment (EIA) processes (see Table 1 in section 2.1). The Canadian *Impact Assessment Act* (2012) requires an environmental impact assessment process for new roads longer than 50 km, but does not explicitly address shorter roads, or road upgrading. It does, however, require project assessments in areas where Indigenous communities may be affected by the proposed project. Co-management board processes require assessment of any project work that would affect local community land use or traditional and cultural practices. In northern Canada, EIAs are conducted under territorial processes that replace the federal EIA, to better integrate Indigenous knowledge, land use and management concerns. The process also considers environmental regulatory requirements under federal and territorial law, and thus an EIA can involve federal departments (Fisheries and Oceans Canada, Environment & Climate Change Canada) as well as relevant territorial co-management boards and committees.

In the Yukon, NWT and Nunavut, an EIA will be managed by regional co-management boards established under modern land claims agreements, following their own EIA processes. The government agencies involved in the EIA, as well as the process, differs from that applied in southern Canada. Various land use and impact mitigation requirements may be imposed by the impact assessment board[14] and associated land use and resource management committees (e.g. the Inuvialuit Game Council, or its community Hunters and Trappers Committees). These committees must be consulted prior to road development, to identify known environmental sensitivities and critical wildlife habitat, as well as traditional knowledge and current and future planned land uses. In Nunavut, local traditional ecological knowledge (Inuit Qaujimajatuqangit) must be integrated with Western science into the environmental assessment, and EIAs must be prepared in accessible language, to allow community members to review the documents and participate actively in the EIA review. The design process for new roads is more complex than practiced in southern Canada, with much higher expectations of community engagement and involvement in the design process and future management.

Construction and Operations

All-season roads are constructed over permafrost or unfrozen ground, with specific engineering design for permafrost conditions. Construction is planned to ensure that permafrost conditions are not compromised, since this would affect road integrity and future maintenance, as well as potentially impacting adjacent terrestrial or aquatic habitats. Ice roads are constructed each year, based on the anticipated traffic levels and load sizes over the winter season, ice thickness and structural quality, and forecasted winter weather conditions. Specific designs and operating conditions are required by territorial transportation ministries, as well as territorial impact assessment and environmental management agencies. Accordingly, both construction and operational requirements are typically identified during the project design phase, then implemented and adapted as required.

Northwest Territories Lands [214] has developed guidelines that outline construction and operational requirements for most all-weather roads. It recommends limiting vegetation clearing in areas with permafrost, so that the shade provided by vegetation can prevent ground thaw. Vegetation may also be retained to serve as a visual buffer between a public highway, and other land uses, as well as physical buffer from aquatic habitats. A study in NWT contradicts these recommendations relative to permafrost conditions and future potential vegetation management requirements. The study assessed the physical impacts on vegetation along gravel roads and permafrost conditions under the road from construction, maintenance and road use [211]. Alder-shrub dominance increased adjacent to the highway and the denser canopy cover also altered other plant diversity, soil properties and ground temperatures. The shrub cover created a warmer microclimate that thawed upper permafrost layers. Regular cutting is now necessary to cut back the alder and maintain permafrost conditions beside the road. Cutting may also reduce risk of WVCs, by removing cover and forage for ungulate species (but see recommendations on mowing from Section 4.1). Results in this study suggest further research is required to identify BMPs for relevant permafrost and vegetation management objectives.

Other differences apply to typical road construction practices in Northern Canadian climates. Tree clearing should be minimized, to protect permafrost layers [214]. Since such clearing is sometimes done with excavation equipment, ensuring that trees are not uprooted, exposing and thawing underlying soils is an important mitigation. Hand-cutting of trees is preferred for this reason. Brush disposal is another concern in permafrost areas. Chipping or mulching will add nutrients to the local soils, enhancing

[14] *Yukon Environmental and Socio-economic Assessment Board (YESAB), Mackenzie Valley Environmental Impact Review Board (MVEIRB) and Nunavut Impact Review Board (NIRB).*

vegetation growth. Burning is not recommended in permafrost areas, since it could cause ground subsidence. In contrast, burning in non-permafrost areas should be considered a fire risk. Brush can be piled in the middle of the cleared ROW for burning, and should be monitored throughout the burn. In addition, culverts placed in permafrost will require insulation. Warm air circulation through the culvert can melt permafrost.

The Northwest Territories Department of Transportation [215] has developed specific guidelines for ice road construction and end of season removal that describe routine, enhanced and acute (special circumstance) construction and operation methods. Routine construction and operation are more commonly applied, and are based on conservative estimates of road use and ice strength. Enhanced construction and operation uses a less conservative load bearing level and thus requires more monitoring and control measures relative to loading. Acute operational guidelines are used for unique situations (e.g. for heavier loads, exceeding normal loading conditions), and are paired with more intensive monitoring and control measures. Confidence in the integrity of ice cover, the loading characteristics and minimum ice thickness are critical to construction and operation of ice roads.

Addressing maximum ice loading of an ice road is an important safety consideration for vehicles travelling along ice roads. Gold's formula is considered a robust and practical guiding principle to estimate the maximum loading for ice roads [216], and is the basis for ice road design in Canada (e.g. the GNWT (2015) *Guidelines for Safe Ice Construction* [215]). Techniques to lengthen the operational use of winter ice roads and ice bridges include flooding the road, plowing snow and restricting hauling to night time near the end of the operational season [216,218]. In some areas though, plowing may be balanced against wildlife management considerations; for example, caribou management requires retention of snow cover ([212] see Section 5.2 below). Similar procedures are used on other winter roads to prolong use and durability, including spraying water on the road to create protective ice layers, 'grooming' snow layers to repack into a hardened layer or hauling snow from nearby sources (e.g. waterbodies, snow fencelines [214]). Aggregates and ice chips can also be placed on winter roads to build up a base, and sprayed with water to bond into a solid layer. Since these roads are built over natural terrain, such practices will impact the local soils and vegetation. Site-specific mitigation may be required in sensitive habitats.

Conversely, to improve road safety, icy roads may require salting in winter, which can affect roadside vegetation and water quality in adjacent aquatic habitats. Many Northern highways are gravel, rather than paved, and dust control is an important safety control. Dust suppression compounds may also contain salts, which may be carried into roadside habitats with surface run-off. Road salts can also attract wildlife to the roadside, increasing risk of WVC. TAC has published various guidelines on road salt use, which provide suggestions for environmentally-friendly alternatives.[15] Wildlife mitigation measures, such as warning signage and radio-controlled road closures during wildlife movements, have been implemented in some new highway projects to address wildlife impacts of road operations (see Section 5.7, Case Studies).

As northern climates continue to warm, ice and winter roads may have shorter duration, prompting more intensive measures to preserve viable ice or winter road conditions for road traffic. Prolonging ice road use will necessarily delay spring ice break-up along the road alignment, which may have localized effects on aquatic habitats. Similarly, delayed thawing of winter roads, and impacts of aggregate used to

[15] *TAC 2013, Salt Management Guide – Second Edition. TAC 2014, Synthesis of Environmental Management Practices.*

build the road base will impact the underlying and adjacent soils and vegetation. Although localized, these effects are not often monitored or assessed, and the extent of impact is thus not well understood. In the face of climate change, such localized impacts may pose an ecological concern, as strategies to prolong road use may be amplified, resulting in delayed seasonal ecological patterns. Such impacts have greater relevance in northern climates, where growing seasons are shorter. For example, dissolved oxygen levels depleted over the winter are refreshed through contact with the air once the ice thaws and water openings emerge. Near shore habitats may thaw later than adjacent riparian areas, potentially influencing other seasonal events such as lake turnover, and water temperature shifts that prompt aquatic productivity. In northern locations, where subsistence use of local resources is part of the cultural and economic aspects of community life, such impacts may be relevant. Monitoring of measures used to mitigate climate change impacts on winter and ice roads may help identify and avoid such cumulative or synergistic impacts. The Peel Plateau Case Study in Section 5.7 provides an example of a robust monitoring program designed to identify and manage road impacts on vegetation.

Reclamation

Restoration potential of winter roads constructed across subarctic peatlands is also sometimes required, and may be more important in the face of climate change impacts and potential requirement to realign problematic sections of road. Reclamation of peatlands is challenging, since it requires re-establishment of peat, living mosses, other bryophytes, and forbs and for fens, re-establishment of local hydrology. Mining studies offer indications of potential for natural restoration, in which native species recolonize the abandoned site, after recontouring to remove roads and other surface disturbance. A study in northern Ontario assessed restoration success of mine access roads across such peatland areas, after abandonment [219]. The roads were not actively reclaimed, and compared to control sites, had significantly lower percent of bryophytes and vascular plants, as well as lower average species diversity and different species composition. When the regenerated sites were compared to revegetation assessments of older mined peatlands in the Low Boreal region though, the results of the natural revegetation of these more disturbed sites were similar, indicating that natural reclamation of abandoned winter roads can be successful, with sufficient time. Restoration of abandoned northern roads is an area that requires additional study to identify relevant BMPs.

5.1.3 Beneficial management practices

While Northern Canada road management is an emerging area of concern relative to road ecology, mitigation recommended in past EIAs for new road development, and in general guidelines offered by territorial agencies, offer broadly applicable measures. During design, BMPs include the following:

- Initiate discussions with relevant co-management agencies and committees early in the design process, to identify potential sensitivities, traditional land use and traditional knowledge, and integrate these into the project design
- Conduct field surveys to verify potential routing options, to supplement desktop analyses [214]
- Consider routing options that will avoid areas of permafrost, or areas that may be susceptible to thawing during road operations
- Apply a wider, 300-m buffer for sensitive wildlife habitat during the route selection process [212]

During construction, mitigation measures will likely be more project specific and dependent on environmentally and culturally sensitive sites. In general though, the following measures would be applicable in most contexts:

- During clearing and stripping, minimize vegetation clearing as much as possible, especially in permafrost areas [214]
- Hand-clear trees, rather than using heavy equipment that may expose and thaw soils [214]
- Construct winter roads in frozen conditions, to avoid disturbing vegetation and exposing soils, to minimize thawing due to the albedo effect [214]
- Consider routing options for ice roads that have consistently thick and high-quality ice, to minimize need for on-going maintenance over winter (e.g. water spraying)

During road operations, past project specific wildlife mitigation measures may be relevant, and applicable:

- Implement radio-controlled routes to monitor for activity of sensitive species, such as caribou [212]
- Limit speeds on areas passing through sensitive habitat areas, including wildlife crossings [212]
- Construct breaks in snow and windthrow berms to provide escape routes for wildlife [212]
- Leave a 10-15 cm snowpack when grading the road surface to facilitate wildlife movement [212], and groom the snowpack to repack it for safe traffic use [214]

Wildlife management is often linked to northern road management, given the potential to cross sensitive habitats or important seasonal migration routes. In the Northern Canadian territories, co-management boards of local Indigenous communities should be consulted early in road design to identify species-specific concerns, including known areas of wildlife activity, sensitive habitats and locations of traditional use. Community members may also be engaged to assist in design and implementation of monitoring studies, capitalizing on local knowledge and experience.

Other provincial mitigation may be applicable to Northern Canadian contexts, and offer solutions for emerging concerns. The BC Ministry of Transportation and Infrastructure has developed operational maintenance guidelines for winter roads that addresses snow removal, and the application of winter aggregate and de-icing compounds [220]. The BMPs include contacting relevant regulatory agencies prior to management activities to discuss mitigation for any sensitive habitats. When considering road salts used for ice management and dust suppression, Sielecki and Wheeler [220] recommend considering alternatives with lesser impact. Alternative materials are available for road salt during the winter. Choosing larger aggregate and prewashed materials will minimize dust generation during summer use and maintenance. The recently completed Inuvik to Tuktoyaktuk ice road also noted the need to manage sands and silt deposited on the ice road, as those materials increase the albedo effect and ice melt, of particular concern due to warmer winter weather patterns linked to climate change [213].

5.2 Caribou

As discussed in Section 3, large mammal interactions with roadways, especially through WVCs, has long been a concern, mainly due to the human safety and insurance cost of such collisions. While interests in biodiversity conservation provided later, additional motivation for reducing WVCs, the recent declines in several Canadian caribou populations across the country have challenged all levels of Canadian government to avoid further losses. In 2003 and 2004, several populations of Canada's boreal caribou populations were listed under the federal *Species at Risk Act* (SARA), including the main Boreal population found across most of Northern Canada. Regulatory change prompted immediate attention to protect caribou in these areas, and if possible, facilitate their recovery.

Recovery planning for listed caribou populations is changing rapidly at the federal, territorial, provincial, and national parks levels. Conservation requirements place increasing pressure on road agencies to reduce collision potential, and habitat disturbance effects. As a result, transportation agencies have been adapting WVC mitigation and other management strategies to reduce collisions and minimize disturbance to listed populations.

5.2.1 General overview

Four caribou sub-species are recognized in Canada, one of which is the woodland, or boreal, caribou (*Rangifer tarandus caribou* [221]). Canada's boreal caribou populations are generally located in northern boreal zones in all provinces and territories except Nova Scotia, New Brunswick and Prince Edward Island [221]. British Columbia and Newfoundland are unique in that populations occur across these provinces, wherever suitable boreal habitat exists. Severe population declines observed in certain populations led to listing of those specific populations federally, and often also provincially or territorially.

The British Columbian populations have been separated out regionally; the southern mountain populations located in the Selkirk and Purcell mountains in southern BC are listed as Threatened species under SARA [222]. The Atlantic Gaspésie is single boreal caribou population, now listed as an Endangered species under SARA, and found only in a small part of the Quebec Gaspésie and Bas-Saint Laurent region [223]. The Boreal populations extend from Labrador to Yukon, with small isolated populations in the southern part of this range [224]. These populations are currently listed as Threatened under SARA. Most provinces and territories have also listed their own boreal caribou populations under protective legislation, although the risk levels are inconsistent, as summarized below:

- Northwest Territories: Threatened
- Yukon: Not Listed
- British Columbia: Red Listed (Threatened – Endangered)
- Alberta: Threatened
- Saskatchewan: Not Listed
- Manitoba: Threatened
- Ontario: Threatened
- Quebec: Vulnerable (Special Concern-Threatened)
- Newfoundland: Threatened

As required under SARA, the federal government has produced recovery plans for the populations considered at risk, as well as progress reports and action plans as efforts developed over the past decade. The rapid release of plans for populations across Canada heightened attention to conservation and recovery measures to be applied:

- Federal Recovery Strategies for the Woodland Caribou (*Rangifer tarandus caribou*) for the Atlantic Gaspésie, Boreal, and Southern Mountain Populations in Canada [225,221,222,224,223]
- The five-year report on the Recovery Strategy [225]
- The *Action Plan for the Woodland Caribou (Rangifer tarandus caribou), Boreal Population, in Canada – Federal Actions* [227];
- Multi-species action plans for Banff, Jasper, Mount Revelstoke, Glacier, and Pukaskwa National Parks and Terra-Nova and National Historic sites of Newfoundland [228,229,230,231,232]

Under the SARA listing, the federal government has delegated responsibility for management to provincial governments, and will only intercede where provinces are not enacting sufficient protective measures. In the three territories and in parts of northern British Columbia, land and resource management is shared between the federal, provincial/territorial and local Indigenous governments under regional land claims agreements (e.g. Nunavut, and Inuvialuit Land Claims Agreements) and legislation enacted to acknowledge self-governance, or land and resource management rights under regional agreements (e.g. *Mackenzie Valley Resource Management Act*, *Yukon Environmental and Socio-economic Assessment Act*; [97]). The respective Indigenous governments with land claims agreements have established co-management boards who play an active role in regional development, land use and resource management, representing cultural and conservation interests of community members [97].

Because of these jurisdictional differences, caribou management can be complex and reflects various interests, from conservation to sustainable traditional harvest. In terms of road mitigation strategies, transportation agencies have drawn on standard WVC measures, but some have developed innovative solutions involving Indigenous and other stakeholders. While still in early stages of implementation, such measures offer alternatives applicable to other animals with mortality risks linked to roadway operations.

5.2.2 Implementation in road management

Roads and road management can affect caribou in a variety of ways, including collision, but also through less obvious means, such as habitat alienation and disturbance. Findings from research on caribou activity near roads, as well as secondary impacts on habitat quality related to road impacts (e.g. noise, predator access, dust), suggest a variety of areas where transportation agencies could help mitigate caribou impacts from roadway development and use.

Caribou response to roads can vary with context. Although some findings suggest that caribou will avoid roads [233], salt use for winter maintenance can attract caribou (and other ungulates) to roadsides, increasing risk of collision [234]. The A la Peche boreal caribou herd near Grande Cache, Alberta encounters roads during seasonal migration, which can also increase potential for collision [235]. Considerable research has explored the interaction of industrial development in caribou habitat, including the effects of roads and other linear disturbances that create habitat fragmentation [236,237,238,234]. Often these disturbance effects are complicated, and involve behavioural responses by caribou (e.g. to avoid road or industrial disturbance), but also other, secondary impacts related to land use. For example, roads facilitate better access by predators, such as wolves to caribou ranges, leading to increased mortality linked to roads, but not directly attributable to them, as with collisions [236,235,238]. Some of these secondary impacts can be far-reaching, and subtle. As an example, recent findings from a study that examined dust impacts on lichen forage used by barren ground caribou, near access roads to the Ekati Mine in the Northwest Territories, suggest dust disturbance could be extensive [239]. The study found that within a ~1,000 m zone of a main gravel haul road through the Bathurst caribou range, the amount of dust on plant leaves was three to nine times that of a lesser used road (the study's control site). Such impacts can reduce forage quality and quantity, important considerations in areas where population declines are already high.

Road mitigation specific to caribou mortality risk is an emerging area, driven by the recent SARA listing and subsequent federal plans developed to inform management across Canada. Yet collision and connectivity impacts have long been of interest relative to caribou and other sensitive carnivore and ungulate species [236,235,238]. Organizations such as the Yellowstone to Yukon (Y2Y) Conservation Initiative have conducted research, outreach, monitoring and implementation of proactive solutions, including crossing structures, fencing and dynamic signage in the Rocky Mountain corridor from Wyoming through British Columbia and Alberta for such species [240]. The knowledge gained through their experiences in road mitigation for large animals can be applied to caribou management, as well as other species. Key learnings include the need to create site-specific solutions, based on an understanding of the spatial and temporal aspects of collisions, and an understanding of the role of adjacent habitat and land use on animal movements. Lastly, they note the importance of public awareness in fostering support for mitigation measures, particularly speed reduction.

Leblond et al. [233] documented caribou reactions to a major highway in Quebec (Route 175) before and after widening, providing rare insight to the influence of road width and increased traffic on caribou behaviour. The seven-year study tracked movements of 53 radio-collared caribou, before, during and after widening of this highway. By tracking actual road crossings, the authors could assess change in crossing rates after widening, and through resource selection analysis in areas adjacent the highway (up to 5 km away), they identified displacement effects. The study found that crossing locations were reduced during the construction phase, and after completion, especially when traffic density was high. Caribou movement was higher nearer the road (i.e. parallel), suggesting displacement away from this wider, busier roadway. This work also confirmed the importance of maintaining connectivity in design of both new or improved roadways, particularly for sensitive and at-risk species.

The Yukon Government faced similar concerns about collisions and displacement effects on caribou, as well as moose, elk and deer, which at the time accounted for 82% of all reported large mammal collisions in the Yukon [46]. Most of these collisions increased in fall through late winter, reflecting seasonal habitat use (e.g. breeding season and migration to lower elevations) and poor driving conditions. Through an interdepartmental working group, EDI Environmental Dynamics Inc. [46] identified improvements to collision mitigation on Yukon highways, including many of the recommendations suggested for large mammal crossings and WVC in Section 3. Examples include:

- continued public awareness campaigns
- use of warning signage
- improvements to ROW vegetation management to reduce roadside attractants
- improvements to the quality of WVC data collection

Specific to northern climates, the study identified need for modifications to snow-clearing, to leave escape routes in snow windrows away from roads in areas with high crossing activity, along with increased warning signage and traffic speed reductions.

Even more progressive mitigation has been developed in areas where co-management with Indigenous governments is required for caribou, as well as other wildlife. For example, the Tsay Keh Dene in northeastern British Columbia, with the Society for Ecosystem Restoration in Northern BC (SERNBC), initiated a pilot program in 2018 to decommission 1,942.5 km of road, within the 971.5 ha Chase caribou herd range [241]. The study used desktop analysis, cumulative effects analyses and road access management planning to identify candidate roads for decommissioning, plus consultation with forest licensees and other Provincial agencies. The Tsay Keh Dene Nation developed a set of guidelines for road decommissioning, based in part on this pilot study. Their 2019 guideline document, *Expectations for Decommissioning Roadways in Caribou Habitat*, identifies restoration considerations specific to caribou behaviour and known mortality risks as well as cultural considerations [242]. Mitigation is based on Western science, such as reducing potential carnivore travel along decommissioned roads through use of roll-back and reforestation, but also incorporates cultural considerations, such as maintaining trapping and hunting access.

Other examples applicable to new road routing and construction include the planning and mitigations incorporated into the Inuvik to Tuktoyaktuk Highway project [213], and the Old Crow winter road project [212], through their respective co-management environmental impact assessment processes. The Inuvik to Tuktoyaktuk project lies within the lands co-managed by the Government of the Northwest Territories (GNWT), the Inuvialuit Land Agreement and its respective resource management committees and the federal government (see case study in Section 5.7). The Old Crow winter road was proposed by the Vuntut Gwitchin First Nation, and was reviewed with the Yukon government under the Yukon Environmental and Socio-Economic Assessment Board process. Mitigation incorporated into road design on the Inuvik to Tuktoyaktuk Highway included reducing the road footprint, and routing to incorporate set-backs from key wildlife habitat features (see also the Case Study in Section 5.7). Operational mitigation included restricting highway access during peak barren-ground caribou migration periods, plus incorporating measures to minimize sound disturbance (e.g. earthen berm barriers). During construction, an active surveillance program was to be implemented, in addition to posting warning signage to stop traffic, or reduce speeds when caribou were on or near the road. Lastly, the environmental impact assessment recommended coordination among the various agencies involved in road, wildlife and harvest management:

- Implementing a caribou mortality reporting system through the Northwest Territories Environment and Natural Resources Department (NWT ENR)
- Creating guidelines and conditions for highway usage and follow-up monitoring of harvesting activities through discussions with the Inuvialuit community Hunter Trapper Committees and Wildlife Management Advisory Committee, plus NWT ENR and Transportation Departments

The Old Crow winter road project included the conventional mitigations of speed limits and warning signage, but also recommended radio controls on traffic, based on monitoring of caribou activity within a 300-m buffer of the road [212]. It also identified the need to break snow and windrow berms at regular intervals to facilitate safe passage for caribou, and other wildlife, as well as snow clearing to leave a minimum 10 to 15 cm snowpack on the winter road surface.

5.2.3 Beneficial management practices

As with other management approaches recommended for large animal crossing management, impacts to caribou can be addressed by site-specific planning, based on a sound understanding of animal movements, habitat use and key sources of mortality. Where Indigenous co-management applies, coordination among all government agencies is critical to ensure that jurisdictional interests are addressed, as well as Indigenous harvest, cultural use and management rights. Involvement of other stakeholders responsible for developing, operating and abandoning roads can also be useful, to facilitate a regional approach to planning of new roads, or decommissioning existing ones.

Specific BMPs are challenging to identify at this stage in mitigation development. Common principles emerging from the studies mentioned above include the following:

- Create site-specific solutions, based on an understanding of the spatial and temporal aspects of collisions, and the role of adjacent habitat and land use on caribou habitat use and travel. Remember that some caribou herds migrate seasonally; planning should consider both home ranges, and known migration routes.
- Recruit public and other stakeholder support for mitigation efforts; awareness and engagement in mitigation goals can foster the cooperation needed for mitigation to be successful.
- Develop accurate collision data collection systems, to ensure that collisions can be located and tracked over time. Such information will help identify crossing locations, and can help inform appropriate mitigation. Post-construction, such information can help confirm the effectiveness of road mitigation design, and adaptation, if needed.
- Consider how road maintenance and operations may influence caribou use of roadside habitat, both as potential attractants (e.g. road salt, or lichens used as forage, including tree lichen), or as detractions (e.g. noise and dust impacts to critical habitat adjacent roads). Such impacts can be considered during routing, to avoid impacts within areas of known critical habitat, as well as in operations and maintenance of existing roads.
- In areas with deep snow, leave breaks in snow windrows to provide escape routes away from the road, particularly in areas with high crossing activity.

5.3 Bats and bridges

Three Canadian bat species (little brown myotis, *Myotis lucifugus*; northern long-eared myotis, *M. septentrionalis*; and tri-coloured bat, *Perimyotis subflavus*) are now listed as Endangered species and one as Threatened nationally (pallid bat, *Antrozous pallidus*), due to increased mortality linked to white-nose syndrome [243]. Protection of habitat, particularly habitat used by maternal colonies, is of increased conservation interest as a result. Transportation infrastructure provides important roosting and maternal habitat for multiple species of bats in some geographic locations, by providing surrogate habitat for natural features [244]. This is particularly true in warmer southern climates in the US, leading to development of new mitigation approaches for colony management on transportation infrastructure. As with caribou, listing of these species under SARA has elevated concerns related to their conservation needs, given the operations and maintenance requirements of bridges and other potential roosting sites. Mitigation measures are not yet well developed, however, and few examples exist within a Canadian context. Instead, mitigation may require adaptation from the US and other jurisdictions.

5.3.1 General overview

Many bat species, including those found in Canada, move seasonally between winter hibernation and summer roost sites [243]. Generally, these three species at risk have not been found to use roadway infrastructure, such as bridges, as overwintering sites. Instead, winter hibernation sites are in underground openings, including old mines, caves, wells, and tunnels that provide a stable, warmer microclimate. The little brown myotis will also overwinter in buildings, if winter temperatures are sufficiently warm. Summer roosts can be more varied, since both females with young (maternal roost colonies) and males (day and night roosts) move between different sites during the summer [243,245]. Bats will move between summer roost types (e.g. between different maternity roosts), and to other types of roosts, to meet specific habitat and life stage needs [245]. The maternal roost is considered critical habitat, since these sites support species reproduction and females generally have only one to two pups per year [243].

Species of bats have been recorded using bridges and culverts across Canada's transportation network, and more than half of North American species are documented as roosting under bridges [245]. In Canada, the little brown myotis is one of a few species found to use bridges and other anthropogenic structures as roost sites, including maternity roosts [243]. The northern long-eared myotis and tri-coloured bat typically use forest trees and snags for maternity roosts. All three will use tree bark and other small cavities as individual day or night roosts. Bridges provide important habitat that mimics form and function provided naturally by caves, rock and tree crevices. Long culverts also offer similar natural function to that provided by caves. Although it is now widely accepted that bats use bridges as roosting sites, in Canada little attention has been given to the characteristics of the bridges associated with use as day, night or maternal roosting sites.

Recently, both summer maternity colonies and day or night roosts have been detected on both culvert and bridge structures in British Columbia [246] and Iowa [247]. Bats in British Columbia are thought to use bridges only during the summer active season [248], which likely applies to most locations in Canada due to harsh winter conditions. A recent inventory by Parks Canada in Grassland National Park, in southern Saskatchewan, detected bats roosting under bridges, but found no overwintering colonies at these sites [249]. The Alberta Program Guide, *Building Bat-friendly Communities,* notes that only two species roost within bridges in the province (little brown myotis and big brown bat, *Eptesicus fuscus*) and only in summer [245].

5.3.2 Implementation in road management

To manage for bat use of existing bridges or culverts, it is important to understand how bats use infrastructure and, secondly, how new infrastructure or upgrades and maintenance might disrupt that use [250]. An understanding of the influence of white-nose syndrome on populations will also be relevant to management, since the high mortality related to this disease makes other sources of mortality even more important. Lastly, human perception of bats will play a role in managing their use of road infrastructure. Bats can carry rabies, transmitted to humans and other animals through bites or scratches, and fungal spores developed on guano can cause respiratory illness. Although these health risks are low, particularly in Canada, public perception of efforts to sustain bat populations in areas of human use is mixed. Regardless, the conservation requirements under SARA mean that use of roadway bridges and culverts by bats, particularly use as material roost sites, may require some accommodation.

An understanding of the legal requirements under SARA is a good starting point to build support for management by Canadian transportation agencies.

Under SARA, disturbance or mortality to a species listed under Schedule 1 of the Act (a Listed Species) is prohibited. Should a Listed Species be found in or on a bridge or culvert structure, ideally, the bats should be left undisturbed. However, in cases where this is not possible (e.g. maintenance requirements, demolition for replacement), advice from Environment & Climate Change Canada will be required. Permits can be issued to disturb animals and habitat, but will often require habitat replacement, specific surveys and avoidance measures, where feasible. Site-specific mitigation planning will be required if disturbance is likely, and specialist consultant advice may also be helpful. Given their current protected status, the presence of roosting bats using transportation infrastructure could delay projects involving bridge and culvert replacement, repair or rehabilitation projects if mitigation (including avoidance) was not initially considered during the project's planning phase.

SARA also requires development of species recovery plans, which will identify critical habitat (the habitat that is essential to sustaining the population), and threats that may be contributing to their current population decline. Such information can be helpful in identifying potential impacts to listed bat species and developing mitigation plans. The following specific threats have been identified in the species recovery plan for these three listed species [243]:

- **White-nose syndrome** is considered a very high-level threat to all three bat species, as it can wipe out entire hibernation colonies. Although it can be transmitted from infected hibernacula by both bats and humans, generally, white-nose syndrome would not be found in the road infrastructure bats might use as summer roosts.
- **Habitat loss and degradation**, particularly of roost sites, is rated as a high threat, in areas with and without white-nose syndrome. Loss of roost sites is attributed to deliberate exclusion from roosts in buildings and other human infrastructure (for little brown myotis), and loss of forested habitat used by all three species as roosts. Given the high site fidelity of these species, particularly for maternity roosts, the loss of such sites can lower reproductive success, or alter home range size, mean colony size, or reduce site fidelity, all of which can cause population decline.
- **Extermination of maternal colonies** occupying human structures, often attributed to human perceptions of disease risk, is considered a high threat where white-nose syndrome exists, but medium to low elsewhere.

Conserving, or enhancing, critical habitat, including maternal roosts sites, is one of the key recommendations in the current recovery plan for these species. Public education, through various coordinated national and regional programs, is another priority action. Both types of mitigation measures can be applied by transportation agencies.

Design

New bridges can incorporate suitable roost sites and, similarly, existing bridges can be modified or retro-fitted without sacrificing safety or operability. Creation of day-roost habitat for bats in new or existing highway infrastructure can often be done at minimal additional cost to a project. For new structures, the minimum needs for day-roosting bats can be met by providing sufficient roost space in potential crevices, such as expansion joints, and installing external bat boxes [244]. When retrofitting a bridge to increase its bat habitat, artificial roosts, such as Texas Bat Abodes and Oregon Wedges, are affordable options [244].

Specific design parameters for new or retrofit roost features on bridges are beginning to be investigated, mainly in the US. Such efforts highlight the innovation possible through partnerships with conservation organizations, including the many bat conservation groups established across North America. The Bats in Bridges Project was designed to aid US transportation departments in creating bat habitat, while reducing project interactions during bridge construction [251]. Bat Conservation International cooperated with 20 state transportation departments in this national study of bats on bridges, focussing on a major highway passing through 25 states. The study found 217 highway structures used as day roosts and 714 highway structures used as night roosts. Parallel box beam bridges were preferred as day roosts, then bridges with cast-in-place or prestressed concrete girder spans. Most bat species chose concrete crevices in bridges that were sealed at the top, at least 6-12 inches deep, 0.5-1.25 inches wide, and 10 feet or more above ground [252]. Bats also preferred a closed surface above them. Similar findings came from study undertaken by the Iowa Department of Transportation to better understand the bridge characteristics that would attract roosting bats [247].

Operations and maintenance

Various studies have explored when and where bridge replacement, repair or rehabilitation projects could have negative interactions with bats and place bats at risk. Bats roosting in highway structures, such as bridges and culverts, can be habituated to noise and vibration associated with traffic and are expected to be minimally affected if maintenance operations stay within these parameters [251]. However, bats are more sensitive to noise effects at certain times of the year [253]. Structural maintenance can also affect roosting bats if the bats suddenly become exposed to foreign materials. Sudden noises associated with highway and bridge construction can potentially disturb bats and cause abandonment of roosts and chronic disturbance may alter colony activity patterns [253]. Seemingly uncomplicated project operational activities can negatively affect roosting bats in bridges (e.g. pavement rehabilitation and reconstruction, bridge deck replacement, and guardrail and fencing installations [254]).

As noted above, human health concerns are a frequent question when bat roosts are discovered in or on manmade infrastructure. Histoplasmosis can be transmitted through fungal spores that may grow on bird or bat droppings, especially in more humid areas [245]. The incidence is relatively low in Canada however. Rabies can be contracted from bites or scratches, but risk can be minimized by not handling or touching bats (including dead animals). The Texas Department of Transportation (TxDOT) studied how the presence of bats in a bridge or culvert affects public safety, worker safety, water quality, structural integrity, and the welfare of the bats [250]. In all cases, when properly managed, bats allowed to remain undisturbed did not put the public or workmen at risk.

5.3.3 Beneficial management practices

Beneficial Management Practices to minimize effects of bridge construction and upgrade projects on bat communities include direction on survey techniques, humane evictions and exclusion techniques, as well as mitigation and compensation measures [254]. Beneficial Management Practices recently created in BC recommend the establishment of bat boxes as replacement habitat [255]. Generally, management practices for bats in transportation infrastructure have been divided into the three main categories summarized below [254,244,253].

Inspection

Prior to construction, sites should be surveyed to detect bat use. It can be quite difficult during a daytime site visit to detect bats and visits rely on detecting their sign including urine and guano [247,252]. Bat emergence and re-entry surveys can confirm the use of bridges and culverts by bats and provide an estimate of colony size [254,252]. Acoustic monitoring of bats can help identify whether bats occur near the infrastructure, however it does not confirm whether the detected bats originate from the bridge or culvert. A combination of the three inspection techniques may be necessary to document the species presence and site use patterns, including using the site for roosting [253].

Bats commonly roost between narrow spaces above bridge beams, above or behind expansion joints, or insulation boards or between guardrails and posts, and between concrete piers and corrugated metal [252]. Access to these areas of the bridge is not often orientated to the ground, therefore bat sign (urine and guano) is not always evident. If no sign or detections of bats are detected during an initial visit it is important to complete subsequent checks because bat presence may vary seasonally and annually.

Once the inspection has identified bat use, a site and project noise assessment can be conducted to assess the expected project noise levels and degree of change. This can be done by estimating the background noise levels, the normal operation traffic noise level and the noise levels expected during the project [253].

Avoidance and minimization

Once bat use is confirmed, the next step is to create a plan to avoid or minimize project interactions with bats during construction or maintenance. During this stage, the estimated potential effects of noise and any potentially deleterious materials can be assessed. Avoidance is the first step in the process and can be achieved by scheduling project activities when the bats are not present. If avoidance is not possible then minimization of noise or reduction of risk of releasing deleterious materials should be explored.

Mitigation

Unavoidable project impact to bats created by bridge construction or maintenance activities can be addressed by preparing a plan to off-set or compensate for negative project effects. Mitigation measures can involve providing habitat replacement during or after project activities. When evaluating the creation of replacement habitat or even the creation of new man-made habitat, consider both structural design and final placement. As an example, to mitigate construction impacts to little brown myotis predicted for the proposed Highway 401 Expansion Project in the City of Mississauga, bat boxes with artificial bark were installed along a proposed retaining wall adjacent a woodlot area [256]. Artificial bark is specifically designed for long-term habitat improvement for bark-roosting bats. At this time, the project has yet to be constructed, therefore the success of the compensation has yet to be evaluated.

5.4 Night lighting impacts

Artificial lighting is an important safety consideration in road design, however it can affect the distribution, abundance and movement of nearby wildlife [257]. The objective of roadway lighting and associated infrastructure lighting is to supplement vehicle headlights and to improve the visibility of features and objects on the roadway [257]. In addition to roadway lighting, underdeck lighting can also be placed under bridges to maintain continuity with the adjacent road lighting. The typical luminance (brightness) levels for roadway lighting are between 3 and 16 Lux, whereas natural lighting sources are much lower [257]. Natural lighting levels range from civil twilight at 3.4 Lux, a full moon at 0.1 Lux, a quarter moon at 0.01 Lux and a total starlight at 0.0002 Lux. This difference between natural and night lit areas can affect wildlife in terms of circadian rhythms, habitat use and navigation. Recognition of potential impacts of night-lighting has spurred design innovations that can also present cost-savings in terms of capital investment and on-going maintenance.

5.4.1 General overview

Natural light levels are important for many wildlife species. Light can be considered a resource as well as an information source. As a resource, light affects photosynthesis, partitioning of activity between day and night, and recovery and repair during the dark [259]. As an information source, light affects circadian rhythm, visual perception and spatial orientation. By altering natural light regimes, artificial light can affect both resource and information functions.

As an example, the use of crossing structures and fences by wildlife species can be influenced by the presence of artificial light. Maintaining light levels similar to the surrounding habitat can likely increase the effectiveness of a crossing structure, as many species require natural lighting at crossings [260]. Amphibians require natural riparian vegetation, soil moisture and natural light conditions throughout an underpass [11]. The direct effects of light at night on some species is well known, but it is the long-term impacts of light and changes to the ecosystem that are not well understood. Studies suggest that frogs and fireflies may be deterred from mating, bats may change their habitat use, and water fleas may be deterred from fish feeding areas [257]. These ecological effects are characterised as disruption of information flows and/or changes in resource use and availability [259].

Some Canadian transportation agencies have adopted night lighting guidelines, with recommended practices and design standards (e.g. Alberta, British Columbia and Quebec have established provincial standards, Appendix A). Others rely on TAC guidelines for roadway lighting (e.g. New Brunswick). In more remote areas such as the Northwest Territories, no lighting standards are applied. In most cases however, these standards and guidelines are based on engineering and road safety, rather than ecological considerations. Design standards are emerging to address night lighting impacts on wildlife, as are mitigation options and they offer alternatives for locations where impact management is desirable.

5.4.2 Implementation in road management

Lighting mitigation is applied mainly in the design stage for new lighting systems, or during design of retrofitting. Design is only beginning to consider wildlife impacts; mostly, design guidelines have aimed to reduce light pollution for human benefits and cost efficiencies. Light pollution can occur along roadways when there is an inefficient or unnecessary use of artificial light [261]. Design guidelines for lighting along roadways address the placement of poles and type of lighting, and thus offer the potential to avoid light ‘trespass’, or pollution effects. Selecting the proper equipment, mounting location and direction of a light can make a significant difference to the level of light pollution [257]. Such measures can also avoid or minimize the negative effects of artificial light on nocturnal wildlife.

Improperly installed lighting can contribute to over-lighting of an area [257]; about 35% to 50% of light pollution is estimated to be from roadway lighting [261]. Provincial and municipal roadway lighting design guidelines now provide standards and information to establish lighting in an economical and energy efficient manner, while providing adequate and uniform lighting for driver and pedestrian safety [262,263,264]. Traditionally, the standards for light levels have been chosen from both the Illuminating Engineering Society of North America (IESNA) *Standard RP-8* and the TAC (2006) *Guide for the Design of Roadway Lighting* [257]. Many Canadian provincial guidelines were updated after the publication of the TAC (2006) *Guide for the Design of Roadway Lighting*, which provided modern techniques and practical recommendations for consistent lighting design across jurisdictions. The TAC (2013) *Roadway Lighting Efficiency and Power Reduction Guide* offers additional options for more efficient lighting that may also reduce indirect trespass lighting effects. Some research suggests that levels lower than IESNA standards may be just as effective. This is a subject of significant scientific interest and ongoing research relative to cost efficiencies, but also for addressing night lighting effects on wildlife.

Artificial light provided by roadway lighting can have negative effects on wildlife, even when properly installed, by creating a perceptual barrier to movement for some species and reducing habitat connectivity [265]. Studies of animal behaviour suggest that wildlife aversion to roadways and possible crossing structures is related not only to traffic noise, but also artificial light [266]. This barrier effect is not the case for all species, therefore consideration of which species move through the area and their sensitivity to light is and important step in the design process. For example, Bliss-Ketchum et al. [265] found that black-tailed deer, a species of concern for collisions, avoided lit areas. In this case, lighting may have helped mitigate collision risk.

Artificial lighting can also affect the use of a wildlife passage or success of a fencing project. Lighting provided on wildlife crossing structures designed for use by both humans and wildlife can create conflict, resulting in no or reduced use by wildlife [11]. This effect may be in part due to shared use with humans, in addition to the effects of lighting. The placement of lighting at fence ends along a roadway may improve the road user's visibility and potentially increase road crossings by ungulate species, but it may also deter movement by some carnivore species [11]. When designing underpasses and modified culverts, it is important to consider ways to minimize the intensity of light coming from the road and traffic. Light, and noise, from vehicles can be reduced by the placement of earth berms, solid walls, dense vegetation, or a combination of these on the sides of the wildlife passage structure [11]. If the light and/or noise levels are high due to high traffic volume above an underpass, then an attenuating wall can be designed above the entrance to the underpass.

Often, lighting studies have focused on bats, due to their nocturnal activity patterns. Lighting can attract insect prey (e.g. moths), which can improve foraging efficiency [243]. Furlonger et al. [267] found all species of bats identified in a study of foraging around artificial lighting in Ontario focused on these lit areas. Others have found that lighting benefits insectivorous bats with high or medium wing-loading and faster flight, while species specialized as vegetation gleaners and flutter-detectors do not use lit areas to forage [268]. Slow fliers are thought to be at higher risk of predation in lit areas, and have been found to avoid such areas [269]. Of the three bat species considered at risk, little brown myotis are fast enough to benefit from lighting [270]. Northern myotis and tri-coloured bats are slow fliers, which would be expected to avoid such areas. Not surprisingly, lighting can also affect insect populations negatively, either through direct predation mortality, exhaustion from avoiding predators, or burning or becoming trapped in light receptacles [222]. Given the dependence of insectivores on such prey, such mortality risks can impact the diet and health of these, and other bat species.

A study on bats and lit underpasses noted an increase in crossing rate for bats above the freeway and a decrease in passage over and through the underpass in the lit areas [271]. The report recommended that underpasses intended to facilitate the movement of wildlife across roads should not be lit. Other studies suggest artificial lighting on bridges on which bats roost or where roosts are present in nearby habitats should incorporate buffer zones (dark zones), particularly adjacent to waterways used as foraging areas. Intensely lit areas may impair bats' vision and cause disorientation, inhibit movements, and prevent access to roosts and foraging areas [272]. As a result, bats may abandon a roost that is illuminated, or they may considerably delay their emergence. This can reduce foraging times (by missing peak levels of insect activity, or decreasing foraging bouts) and thus, affect body weight, reproduction and winter survivability [273]. It is essential that lighting plans for a new development site around known roosts take into consideration the exit points, flight paths and foraging areas for bats and ensure these areas are not illuminated.

Conversely, lighting can dissuade some bat species from using customary flight paths that cross traffic and thus, reduce the potential for bat-vehicle collisions. Lights positioned close to identified crossing points can deter bats when placed at 10 m intervals [254].

5.4.3 Beneficial management practices

Mitigation of night-lighting effects, being an emerging issue in road ecology, has generated limited study on means to avoid or minimize impacts. Gaston et al. [259] suggest five management options to reduce the ecological consequences of light pollution:

- prevent areas from being artificially lit
- limit the duration of lighting
- reduce the 'trespass' of lighting into area not intended to be lit
- change the intensity of the lighting
- change the spectral composition of the lighting

Preventing areas from being artificially lit is the most effective option, however is likely to conflict with economic and social objectives of lighting around transportation infrastructure [259].

Options also exist as equipment is being replaced. Light standards have a general lifecycle of 25 years and when replacing older equipment, opportunity exists to reduce excessive light pollution through 'trespass' light [261]. Full cut-off street lighting is designed to direct the light only to the roadway, where it is needed and avoid light pollution (trespass). Reducing light trespass maintains darkness even in otherwise well-lit areas, providing dark refuges wildlife can exploit [259]. Changing the spectral properties of artificial lights can also minimize the negative effects on some wildlife species. Broader spectrum light sources, such a light-emitting diodes (LEDs), facilitate color discrimination, allowing animals to better navigate, forage, hunt and find mates [259].

Ecological research on the impact of artificial light has focused on relatively few species and leaves many questions still answered relative to lighting options, and the differential impact on nocturnal species. Gaston et al. [259] suggest future research should be directed to assessing the environmental effects of intensity, spectra and periodicity of artificial light.

5.5 Restoring habitat connectivity

Habitat connections at the landscape scale became a concern as habitat fragmentation effects became better understood, particularly for species with high mobility and large home ranges. In many parts of southern Canada, the US and Europe, the pace of development and urban expansion has intensified the developed footprint on the landscape, such that natural habitats have become fragmented and isolated. In the face of climate change and predictions of large-scale shifts in habitat distribution, restoration of connectivity is even more imperative to protect routes that will allow species to move to more favourable habitat over time. This includes provisions for less mobile species such as snakes and amphibians, for which larger roads might pose a significant barrier. Restoration planning has thus become a proactive response to past and future change.

Restoring Landscape Connectivity

Some species, such as elk, grizzly bear and wolves appear to have thresholds of tolerance for road density, above which they avoid certain landscapes [279,280]. The thresholds vary by species: those requiring larger home range sizes have relatively low tolerance to road density [280]. Habitat displacement affects the individual and the population through changes in habitat use, home range selection, movements, population fragmentation, survival, and reproductive rates [280]. Restoration for these species would require management of active road density at a landscape level (e.g. with seasonal closures or strategic abandonment). By necessity, such projects must involve partnering and collaboration.

5.5.1 General overview

Connectivity can be affected by the barrier or filter effect of roads, or by habitat degradation associated with long established roads, such as aggressively invasive species and damaged or degraded stream crossings. Restoration efforts, accordingly, have ranged from retrofitting or installing wildlife crossing structures, to habitat improvements such as vegetation removal and replanting. Wetland restoration is a specific technique applied to repair temporary disturbances, or to replace lost habitat, discussed in more detail in Section 4.5, and the case studies in Section 4.6. In rural areas, restoration opportunities can occur as roads are abandoned or as older roads are replaced, realigned or upgraded. In urban settings, similar restoration opportunities occur as roads and neighbourhoods are redeveloped for new land use.

5.5.2 Implementation in road management

Restoration ecology hinges on a holistic understanding of the ecosystem where a project is proposed, as well as the target species. Accordingly, early involvement of vegetation, wildlife and landscape ecologists familiar with the ecosystem and methods of restoring it is critical, particularly for more complex projects.

As an example, the density and configuration of road networks at the landscape level are known to influence the scale and intensity of barrier and mortality impacts of roads on wildlife [274]. Restoration design would require an understanding of the barrier effects, critical thresholds and ecological effects on species intended to benefit from restoration (see text box example, Restoring Landscape Connectivity). Conversely, road ROWs have been found to provide linkages between habitat patches for other species, such as pollinators [167]. Understanding the scale and habitat requirements of species targeted to benefit from restoration efforts is critical to planning.

Such information can influence restoration options when roads are decommissioned and reclaimed, or where new crossing structures are considered to enhance connectivity, since the condition of the broader landscape will affect restoration success. In some instances, restoration may not be feasible without other, larger scale management action and involvement of other parties (e.g. forestry tenure holders).

Restoration must be holistic in terms of social factors as well. Restoration may be limited by legislative constraints, including land use by-laws, and jurisdictional controls. For example, enhancements for improved connectivity may extend beyond the lands under transportation agency control, or may trigger other permitting requirements, such as water crossings. Public support for restoration is essential; animals will move beyond restored lands, ideally to locations where they are welcome. Planning is an important first step in this process that allows an agency to define the problem and restoration objectives well, which will facilitate subsequent project stages of design, implementation and operation [275].

Across Canada, documented examples of restoration projects associated with road systems are relatively limited. Most examples were in Eastern Canada (Ontario, Quebec and the Maritimes), but a few projects have been completed in British Columbia's Lower Mainland. Projects spanned a variety of species and management situations, from landscape level connectivity restoration [276], to restoration of abandoned roads and stream ford sites [277]. Some projects have generated recommendations for future practice through case studies or prescriptive guides. For example, Metro Vancouver and the Invasive Species Council of Metro Vancouver generated a BMP document specific to removal and restoration of areas affected by Himalayan Blackberry, an invasive plant species [278]. The guideline document outlines methods for control, disposal, cleaning/disinfection and monitoring and restoration prescriptions applicable to the Lower Mainland ecosystem. The landscape level project for restoring caribou habitat mentioned in Section 5.2 involved collaboration between the Tsay key Dene, and various land tenure holders, as well as an ENGO partner, and generated a guideline document for future similar Indigenous co-management efforts [241].

Other examples of restoration of wildlife connectivity used retrofitting, by constructing wildlife passages that would help provide safer crossing locations. For example, a project completed by the Fraser Valley Conservancy (FVC) installed a permanent amphibian crossing structure in partnership with Lafarge Canada, The Langley Concrete Group and Environment & Climate Change Canada [83]. The road, located near Ryder Lake, was recognized as a mortality sink for Western toads in annual migrations from wetland to upland habitat. FVC worked with local industry to implement selective road closures during spring migration of amphibians for several years, before proposing a new crossing structure as a longer-term solution. Engagement with local industry and government partners, and a depth of understanding of the context of the problem provided the support required to solicit necessary funding, and support for the project.

5.5.3 Beneficial management practices

Resources are available to help identify connective habitats at the landscape scale, and can be used to inform restoration decisions, as well as new road design. Often, this work has been completed by ENGOs with interests in conservation at the landscape level, providing vital information beyond the jurisdictional scope of most transportation agencies. Examples include:

- The Staying Connected Initiative website (http://stayingconnectedinitiative.org/our-places/our-places-overview/)

- Studies undertaken by the Yellowstone to Yukon (Y2Y) Conservation Initiative (https://y2y.net/resources/research-and-reports/) and the Miistakis Institute (https://www.rockies.ca/reports.php)
- Connectivity analysis by the Nature Conservancy of Canada (NCC) in the Chignecto Isthmus, a choke point between New Brunswick and Nova Scotia (https://novascotia.ca/natr/wildlife/habfund/final15/NSHCF15_02_NCC_Wildlife-connectivity-on-the-Chignecto-Isthmus.pdf)

Restoration planning should consider factors such as the following:

- Target species, and the habitat features required to provide secure connective corridors [281]
- Locations of core areas and other existing corridors, as well as the type of barriers and apparent gaps in the corridor system, linking larger habitat patches [276]
- Off-road mortality risks and adjacent landowner support for restored connectivity [275]

Note that restoration projects have often been triggered by a specific problem (e.g. a species at risk, large animal collisions). Other considerations could include targeting ecological processes, rather than species (e.g. providing movement for a variety of species, rather than just one). This approach would have the benefit of enhancing habitat for a range of species, and avoiding unintended impacts on non-target species.

Depending on the restoration project, follow-up activities could include:

- Monitoring to track restoration effectiveness and incorporate adaptive management [281,276,275]
- Awareness programs to modify human behaviour in restored areas [282]
- Analysis of lessons learned from improving connectivity that can be applicable to future road planning [277]

Successful implementation is also linked to agency communication and planning processes, and consideration of design, construction and maintenance requirements [283]. Plans should identify the resources and agency or public support required to complete and maintain restoration projects, as well as the ecological inputs to design. For example, the success of roadside restoration work undertaken by Washington State Department of Transportation (WSDOT) involved extensive consultation with maintenance and design staff, plus consideration of lifecycle costs to maintain restored roadside landscapes, the ecological considerations for stable plant communities and the social impacts of discouraging transient camping [283]. As each situation is unique in terms of the agency, and ecological, financial and social considerations, consultation within and across related agencies is a key step in planning.

5.6 Climate change and invasive species

Despite the extensive experience in managing invasive species in roadside environments discussed in Section 4.2, future management holds uncertainty, particularly in the face of a changing climate. Both climate change and invasive species pose extraordinary ecological challenges, and interaction between the two is complex and not necessarily additive. It is generally thought that climate change will exacerbate the problems associated with invasive species, by facilitating range expansion and spread to new areas. The challenge lies in understanding where invasive species are more likely to thrive in future climate scenarios, which in turn involves predicting new climate conditions. Preventing their dispersal and establishment in new areas will also depend on understanding how these species might react to predicted changes in climate, and habitats.

The following are some of the ways in which climate change may intensify the challenges of managing invasive species:

- Rising temperatures will likely allow the spread of invasive species further north [284] and roadways could act as conduits to new settlement areas.
- Invasive species may become more aggressive with warmer temperatures (e.g. growing faster), or native species may become less well adapted to their environments, allowing invasive species to dominate habitats more effectively [285].
- Resource scarcity created by drought, flooding or changing temperatures will put stress on ecosystems, resulting in greater competition among native flora, again making ecosystems more vulnerable to invasion [286].
- Invasive species tend to be highly adaptable by nature and respond to environmental changes more rapidly than native species, giving invasive species a competitive advantage [285].
- Changes in climate may render existing biocontrols less effective[287,288].

Whatever the results of climate change on invasive species, transportation networks are likely to remain key pathways of dispersal. The mitigation measures discussed in Section 4.2 offer potential solutions, particularly Integrated Pest Management Plans, which examine the problem at a wholistic level, more appropriate to dealing with invasive, non-native species that can adapt to change so readily. Future management systems may also focus on individual species (e.g. *Phragmites* spp.) considered particularly adaptable to climate change, as the speed of spread, and need for management of invasive species becomes more apparent.

5.7 Case studies

CASE STUDY

Inuvik to Tuktoyaktuk Highway

WHAT'S THE ISSUE?

The addition of a permanent highway from the Town of Inuvik to the Hamlet of Tuktoyaktuk has been a long-standing goal of the residents and the Government of the Northwest Territories (GNWT) since the early 1970s. Planning began in 2009, however the highway's route posed several environmental constraints, including development within three caribou herd ranges (Bluenose-west, Cape Bathurst and Tuktoyaktuk peninsula herds) (Kiggiak-EBA, 2011). Caribou and other large mammals such as moose, grizzly bear, wolverine and fox are of keen interest to the communities surrounding the highway development for substance and cultural value.

The proposed Highway alignment was within important habitat of the Bluenose-west herd, the Winter Range Management Area and spring and winter caribou harvesting areas.

QUICK FACTS

Category: Highway development

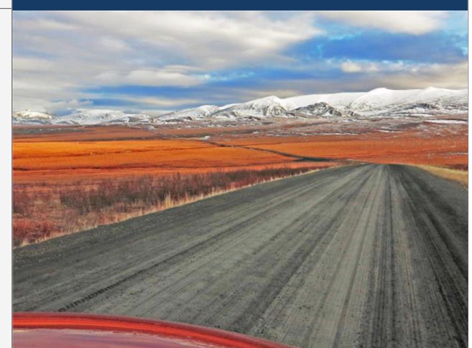
Location: NWT

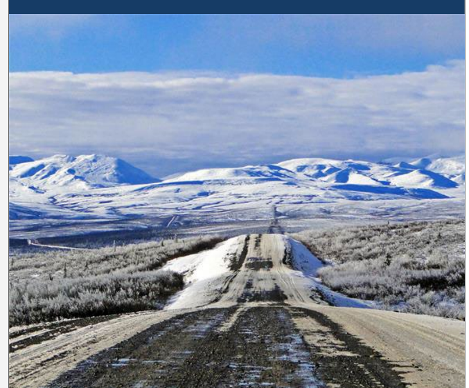
Completed: 2017

Costs: unknown

Objective: Wildlife collision reduction

Species: Large mammal species (including caribou, grizzly bear, wolf and wolverine)





WHAT'S THE APPROACH?

Predicted effects on wildlife and wildlife habitat included habitat loss, physical or physiological disturbance, delayed or failed crossings and mortality associated with Highway construction. Mitigation measures were implemented during construction and operation, including standard best management practices:

- reducing footprint size
- restricting development to previously disturbed areas
- worker training

Additional mitigations were developed to prevent sensory disturbance and mortality for caribou:

- Caribou have the right-of-way at all times (a standard GNWT road mitigation practice)
- Speed reductions when animals are observed in proximity to the road surface or on it
- Increased signage and warnings regarding the potential for wildlife on the roadway
- Access restrictions to the highway during peak caribou migration periods and highway closures during times of high caribou presence
- The five-year Inuvik to Tuktoyaktuk Highway (ITH) Wildlife Effects Monitoring Program (WEMP) was designed to evaluate the residual effects on the abundance, distribution and direct mortality of caribou, grizzly bear and wolverine associated with Highway construction
- A Wildlife and Wildlife Habitat Protection Plan was developed for the project
- Monitoring programs were initiated prior to, during and after construction

CASE STUDY

Inuvik to Tuktoyaktuk Highway

WHAT'S BEEN OBSERVED?

- Both the WEMP and Wildlife and Wildlife Habitat Protection Plan have been implemented
- Post construction wildlife monitoring work is currently on-going, but no final results of the monitoring program are yet available

WHAT'S BEEN LEARNED

This project **highlights some differences in road planning process, relative to Southern Canada**:

- Mitigation was developed after a **two-year EIA process, including community consultation** on wildlife concerns
- Many of the **road mitigation practices included here are standard practices in the NWT**, and are accepted project costs, in financial terms (e.g., lengthy wildlife monitoring) and in terms of impacts on road users (e.g., wildlife right-of-way).

Broader questions regarding effectiveness could be examined, to better inform new road development in the north, and elsewhere in Canada:

- Has giving wildlife and caribou the right-of-way reduced mortalities?
- How effective have increased signage and warning systems been?
- Have seasonal warning systems been used or just conventional roadside signage?
- Has the addition of a permanent roadway altered wildlife behaviour in the area?

Photo Credits: Nathalie Oldfield, Northwest Territories Department of Transportation

CASE STUDY

Peel Plateau, Northwest Territories, University of Colorado

WHAT'S THE ISSUE?

Northern roads are essential for transportation between northern and southern communities, and increasingly vulnerable to environmental changes, including changing precipitation patterns and permafrost degradation. Roads affect adjacent lands by increasing dust deposition and runoff, altering soil properties and impacting plant physiology.

The Dempster Highway is a 740 km gravel road between Dawson City, Yukon, and Inuvik, Northwest Territories. Residents in nearby communities were concerned about the impacts of the road on vegetation and terrain stability.

QUICK FACTS

Category: Vegetation management

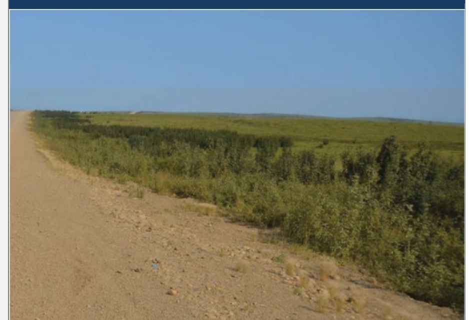
Location: Peel Plateau, Northwest Territories

Completed: 1979

Costs: $132 million

Objective: Vegetation management

Species: Various vegetation, including green alder



WHAT'S THE APPROACH?

- Construct a 1.2 m to 2.4 m thick raised gravel embankment to reduce heat transfer and maintain a frozen foundation to prevent settlement and road surface cracking
- Maintenance: gravel deposition, grading, culvert replacement, application of calcium and water for dust control in the summer and snow removal in the winter
- Effectiveness evaluation (Gill et al., 2014):
  - Study area: 70 km^2 area, 15 m and 500 m from the embankment, between Fort McPherson and the Yukon border
- Data collection: Measured ground temperatures using HOBO data loggers, snowpack thickness using a graduated avalanche probe, active layer thickness using a graduated soil probe, plant-available nutrients using a Plant Root Simulator nutrient probe, soil pH in the lab, and community composition using PRIMER
- Evaluation goals: Examine the effects of the road on vegetation composition and structure and their impact on permafrost conditions

WHAT'S BEEN OBSERVED?

- Alder cover was significantly greater at roadside tall shrub sites than at all other site types. Other deciduous shrubs were not influenced by the road and had similar abundance across site types.
- Roadside sites compared to control dwarf shrub sites had a lower cover of lichens, mosses and Petasites spp. and a higher cover of E. vaginatum and dwarf shrubs.
- Alders at roadside tall shrub sites were significantly younger, taller and faster growing, spreading within 100 m of the road, compared to controls.
- The control tall shrub and roadside dwarf shrub sites had similar vegetation composition with an understory mostly of sedges and dwarf shrubs, except the dwarf shrub sites, with fewer alders.

CASE STUDY

Peel Plateau, Northwest Territories, University of Colorado

- Edible berry plants were less abundant at tall shrub sites compared to dwarf shrub sites regardless of road proximity.
- Near-surface ground temperatures beneath areas of tall shrubs 15 m from the road embankment were significantly higher than in control areas, and freezeback was delayed more than three months.
- Abiotic parameters, such as snow, active layer, litter, and organic soil thicknesses, were higher at roadside sites compared to controls and at tall shrub sites compared to dwarf shrub sites, and were linked to alder cover.
- Ground temperatures and pH were higher at roadside sites compared to controls, with significant pH differences at tall shrub dominated sites
- Significantly higher levels of total nitrogen, calcium, magnesium, and sulfur were detected at tall shrub sites near the road.

WHAT'S BEEN LEARNED

Key results from effectiveness monitoring:

- Road construction led to **environmental changes enabling alder growth near the embankment**.
- Alder populations near the road were **two to three times faster-growing than at control sites** and dominated by individuals introduced in the last two decades.
- Tall alders **trapped snow and limited compaction of the snowpack**, insulating the ground, preventing ground heat loss in winter.
- **Dust and nutrient deposition** by the road was more evident in areas dominated by tall shrubs
- **Increased temperatures and changes to soil chemistry** caused by tall shrubs promoted the growth and spread of shrubs.
- When tall shrubs were not introduced during vegetation disturbances, **impacts were less pronounced because snow and dust were spread over larger areas**
- The impacts of all-weather roads can **extend much further than the surface of the road** due to dust redistribution, shrub growth and ground temperature changes.
- **Regular shrub cutting is recommended** to maintain permafrost conditions in and around roads. **Further research** will be conducted to determine feasibility and impacts of this strategy.
- **Additional research** is needed to determine the factors promoting and deterring shrub growth (e.g., using historical air photos to map vegetation changes and examine relationships between shrub growth and landscape changes).

Photo Credits: Gill, H.K., Lantz, T.C., O'Neill, B., and Kokelj, S.V. (2014). Cumulative impacts and feedbacks of a gravel road on shrub tundra ecosystems in the Peel Plateau, Northwest Territories, Canada. Arctic, Antarctic and Alpine Research. 46: 947-961.

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Northern roads

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Restoring habitat connectivity

Online Resources:

- *Staying Connected Initiative* (http://stayingconnectedinitiative.org/our-places/our-places-overview/)
- *Yellowstone to Yukon (Y2Y) Conservation Initiative* (https://y2y.net/resources/research-and-reports/)
- *Miistakis Institute* (https://www.rockies.ca/reports.php)

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6. Conclusions

6.1 General conclusions

This synthesis provides a general overview of the range of practices used to manage terrestrial road ecology issues across Canada. Further, it identifies the 'state of the art' for mitigation options, relative to their application across Canada. The information provided here offers solutions and considerations for appropriate use in a given ecological setting, and relative to the stages of the road life cycle. The resulting recommendations of Beneficial Management Practices, or BMPs, builds on scientific research and practitioner experience, illustrated with applied project examples and case studies. It also provides a range of resources for additional information on the mitigation options relevant to the Canadian transportation context. Each section provides insights on the benefits and cost, resource and other supports needed for successful application of mitigation, from the planning, operational and decommissioning stage of the road life cycle.

The process of compiling this synthesis also generated insights on the state of practice of road ecology in Canada, relative to challenges, data gaps and future directions. Globally, road ecology has become a recognized discipline, with extensive expertise at the research and practitioner level. In examining the practice within Canada, we considered several guiding questions:

- Where have practices become standardized, and where are they still emerging?
- What are the general management goals relative to a given road ecology concern?
- What are some of the constraints applicable to a given road ecology concern?
- How are multi/interdisciplinary approaches being applied to the design of BMPs?

We also explored three additional considerations applicable to a Canadian context:

- Does geographic location (East/West/North) influence the BMPs being used?
- Do BMPs differ for specific species?
- Do road type and location (e.g. urban/rural, freeway/ collector road) influence BMPs?

Over the course of preparing this synthesis, we were able to answer many of these questions, but we also discovered gaps in the available mitigation measures, as well as in standardized practice.

Several challenges apply to completing a synthesis of standardized road ecology practices across Canada. First, the diversity of the country and its ecological, regulatory and transportation systems means that managers face a range of different species, habitats, levels of development and conservation challenges. For example, southern Canada has experienced considerable landscape level change and development, and natural habitat can be fragmented by human land use, including road networks within a context of urban, industrial and agricultural development, and small to large areas of habitat. In contrast, development in Northern Canada is less dense and more dispersed, and roads to connect urban and industrial land uses may traverse large areas of natural habitat, with ecological and Indigenous cultural values. Second, the type of road, in terms of width, traffic levels, speeds and construction and operational constraints (including climate) does influence the degree of impact on ecosystems and the species that comprise them.

The objectives of ecological conservation can vary considerably given such diversity, so that solutions to road ecology concerns are necessarily customized to site-specific conditions and planning objectives. Further, solutions must be adapted to the behaviour and habitat use of species of concern to be effective. As a result, the BMPs presented here incorporate an element of contextual interpretation. Solutions will always depend on the species and local or sometimes regional ecology, land use, stakeholders, and regulatory requirements, as well as available funding. Road ecology does not lend itself to 'one-size-fits-all' solutions.

Often successful solutions to road ecology problems are collaborative, a theme repeated in many of the applied project examples presented in this synthesis. Involving a variety of potential partners has several benefits. Firstly, cooperation helps provide access to resources, skills and knowledge that may be otherwise unavailable to a single agency. Secondly, and perhaps more importantly, solutions may require public and political support in some form, particularly where sustained funding is needed.

Landscape level changes, such as naturalization and habitat restoration, may substantially change how roads and ROWs are managed, function or look. Developing shared and realistic understandings of project goals, outcomes or benefits, and timelines can help foster support needed to sustain changed practices, and avoid future management conflicts. Although the BMPs presented here often focused on planning and implementation steps under control of a transportation agency, many of the case studies and project examples also involved public outreach at a minimum, or engagement at best. Long-term programs provided the best examples of public involvement (e.g. the Wild Kidz program offered by British Columbia Wildlife Program and the BC Wildlife Federation, or the public engagement efforts during Herb Gray Parkway Tall Grass Prairie naturalization project). Often, program managers noted the importance of such measures in creating broad support, and community champions that contributed to on-going agency or political support. An interdisciplinary approach that can present the ecological, social, economic, and engineering aspects of a solution can play an important role in building and sustaining support, especially for new mitigation approaches.

Funding is a constant challenge for transportation agencies, and building a business case for a preferred solution is as important as ecological justification. The multi-criteria approaches discussed in Section 2.4 offer an interdisciplinary framework for evaluation, as well as means of comparing financial and non-monetary criteria relevant to such decisions. Costs of implementation may seem less daunting when compared to potential future costs of on-going maintenance, dealing with invasive species, or meeting societal expectations for ecologically and financially sustainable transportation systems. Presenting BMPs relative to standard operational costs, as well as ecological and social sustainability can and has provided convincing arguments, particularly if coupled with successful examples of implementation. Examples of such benefits include the reduced mowing and maintenance cost with naturalized ROWs, as well as drought resistance, improved erosion control, reduced need for weed control, and attractive aesthetics, plus sustaining native biodiversity (e.g. pollinators). The projects, case studies, and key resources provided here offer suggestions of benefits to help frame new mitigation proposals, as well as demonstrated examples of cost-effective approaches used to address well-understood and emerging road ecology issues.

Funding discussions should also include sufficient resources for monitoring. Some types of road ecology mitigation can expensive, and without robust scientific evidence of cost-effectiveness, a business case would be far less compelling. Although we found applied examples of different types of mitigation for road ecology problems from across Canada, follow-up monitoring was less often available. Both successes and failures can help inform future efforts. The global adoption of WVC mitigation such as wildlife fencing and crossing structures links to the extensive research that has evaluated the best techniques and design options, in a variety of contexts, as well as the proven reduction in collisions. Monitoring has also helped to reduce project construction and operating costs, by refining techniques that can minimize on-going maintenance, or avoid failures. The Herb Gray Roadway case study from Section 4.6 provides a good example of monitoring benefits to an on-going project. Through a well-designed monitoring program offering scientific evaluation and adaptive management insights, the original 15 seed mixes were reduced to only three, a far cheaper, and sustainable approach for long-term maintenance and reclamation needs (e.g. for utility maintenance).

Another data gap relative to monitoring was in evaluation of engineering design, construction, social and economic outcomes of specific mitigation approaches. Ecological benefits have been far more often examined in scientific studies of road ecology mitigation. In contrast, operational and maintenance costs, or unintended consequences of design, construction, operation, or decommissioning were rarely documented, or evaluated against other benefits. The multi-criteria evaluation techniques mentioned in Section 2.4 require some sense of the input costs for construction, operation and maintenance, as well as the specific factors that may influence successful implementation. While costs will likely vary across jurisdictions, such costs could be better determined if an understanding of the full suite of factors that could influence successful, effective implementation was available.

Lastly, in terms of future directions, Canadian transportation agencies must deal with other social and environmental changes. With increasingly urban populations, the effects of human density, disturbance and pollutants on natural ecosystems must be addressed, to sustain urban green space, and associated ecological goods and services. Yet, in a large country like Canada, the national road network also passes through less developed areas, including protected areas and lands co-managed by Indigenous residents for their ecological and cultural values. Maintaining functional ecosystems that can support current biodiversity and land-based cultural activities will require different management and mitigation approaches than in urban and rural landscapes. Climate change will also affect management, relative to permafrost and northern roads, as well as the movements of species adapting to new habitat conditions, including invasive species. These changes will require development of new mitigation methods, plus collaboration among various stakeholders to set management priorities, and identify appropriate solutions. Again, there are no universal solutions to road ecology problems; collaborative, interdisciplinary approaches will be essential to innovative, appropriate solutions.

6.2 Summary

In summary, the process of compiling this synthesis also generated insights on the state of practice of road ecology in Canada, relative to challenges, data gaps and future directions. Globally, road ecology has become a recognized discipline, with extensive expertise at the research and practitioner level. In examining the practice within Canada, gaps were discovered in the available mitigation measures, as well as in standardized practice. These broader observations include:

- The **need for context specific solutions**, customized to geographic ecological conditions, broader land use planning objectives, stakeholder interests and available funding. Universal, one-size-fits all solutions are not realistic, particularly in a county as geographically diverse as Canada.

- The **need for collaboration and partnerships**, to generate the public and political support to sustain mitigation projects and programs. Often mitigation measures aim to create change, sometime over several years. Building realistic expectations for outcomes, benefits and timelines among stakeholders can foster the broader support needed throughout implementation.
- **Building a business case** for a preferred solution is as important as ecological justification. Multi-criteria decision-making frameworks can present a comparison of monetary and non-monetary elements relevant to selecting mitigation options.
- Funding discussions should also **include sufficient resources for monitoring**, for both scientific assessment and adaptive management. Some types of road ecology mitigation can be expensive, and without robust scientific evidence of cost-effectiveness and information to refine techniques, current and future business cases are less compelling.
- **Monitoring should also evaluate other factors** relevant to a business case, such as engineering design, construction, social and economic outcomes of specific mitigation approaches. Ecological benefits have been far more often examined in scientific studies of road ecology mitigation, leaving gaps the information needed for robust decisions.
- **In terms of future directions,** Canadian transportation agencies must deal with emerging social and environmental changes, including climate change, and develop tools for urban, and more natural landscapes, including Northern Canadian road systems. Collaborative, interdisciplinary approaches will be essential to innovative, appropriate solutions.

Glossary

Afforestation: Planting to restore forested habitat in areas that were not previously forested

Albedo effect: The reflectance of solar energy away from the earth's surface, which is higher in areas of snow cover, and less in areas with darker colored land cover (e.g. soil, rock, and some vegetation)

Compensation: Replacement of habitat loss, often done through financial or 'offsetting' programs that replace equivalent area or quality of habitat

Compensation ratios: Establishes the amount of development needed to restore similar ecosystem services compared to those that were lost in order to meet a certain goal

Core habitats: The most used area within an animal's home range, necessary to its survival and reproduction for food availability and shelter

Cover: Structural habitat features that can hide animals from predators or humans, reducing risk of predation, or concealing movement for other purposes (e.g. stalking prey, hunting)

Critical habitat: In Canada, a term used to define habitat important for the survival of a species protected under the *Species At Risk Act*

Endangered species: Living thing on the verge of disappearing, triggered by a fast population decrease or loss of essential habitat

Environmental Non-Government Organizations (ENGO): An organization that is not part of the government and with a focus on the environment and environmental issues

Ecological effects: Changes in the way an ecosystem functions over a long or short period of time, causing losses to the environment, economy, society or aesthetics

Ecological function: Interactions between species or performance of their role within the ecosystem that maintain the productivity of that ecosystem

Fragmentation: Action of breaking large areas of habitat into smaller ones (e.g. through development that replaces habitat with human-influenced land uses), so that the smaller areas are not easily accessible to one another

Hiding or security cover: Vegetation, topography or other obstruction that can obscure view of an animal, such that it feels safe, calm and not vulnerable to known dangers nearby

Invasive species: A species that did not originate from the area, which has negative impacts on the economy, environment or human health through its spread or presence

Mitigation: Measures taken to reduce the negative impacts to wildlife, the environment or an ecosystem

Mortality sinks: Dangerous areas to which animals may be drawn that have a higher death rate compared to other areas (e.g. road crossings near movement corridors for wildlife)

Natural: An environmental feature (e.g. vegetation) that has not been influenced or introduced by humans; an organism endemic to an area

Naturalized landscapes: An area of land supporting natural or non-native vegetation that is left to grow without any human involvement

Off-setting: Habitat compensation that replaces or enhances habitat lost to development, in an equivalent form; the term 'habitat compensation' is used in some legislation (e.g. wetland policies), with the same meaning

Openness ratios: Species-specific ratios that relate to the frequency of use of crossing structures by wildlife; ratios approximate the amount of light that can be seen at the end of a wildlife passage, determined as its (height x width/ length)

Stepping stones: Small patches of habitat that themselves may not support all life requirements of wildlife or plant species, but can provide shelter and thus provide connection to larger habitats, improving wildlife movement in a developed landscape

Sustainability: State that can be maintained over time, at which it is possible for current levels of use can be met without impacting the ability of future needs to be met

Sustainable transportation systems: Elements that contribute towards the movement of goods and people in a way that can be maintain at the same level over time and that is available to everyone, safe, environmentally friendly, and reasonably priced

Wildlife-vehicle collision (WVC): An event in which a vehicle strikes an animal, causing human or animal mortality, and/or vehicle damage

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Appendix A: Results of survey by Environmental Issues Committee on Road Ecology Management Practices

1. Mowing Width Standard for Road Rights-of-Way

Jurisdiction	Width per Road Type			
	Freeway/Highway	Arterial roads	Collector roads	Local or gravel roads
New Brunswick	15 m max from edge of travel lane or toe of backslope	2 x 3 m swaths or toe of backslope	1 x 3 m swath	1 x 3 m swath
Quebec	1.8 to 3.0 m	1.8 to 3.0 m	1.8 to 3.0 m	1.8 to 3.0 m
Saskatchewan	Full width of rights-of-way	4.0 m shoulder cut	4.0 m shoulder cut	4.0 m shoulder cut
Alberta	N/A	N/A	N/A	N/A
BC	1.8 m	1.8 m	1.8 m	1.8 m
NWT	60 m	60 m	60 m	60 m or less
City of Brampton	N/A	1.0 - 4.5m	1.0 - 5.0 m (window roads only)	1.0 - 5.0 m (window roads only)
City of Calgary[16]	curb to property line	curb to property line	curb to property line	curb to property line
Parks Canada Agency	1.8 m	1.8 m	1.8 m	N/A

[16] *In certain locations (currently totalling 11% of our approximately 1,000 ha land inventory that we manage), particularly areas having greater than 3:1 slopes and adjacent to natural environment areas, Calgary only does 2-3 m wide shoulder cuts as a minimum. Shoulder cuts are done four times per year. That minimum cut width is not a standard per se; it is a protocol developed at City of Calgary to maintain sightlines and provide pullout capability, and it is a practicality of the mowing equipment used (it has a 72" deck so that represents one pass of the mower).*

2. Standard for Topsoil Salvage and Stockpiling

Jurisdiction	Standard in Place? Y/N	Comments
New Brunswick	Y	see NBDTI's Standard Specifications
Quebec	N	At the design stage of the work, it is suggested to carry out an inventory of topsoil that can be recovered. The inventory must contain the location of the recoverable areas and their respective thickness.
Saskatchewan	N	The Ministry has a draft topsoil policy that has not been finalized, but is generally in use.
Alberta	Y	Provincial laws and AT standards require soil assessment and project-specific mitigation for soil salvage and handling
BC	N	BC does not have a topsoil salvage specification in the Highway Maintenance Agreement. For major works projects, it is completed on a case by case basis
NWT	N	The Department of Infrastructure (INF), GNWT does not have a standard for topsoil salvage however when required the topsoil is regraded in the Right of Way and is not wasted as topsoil provides excellent medium for vegetation root structure development
City of Brampton	Y	The City of Brampton uses the OPSS. Muni 802 with modification.
City of Calgary	Y	The City of Calgary's *Guidelines for Erosion and Sediment Control* (2011) specify requirements and recommended best management practices for stripping, grading and site preparation including topsoil salvage and placement, and various ESC practices (12 BMPs) applicable to stockpiling of materials.
Parks Canada Agency	Y	There are some local standards across the country but in most cases the national guidance document is used, i.e. *Parks Canada National Best Management Practices: Roadway, Highway, Parkway, and Related Infrastructure* (2015).

3. Standards for Road Lighting (location/road type, area of illumination, type of lighting)

Jurisdiction	Standard in Place? Y/N	Comments
New Brunswick	Y	TAC's *Illumination of Isolated Rural Intersections* (2011)
Quebec	Y	The purpose of these standards is to determine the Ministry's requirements for lighting road infrastructure.
Saskatchewan	N	
Alberta	Y	Alberta Transportation (AT) has their own *Highway Lighting Guide* (2003). In addition, several recommended practices and design bulletins are there to support the guideline, for instance, LED luminaire specification.
BC	Y	Road lighting standards can be found in the following documents: • Electrical and Traffic Engineering Manual, Sect 300 – Lighting Design • Sect 305 looks at Obtrusive Light and Light Pollution • Electrical and signing Materials Standards, Chapter 500 – Lighting Equipment • Standard Specifications for Highway Construction, Section 635 – Electrical and Signing Road lighting standards are focused on highway safety.
NWT	N	
City of Brampton	Y	Follows IESNA RP-8 for roadway lighting. In new designs, roadway lights are installed behind the sidewalks, illuminating the sidewalk as well as the roadway. The City installs 'Night Time Friendly' LED luminaires that have no back light or up light.
City of Calgary	Y	Follows TAC guidance for illumination (2006 and most recent update; pending change in standard). Also follow IESNA (Illumination Engineering Standard for North America), which mirror TAC guidance, for how/where we illuminate our urban roadways. • design and manage our streetlight system to not "over-light" • don't take into consideration "night ecology impacts" for our roadway illumination
Parks Canada Agency	N	Decisions on lighting are based on engineering consulting advice (which in turn would incorporate TAC guidance and related standards) in combination with oversight by local engineering and impact assessment staff.

4. Standards Regarding Wetland Management, including compensation requirements for disturbance or loss

Jurisdiction	Standard in Place? Y/N	Comments
New Brunswick	Y	All wetlands must be replaced using compensation at a ratio of 2:1 – all alterations to wetlands require a Watercourse and Wetlands Alteration Permit (WAWA) under the same-named regulation. NB has a no-net-loss wetland policy.
Quebec	Y	Projects on wetlands are governed by the Environment Quality Act (article 22, par. 4 and articles 46.0.1 to 46.0.12). Ministry of the Environment applies the avoid-minimize-compensate sequence. Compensation for residual losses from wetlands is governed by the Regulation respecting compensation for adverse effects on wetlands and bodies of water.
Saskatchewan	N	There is currently no official provincial policy in place. Wetland management is handled on a case-by-case basis following discussions with provincial regulators or through project-specific permit conditions.
Alberta	Y	Many pieces of legislation and regulations protect wetlands. The Water Policy outlines wetland management, including compensation for impacts to wetlands.
BC	Y	BC has legislation/policies related to wetland management and compensation requirements; however, they are managed by a different Provincial Ministry (Ministry of Environment and Climate Change Strategy).
NWT	N	Do have a NWT Water Stewardship Strategy and 2016-2020 Action Plan which refer to wetlands.
City of Brampton	Y	Follows the requirements outlined by the local conservation authorities (CVC, MOECP and TRCA).
City of Calgary	N	Follows provincial wetland policy and the implementation directives associated with it.
Parks Canada Agency	Y	There is a policy for federal land that there is to be no net loss of wetland function. Offsets are determined on a case-by-case basis in consideration of the type, value and amount of wetland lost, and the local opportunities for compensation.

5. Standards for Erosion and Sediment Control (If yes, please provide the name of the standard and provide the name of the standard(s))

Jurisdiction	Standard in Place? Y/N	Comments
New Brunswick	Y	See NBDTI's Standard Specifications. Division 600 outlines various erosion and sediments control methods and their requirements. NBDTI's EMM also outlines requirements for ESC.
Quebec	Y	Three basic rules are applied: 1. Control runoff water at the boundaries to prevent it from entering the construction site; 2. Control rain erosion and erosion from water that could not be contained outside the site; 3. Keep the sediments within the perimeter of the site. • TOME II - Road construction / 9. Environmental protection • Volume IV - Permanent mitigation measures
Saskatchewan	Y	Permit Conditions (Aquatic Habitat Protection Permit) address both interim and long-term erosion and sediment control, must be followed. Included in questionnaire response are a few phrases from several AHPPs. • ESC Manual • Ministry Manual Grading- 450-25
Alberta		No response
BC	Y	Erosion and Sediment Control requirements can be found in the following documents: • *Standard Specifications for Highway Construction*, Section 165 – Protection of the Environment • *Environmental Best Practices for Highway Maintenance Activities* • *Best Practices for Managing Invasive Plants on Roadsides*
NWT	Y	*Government of the Northwest Territories, Department of Transportation - Erosion and Sediment Control Manual* (2013)
City of Brampton	Y	Uses the OPSS.Muni 805 with the attached modification.
City of Calgary	Y	*Guidelines for Erosion and Sediment Control* (2011), a document that provides detailed information on control of erosion and sediment during urban construction, operational and maintenance activities that disturb soil or sediments.
Parks Canada Agency	Y	Covered in *Parks Canada National Best Management Practices: Roadway, Highway, Parkway, and Related Infrastructure* (2015). Individual ESC plans are developed for each construction project.

6. Standard for Weed Control (Is it specific to certain road types? Does it include recommendations for herbicide use?)

Jurisdiction	Road Type				Herbicide Requirements
	Freeway/ Highway	Arterial roads	Collector roads	Local or gravel roads	
New Brunswick	N	N	N	N	No regulatory structure to manage the introduction of invasive plants and no formal list of plants deemed invasive.
Quebec	Y	N	N	N	None
Saskatchewan	N	N	N	N	Responsibility is delegated to the municipalities who have designated a Weed Inspector.
Alberta	Y	Not in mandate	Not in mandate	Not in mandate	Relies on provincial Weed Act, and AEP as enforcement agency for freeway/highway.
BC	N	N	N	N	Invasive plants are managed based on a priority basis considering budget, invasiveness, and likelihood of control.
NWT	N	N	N	N	None
City of Brampton	N	N	N	N	
City of Calgary	N	N	N	N	Required under the provincial Alberta Weed Control Act to control regulated noxious weeds, and to eradicate prohibited noxious weeds. Beyond that there are no standards per se, but there are thresholds established (i.e. weed density of 20 plants per square metre for roadsides, lower for regional parks and sport fields) for broadleaf weeds like dandelions that trigger control efforts.
Parks Canada Agency	Y	Y	Y	Y	Most or all national parks and national historic sites (or more accurately, geographic clusters of these known as 'field units') have local plans for the integrated management of invasive plants and other pests. Those cover all park lands, not just the roadways in them. The guidance in those documents is variable but in most or all cases herbicide use is an option, though typically with considerations about where it is appropriate and where it is not.

7. Specified recommended seed mixes

Jurisdiction	Specified recommended seed mixes (Y/N)
New Brunswick	Y
Quebec	Y
Saskatchewan	Y
Alberta	Y
BC	Y
NWT	Y
City of Brampton	Y
City of Calgary	Y
Parks Canada Agency	Y

8. If yes, do standards include provisions for native mixes on road rights-of-way or naturalized parts of road rights-of-way, and if so, where required?

Jurisdiction	Comments
New Brunswick	Yes – we have two different seed mixes in our Standard Specifications, but they are not native seed mixes. On rare occasions, we will specify native seed mixes but the species composition is not specified in our standards.
Quebec	The lawn mixture used for mechanical or hydraulic seeding is made up of species with good growth on soils covered with topsoil, as found along roads. This mixture consists of – 50 % Festuca rubra L.var.; – 30 % Poa pratensis L.; - 10 % Agrostis gigantea Roth; – 10 % Lolium perenne. • TOME IV - Roadsides / 9. Grassing / 9.7. Lawn mix and seed mix
Saskatchewan	On provincial crown land native grass seeds are used. On agricultural land, there is no regulatory agency that provides guidance, but MHI tries to use native grasses as much as possible, and where feasible. Near agricultural farm land that is cropped, MHI will usually plant native grasses because there is no competition from hay land. Near areas that are hayland, the hayland species will usually outcompete native grasses so MHI will use an agronomic selected mix. • Environmental Seeding Practice • Standards Specification Manual 6025 • Revegetation Reference Manual • Revegetation Pocket Guide
Alberta	The standard outlines how seed mixtures are identified for Alberta Transportation Projects. • Alberta Infrastructure and Transportation Design Bulletin No. 25 Grass Seed Mixtures Used on Highway and Bridge Projects
BC	No, although native seed mixes may be considered on a case-by-case basis.
NWT	Mix design seeding will be required where topsoil has been regraded/relocated permanently or disturbed due to road construction/rehabilitation related activities.

Jurisdiction	Comments
City of Brampton	Use appropriate seed mix in areas as specified. Ensure that areas to be seeded have been cultivated to a depth of 25 mm and are moist to a depth of 150 mm before seeding. Apply seed mix at a rate as specified by supplier.
City of Calgary	City landscape design specifications for construction administered by Calgary Parks identify six different classifications for seed mixes for grasses and wildflowers, including combinations thereof and both native and non-native plants, that are to be applied to roadways.
Parks Canada Agency	Requirement to use native seed for roadside revegetation, and there is generally at least one standard mix required (with some flexibility to account for the changing availability of certain species). In most parks, there are several mixes that vary by ecological conditions. There are no doubt some roadways within national historic sites and the urban portions of some parks where native seed is not required.

9. If rare plants discovered within or near road rights-of-way, how are species managed (e.g. protect the area, avoid use of herbicide, adjust mowing schedules, transplant to more secure location)?

Jurisdiction	Comments
New Brunswick	Do not typically conduct surveys for rare plants on roads that are already completed except when there are structures to be replaced or alignments to be shifted. In such cases when rare plants are found, various mitigations are used to help avoid the plants including: • Shifting alignment, access roads or work pads to avoid • Flagging plant locations and avoiding traffic or disturbance in area of plant • Transplanting plant out of ROW when unavoidable • Collecting the plant if unavoidable and pressing it for university herbarium collection
Quebec	To preserve these sensitive ecosystems, it is advisable to document the presence of fauna and flora species, in collaboration with the representatives of the responsible officials, before beginning any activity within the limits of or nearby the planned projects to determine the measures of temporary mitigation to be applied, if applicable. • TOME II - Road construction / 9. Environmental protection / 9.5.3. Protection of fauna and flora ecosystems
Saskatchewan	Activity restriction policy for rare species. In some cases, MHI's projects can not avoid these restrictions, so mitigation measures will be utilized. Typically, rare plants are not recommended to be translocated, so the best management practice is to manage topsoil for a construction project (remove and replace in areas where rare plants may exist). MHI will present this to the environmental regulator, and it is usually an acceptable alternate. MHI does not have a mowing policy regarding rare plants.
Alberta	Rare Plants are regulated federally by the Species at Risk Act and provincially by the Alberta Wildlife Act. If rare plants are identified as a part of an Environmental Assessment the project team will first try to avoid impacting them. If impacts cannot be avoided efforts to minimize or mitigation impacts are made. Typical mitigations include relocation and/or collection of seeds.

Jurisdiction	Comments
BC	Depend on a variety of factors including the species life history and reproduction method, distribution, abundance, site conditions, public safety, and surrounding invasive plant priority among many others.
NWT	NWT has not come across to this situation; however, efforts will be made to protect the area and avoid use of herbicide.
City of Brampton	Typical we look to the CVC and TRAC for guidance on procedures for this, however we have a standard that we review and confirm the acceptance by CVC and TRCA.
City of Calgary	Not required in support of roadside operations. However, new road development or road widening in environmentally sensitive areas do trigger a Calgary Parks requirement to conduct biophysical impact assessments (completed by qualified environmental consultants) and address their recommendations for environmental protection and management. We've responded to the identification of rare plants with various measures: adjusted routing and design for impact avoidance; relocation i.e. transplants of plant material or collection and propagation from seed; and establishment of "no go zones" (i.e. no construction, mowing, or herbicide use), as appropriate.
Parks Canada Agency	Not legally obliged to protect provincially listed rare plants, but normally do anyway in keeping with Parks Canada's conservation mandate. Typically, the location and a buffer around it would be identified in a database and there would be no herbicide use, mowing it or other routine disturbances within it. It would be identified during construction project planning with a preference to avoid it or, in some cases, to transplant individuals, transplant sods containing the plants, or collect seeds or other propagules. For SARA-listed plants, there is a much stronger likelihood of avoidance, and any loss to the plants or their Critical Habitat must be permitted by a Field Unit Superintendent. Associated with that permitting there is normally a mitigation package. Commonly that involves growing the plants in a greenhouse and transplanting back to the park.

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